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"MARGANETS BILAN LEGIRLANGAN KREMNIYNING XOSSALARINI O'RGANISH "

mavzusidagi

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Mavzuning dolzarbligi. Yurtboshimiz I.A. Karimovning mustaqillikka erishish oldidan davlat boshqaruviga kelganda barcha sohalar kabi ilm-fan rivojiga ham muhim e'tibor qaratdi. Bu paytda Respublikamizda ilm-fani ham boshqa sohalar kabi markaz manfaati va mafkurasiga xizmat qilar edi. Markazdan bo'lgan tinimsiz taziqlarga qaramay, 80-yillarning ikkinchi yarmida O'zbekiston ilm-fanida bir qator o'zgarishlar sodir bo'ldi. O'zbekiston Fanlar Akademiyasi, oliy o'quv yurtlari tizimidagi ilmiy-tadqiqot muassasalari, ilmiy labaratoriyalar o'z faoliyatini takomillashtirishga harakat qila boshladi. Bu davrda tabiiy va ijtimoiy fanlar bo'yicha jiddiy izlanishlarga qo'l urilayotgan edi.

Bugungi kunda O'zbekistonda ta'lim sohasida amalga oshirilayotgan isloxotlar ko'p jihatdan mamlakatimizni modernizasiya qilish jarayorlari bilan hamohang tarzda olib borilmoqda. Bunda asosiy yo'nalishlar sifatida oliy va o'rta maxsus ta'lim tizimida o'quv, o'quv-uslubiy va ilmiy faoliyatini modernizasiya qilish, ta'lim tadqiqot jarayonlardagi inavatsion yo'nalishlarni kuchaytirish tadbirlari izchil amalga oshirilmoqda. Mustaqil huquqiy demokratik davlat, erkin fuqarolik jamiyat qurish yo'lida ulkan ishlar olib borilib, inson moxiyatini yangidan ochishga, uni - o'zini anglashga, imkoniyatlarni ro'yobga chiqarishga va ma'naviy intelektual, aqliy-amaliy rivojlanishga ega shart-sharoitlar yaratib berildi. [2]. Xalqimizning boy intellektual merosi va umumbashariy qadryatlari zamonaviy madaniyati, iqtisodiyot, fan, texnika va texnologiyalar asosida yetuk mutaxassislar tayyorlash tizimi ishlab chiqildi va jadal sur'atlar bilan hayotga tadbiq etilmoqda. Ta'lim tizimini rivojlantirish va avlodlarni tarbiyalash ta'lim tizimini qayta shakllantirishning eng muhim yo'nalishlaridan biri hisoblanadi [1].

Bugungi kunda ko'pchilik davlatlar qatori bizning davlatimizda ham aniq fanlarga, jumladan fizika faniga alohida e'tibor berilayotgani bejiz emas, chunki yuqori texnika va texnologiyalar rivoji bevosita fizika bilan bog'liq. Fizikaning turli sohalari qatori bugungi kunda juda ko'pchilik qiziqib o'rganayotgan "Yarim o'tkazgichlar fizikasi" ham eng qiziqarli va muhim yo'nalishlardan biridir, bunda asosiy maqsadlardan biri - tashqi ta'sirlarga chidamli issiqlik ta'sirlarida barqaror va turli radiasiyaga chidamli yangi yarimo'tkazgich materiallar izlash bilan bog'liq. Turli legirlovchi elementlar yarimo'tkazgich materiallar xossalariga ta'sirini o'rganish bir tomondan issiqlikka barqaror materiallar yaratish imkoni bilan bog'liq bo'lsa, boshqa tomondan marganes nurlanishga barqarorlikni oshirish bilan bog'liqligidan kelib chiqadi . Marganes kiritilgan kremniy xossalarini o'rganish ko'p yillardan beri olib borilsa ham, bu materiallarga qiziqish tadqiqotchilarning yetarlicha diqqatini xozirda ham jalb qilmoqda. Kremniy monokristalli panjarasiga yuqori temperaturalarda diffuziya vositasida kiritilgan marganes kirishmalari, sirt sohasida yarimo'tkazgich o'tkazuvchanlik turini o'zgartirishiko'rilgan.

Yarimo'tkazgich moddalar haqida. Qattiq jismlar elektr o'tkazuvchanligiga ko'ra o'tkazgichlar, dieletriklar va yarimo'tkazgich moddalarga bo'linadi, bu guruhlarga bo'linishining asosiy sababi qattiq jismlar tuzilishidagi taqiqlangan zonalarning kattaligi bilan belgilanadi. Agar qattiq jismning taqiqlagan zona kengligi $\mathbf{E_T > 3eV}$ bo'lsa dielektrik, $\mathbf{E_T < 3eV}$ bo'lsa , yarim o'tkazgich, $\mathbf{E_T \approx 0\ eV}$ bo'lsa metallar deb ataladi. O'tkazgichlar va dielektrik moddalar xossalari juda yaxshi o'rganilgan bo'lib, ularning deyarli barcha xossalari ma'lum. Yarim o'tkazgich moddalar esa qiziq xususiyatga ega , ular ba'zi hollarda elektr tokini o'tkazadilar ba'zi hollarda esa yo'q. Ularning bu ajoyib hususiyatidan texnikada amalda juda yaxshi foydalanish mumkin. Yarim o'tkazgich moddalarga misol qilib - Kremniy (Si), Germaniy (Ge), Galliy fosfidi (GaP) , Galliy arsenidi (GaAs), Indiy fosfidi (InP) larni keltirish mumkin. Yarim o'tkazgich moddalar asosida turli asboblar yasaladi, masalan: diodlar, triodlar, tranzistorlar , fotoelementlar va hakazo… Bu yarim o'tkazgichlar orasida eng ko'p qo'llanadigani Kremniy (Si) va Germaniy (Ge) elementlaridir. Yarim o'tkazgichli asboblar yasashda faqat yarim o'tkazgich moddalardan tashqari qo’shimcha “legirlovchi” (aralashma sifatida yarim o’tkazgichga kiritiladigan moddalar) moddalar ham ishlatiladi. Bu moddalarga - Alyuminiy (Al), Bor (B) , Galliy (GaAs) va boshqalarni misol qilib keltirish mumkin. Asosiysi shuki, yarim o’tkazgich moddalarga qo’shimcha kiritmalar kiritish orqali ularning xossallarini bizga kerakli yo’nalishda o’zgartirishimiz mumkin.

Yarimo'tkazgichli asboblarning juda ixchamligidan tashqari ularning soddaligi va kichikligi, mikromodullar sifatida uzluksiz ravishda bosib chiqarish usuli bilan tayyorlash imkonini yaratdi. Mikromodullar yupqa varaqlardek bo'lib, ularda diodlar, triodlar, qarshiliklar va radiosxemaning boshqa elementlari zarb qilinadi. Mikromodullarning turli kombinatsiyalarini tuzib, oldindan belgilangan parametrli radioqurilmalarni yasash mumkin. Hozirgi paytda yarimo'tkazgichli diodlar, triodlar, rezistorlar ishlatilmaydigan asboblaming o'zi mavjud emas. Yarim o'tkazgichli termistor (termorezistor) yordamida temperaturani o'1chovchi detektor, elementar zarralarni qayd etuvchi, fotorezistor - yorug'lik energiyasini qayd etuvchi va ko'plab boshqa asboblarni misol qilib keltirish mumkin. Kosmik kemalarning barchasi quyosh energiyasini elektr energiyasiga aylantirib beruvchi yarim o'tkazgichli quyosh batareyalari bilan jihozlangan bo'lsa, tibbiyot insonning nozik organlariga kirib, uning faoliyatidan ma'lumot beruvchi datchiklar (qayd etuvchilar) bilan jihozlangandir. Garchi, ushbu dalillarning o'zi ham yarim o'tkazgichli asboblaming foydalanish sohasi kengligini ko'rsatib tursa-da, hali ularning ishlatilish istiqbollari juda keng. Bu sohadagi izlanishlar tugamagan bo'lib, insoniyat yarim o'tkazgichlar fizikasidan ko'plab yangiliklarni kutmoqda.

Bitiruv malakaviy ishining maqsadi – Marganes elementi bilan legirlangan kremniyning solishtirma qarshilgini o’lchash va uning temperaturaga bog’liqligini o’rganish, Infraqizil yutilish spektrini o’lchash.

Bitiruv malakaviy ishining obekti - Marganes bilan legirlangan kremniy elementi.

Bitiruv malakaviy ishining predmeti – kremniyni turli elementlar bilan legirlash va uning elektrofizik xossalarini aniqlash usullari.

Bitiruv malakaviy ishining vazifalari:

1. Asosiy yarim o’tkazgichlar haqida ma’lumot to’plash va ularni o’rganish,
2. Yarimo’tkazgichlarning elektrofizik xossalari bilan tanishish,
3. Yarimo’tkazgich moddalarning asosiy parametrlarini aniqlash yo’llarini o’rganish,
4. Kremniyning Marganes elementi bilan legirlagandagi solishtirma qarshiligini o’lchash va uning temperaturaga bog’liqligini aniqlash,
5. Kremniyning Marganes elementi bilan legirlagandagi Infraqizil yutilish spektrini o’lchash.

1-BOB . ASOSIY YARIM O'TKAZGICH MODDALAR VA ULARNING PARAMETRLARINI O'LCHASH METODLARI

1.1-§ Asosiy yarimo'tkazgich moddalar va ularning asosiy parametrlari.

Yarimo'tkazgichlar orasida eng ko'p tarqalgan va ko'p qo'llanadgan asosiylari quyidagilar: Kremniy, Germaniy, Galliy fosfidi, Galliy arsenide, indiy fosfidi, indiy arsenide, indiy antimonidi. Endi ularning har birining fizik tabiati va asosiy xossalariga (parametrlariga) to'xtalib o'tamiz.

Kremniy (Si) ning elektrofizik xossalari. Yarim o'tkazgichli asboblar va tizimlar ishlab chiqarishda eng ko'p ishlatilayotgan modda bu kremniy. U elementlar davriy sistemasida 14-o'rinda turadi.Atom og'irligi 28, uing eng katta valentligi 4 ga teng, normalish sharoitdagi suyulish temperaturasi 1414 ^{o}C , qattiq kremniyning zichligi 2330 kg/m^3 , dielektrik singdiruvchanligi -11.7 ga teng, ya'ni diamagnit. Xona temperaturasida turgan kremniy kimyoviy jihatdan barqaror, suvda erimaydi, ko'p kislotalarga nisbatan bardoshli. Nitrat va ftorit kislototlar aralshmasida yaxshi eriydi. Kremniy xavoda 900 ^{0}C gacha qizdirilganda barqaror qoladi. Ammo yuqoriroq temperaturlarda oksidlanadi. Vodorod bilan kremniy 2000 ^{0}C chamasidagi temperaturada bevosita reaksiyaga kirishadi. Si_nH_{2n+2} silanlar hosil bo'ladi. Azot bilan kremniy 1100-1300 ^{0}C da reaksiyaga kirishib nitritlar hosil qiladi. Kremniy galogenlar bilan oson ta'sirlashadi, ftor bialn xona temperaturasida, xlor bilan 200-300 ^{0}C da, brom bilan 450- 500 ^{0}C da , yod bilan 700-750 ^{0}C da. Suyulgan kremniy yuqori faollikka ega bo'ladi. Kremniy monokristalini o'stirish uchun eng maqbul modda sintetik kvars - SiO_2 dir. Kremniyning elektronli turdagi monokristallari fosfor bilan legirlanadi, kovak turdagisi bor bilan legirlanadi.

Germaniy(Ge)ning elektrofizik xossalari. Germaniy elementi ham eng ko'p qo'llanadigan yarim o'tkazgich moddalardan biridir. U elementlar davriy sistemasida 32-o'rinda turadi, atom og'irligi 72.5, eng katta valentlgi 4, suyulish temperaturasi 936 ^{0}C , zichligi 5300 kg/m^3 , dielektrik singdiruvchanligi 16 ga teng, diamagnit. Xona temperaturasida germaniy kimyoviy jihatdan barqaror, suvda deyarli erimaydi. Xona temperaturasida germaniyni eritish uchun shox arog'i – (HF), vodorodning - H_2O_2 oksidi va oksidlovchi kislotolari qo'llanadi. Xavoda 700 ^{0}C dan yuqorida qizdirilsa germaniy oksidlanadi, shu temperaturada uni uglerod oksidi ham oksidlab qo'yadi. GeO oksidi qora kukun , uni 700 ^{0}C dan yuqorida oson haydash mumkin. 1100 ^{0}C dan yuqori temperaturalarda germaniy vodorod bilan reaksiyaga kirishib , Ge_nH_{2n+2} birikmalar hosil qiladi, ammo u azot bilan tasirlashmaydi. Suyuq germaniy 1500 ^{0}C gacha na uglerod bilan, na kremniy oksidi bilan ta'sirlashmaydi, bu xususiyati tufayli germaniyni grafit va kvars idishlarida saqlash mumkin.

Galliy fosfidi (GaP)ning elektrofizik xossalari. Galliy fosfidi yuqori kimyoviy barqarorlikka ega **:** u 700-800 ^{0}C gacha xavodagi kislorod bilan ta'sirlashmaydi, kislotali va ishqorli ko'p eritmalarga nisbatan ham barqaror. Galliy fosfidining xona temperaturasida turgan azot kislotasidagi erish tezligi 0.16mg/(sm^2 soat), qaynayotgan tuz kislotada (110 ^{0}C) 0.01 mg/(sm^2 soat), azot va tuz kislotalarining 1/3 aralashmasida (aralashma qaynoq) – 7.8 mg/(sm^2 soat). Agar kislotalar aralashmasiga vodorod peroksid qo'shilsa , GaP ning eruvchanligi keskin oshib ketadi. Galliy fosfidi kislotalarda eriganida kuchli zaxarlovchi fosfin PH_3 ajaraladi. GaAs va InAs – arsin AsH_3 ; InP – fosfin PH_3 va INSb – stibin SbH_3 dan iborat zaxarli moddalar ajratadi. Suyuq GaP barcha konteyner moddalar bilan faol ta'sirlashadi, chunki uning susyulish temperaturasi taxminan - 1500 ^{0}C . Polkristall Gap sintez qilish uchun top-toza grafit, monokristall GaP o'stirish uchun esa kvars konteyner vazifasini bajaradi. A^3B^4 birikmalarida (GaAs, GaP) 2-guruh elementlari akseptor, 4-guruh elementlari donor bo'ladi. 4-guruh elementlari atomlari galley atomlari o'rnida joylashgan bo'lsa , ular donor, agar fosfor arseniy o'rnida joylashsa akseptor vazifasini o'taydi. Legirlanmagan GaP electron turdagi o'tkazuvchanlika ega, bunda $n > 10^{17}$ sm^{-3} va $\mu<120$ sm^2/Bs. Te va S bilan legirlangan GaP kristallarida asosiy zaryad tashuvchilar elektronlar va ularning taxminniy miqdori – 1.25 – $40*10^{17}$ sm^{-3} , harakatchanligi – 110 – 60 sm^2/Bs. Ba'zi kirishmali GaP ning solishtirma qarshiligi 10^6 O'm*sm dan ortiq.

Galliy arsenide (GaAs) elektrofizik xossalari Galliy arsenide suv bilan ta'sirlashmaydi, kislotalar bilan faol ta'sirlashib , zaharli AsH_3 arsin modda ajratadi. Galliy arsenide eruvchanligi kislotalar aralashmasida ancha katta bo'ladi.uning eruvchanligi tuz kislota eritmasida $2*10^{-5}$ mg/(sm^2 soat), tuz va azot kislotalarining suvli aralashmasida (1/1/1 aralashma) – 60 mg/(sm^2 soat), azot va ftorid kislotalarining suvli eritmasida 1200 mg/(sm^2 soat) gacha. 300 ^{0}C gacha qizdirilganda GaAs oksidlanmaydi, 600 ^{0}C dan boshlab u parchalanib, arseniyni ajratadi. Suyuq GaAs juda faol. GaAs texnologiyasida sintetik kvars SiO_2 eng ko'p qo'llanadi. GaAs ning zichligi – 5320 kg/m^3 , suyulish temperaturasi – 1238 ^{0}C ga teng. Legirlanmagan GaAs monokristallari n-tur o'tkazuvchanlikka ega, bunda $n<6*10^{16}$ sm^{-3} , va harakatchanlik (T=300K da) $\mu>4200$ sm^2/Bs n-GaAs monokristalarini Te yoki Sn bilan legirlanadi. P- GaAs monokristallarini Zn bilan legirlanalanadi. Ko'p hollarda GaAs monokristallarini xrom Cr bilan legirlansa , ularning solishtirma qarshiligi 10^5 dan 10^7 O'm*sm gacha bo'ladi.

Indiy fosfidi (InP) ning elektrofizik xossalari . InP suvda erimaydi. Uning eng yaxshi erituvchisi tuz kislotasi bo'lib, kislota zichligi ortishi bilan In Perish ezligi ortib ketadi, ammo bunda zaharli fosfin PH_3 ajralib chiqadi. Zichligi 4800 kg/m^3 , suyulish temperaturasi 1058 ^{0}C. 300 ^{0}C gacha qizdirilganda InP oksidlanmaydi, undan yuqoriroq temperaturalarda parchalanib, fosforni ajratadi. Suyuq InP kvars sust ta'sirlashadi, shuning uchun InP ni o'stirish qurilmalarida sintetik kvars ko'p qo'llanadi. Legirlanmagan InP kristallarida zaryad tashuvcilar zichligi $5*10^{16}$ sm^{-3} dan ortiq emas, harakatchanlik 3000 sm^2/(Bs) dan kam emas. n-InP monokristallarini Te va Sn bilan legirlanadi. Ularda elektronlar konsentratsiyasi n , $5*10^{16}$ sm^{-3} dan $5*10^{18}$ sm^{-3} gacha, harakatchanlik esa - 2500-1000 sm^2/(Bs). Rux bilan legirlangan p -InP da $5*10^{17}$ dan $8*10^{17}$ sm^3 gacha. Yarim izolyatsiyalovchi InP monokristalini temir Fe bilan legirlanadi. Ularda solishtrma qarshilik 10^7 O'm*sm dan yuqori bo'ladi.

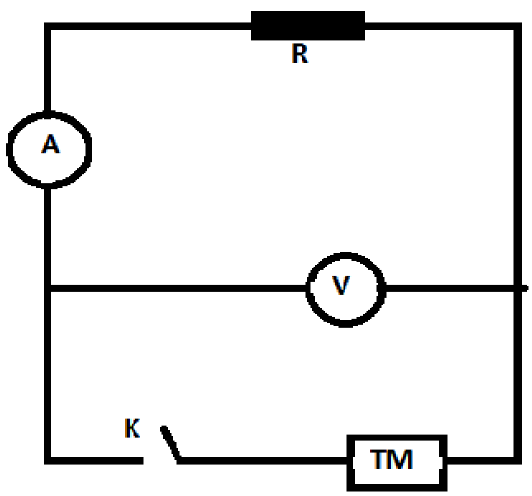
Indiy arsenide (InAs) ning elektrofizik xossalari - InAs suvda erimaydi, tuz kislotasida +75 ^0C da edirilish tezligi 300 mg/(sm^2 soat). Azot kislotasi qo'shilsa bu tezlik oshib ketadi. InAs kislotalarda eriganida zaharli AsH_3 arsin ajraladi. 450 ^0C dan yuqorida oksidlanadi. Vaquumda 700 ^0C va undan yuqori temperaturalarda InAs parchalanib arseniyni ajratib chiqaradi. Zichligi 5670 kg/m^3 , suyulish temperaturasi 942 ^0C . Legirlanmagan indiy arsenide mookristallarida asosiy zaryad tashuvchilar zichligi $3*10^{16}$ dan $5*10^{16}$ sm^{-3} gacha, harakatchanligi 30000 dan 40000 sm^2/(Bs) gacha (77K da). Te va Sn bilan legirlangan InAs monokristallari p-tur o'tkazuvchanlikka ega, unda asosiy zaryad tashuvchilar konsentratsiyasi 10^{16} dan $8*10^{19}$ sm^{-3} gacha.

Indiy antimonidi (InSb)ning elektrofizik xossalari -InSb suvda erimaydi, kislotalarda yaxshi yediriladi: azot kislotada yedirilish tezligi – 360 mg/(sm^2 * min), NHO_3+HF+H_2O - 1/1/1 nisbatdagi aralshmasida - 480 mg/(sm^2 * min). InS ning kislotalarda erishida zaharli SbH_3 – stibin moddasi ajraladi. InSb zichligi – 5780 kg/m^3, suyulish temperaturasi 525 ^0C . InSb xavoda 500 ^0C dan yuqori temperaturalarda oksidlanadi. Legirlanmagan va Ge, Zn, Mn elementlari bilan legirlangan InSb p-tur o'tkazuvchanlikka ega. Zarralar konsentratsiyasi $n \approx 10^{12}$ - 10^{18} sm^{-3} , solishtirma qarshilik $\rho\approx500$ O'm*sm, harakatlanuvchanlik $\mu \approx 3000 – 5000$ sm^2/Vc (77K da).

Tellur bilan legirlangan InSb monokristallari n-tur o'tkazuvchanlikka ega. Zarralar konsentratsiyasi $n \approx 8*10^{13} – 5*10^{18}$ sm^{-3} , solishtirma qarshilik $\rho\approx50$ O'm*sm, harakatlanuvchanlik $\mu \approx 7*10^5 – 8*10^5$ sm^2/Vc (77K da).

1.2 - § Namunalarning solishtirma qarshiligini o'lchash usullari.

Yarimo'tkazgichli namunalarning solishtirma qarshiligini uning to'la qarshiligi bo'yicha aniqlash - solishtirma qarshilik ρ ni namunaning to'la qarshiligi bo'yicha aniqlash tayoqcha (sterjen) ko'rinishidagi namuna ko'ndalang kesimlariga metall kontakt olinadi. Metall yarimo'tkazgich chegarasida zaryad tashuvchilar konsentratsiyasi yarimo'tkazgich hajmidagidan kichik bo'lgan potensial to'siq hosil qilishi mumkin , shuning uchun bu qatlam namuna qarshiligini oshiradi. Namunada O'm kontakti olinganda qarshiligi katta bo'lgan qatlam hosil bo'lmaydi. Xajm bo'yicha namunada metall chegarasigacha zaryad tashuvchilar konsentratsiyasi bir xil bo'ladi yoki zaryad tashuvchilar bilan boyigan qatlam hosil bo'ladi. Zaryad tashuvchilar bilan boyigan qatlamning qarshiligi kichik bo'lgani uchun uning namuna qarshiligiga qo'shgan hissasini hisobga olmaslik mumkin. Ko'rilayotgan holatda kontaktlardan oqayotgan tok namunaga tushayotgan kuchlanish orqali to'la qarshilikni, undan esa solishtirma qarshilikni topamiz, uning zanjir sxemasi quyidagicha:



(1-rasm)

$$R = \frac{U}{I} = \rho \frac{l}{S} \qquad \textbf{(1)}$$

bundan esa solishtirma qarshilikni topamiz : $\rho = \frac{US}{Il}$ **(2)** bunda U-vo'ltmetrning ko'rsatishi, I-ampermetrning ko'rsatishi S – namunaning ko'ndalang kesim yuzasi, l – uzunligi

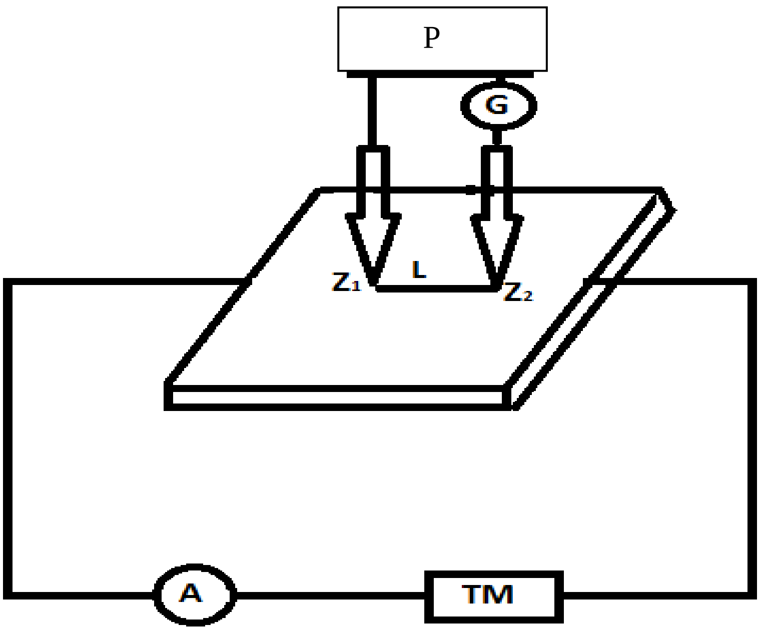
Bunda R-namuna qashiligi, A- Ampermetr, V- voltmeter, TM - to'k manbai, K – kalit.

Solishtirma qarshilikni namunaning to'la qarshiligi bo'yicha aniqlash kichik ($\rho<0.01$ O'm*sm) va o'rta ($0.01<\rho<10^6$ O'm*sm) solishtirma qarshilikka ega bo'lgan namunalarda hech qanday qiyinchilik tug'dirmaydi.

Ammo katta solishtirma qarshilikka ega ($\rho>10^6$ O'm*sm) namunalarda aniqlashda bir qancha hodisalarni , ya'ni, sig'im tokini, namuna qutblanishini, tokning sirt o'tkazuvchan -- lik bo'yicha sirqib oqishini hisobga olish lozim, shuning uchun bu usul katta solishtirma qarshilikka ega namunalarning solishtirma qarshiligini aniqlashda ko'pam maqul ko'rilavermaydi.

Namunaning solishtirma qarshilgini aniqlashning bir va ikki zondli usullari

a) Ikki zondli usul bilan solishtirma qarshilikni aniqlash: Yuqorida ko'rganimiz solishtirma qarshilikni to'la qarshilik bo'yicha aniqlashda O'm kontakti lozim va ammo bu usul katta solishtirma qarshilikni o'lchashda solishtirma qarshilikning haqiqiy qiymatini biroz orttirib ko'rsatadi. Bu kamchilikni zond usullari bilan o'lchashda yo'qotish mumkin. Buning uchun quyidagi sxema tuziladi:

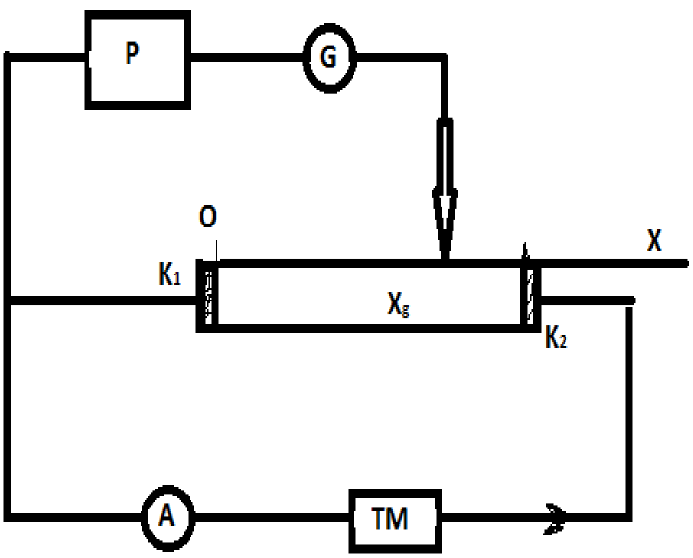


(2-rasm)

Bu sxemada **P** – potensiametr, **TM** – tok manbai, $\mathbf{Z_1}$ va $\mathbf{Z_2}$ zondlar deyiladi, **L** – zondlar orasidagi masofa, **G**-galvonometr

Bu yerda qanday ish bajarilishini ko'raylik: Namunaning ko'ndalang kesim yuzasiga K_1 va K_2 O'm kontaktlari o'tkazilgan va uning sirtiga bir-biridan L masofadagi ikkita Z_1 va Z_2 zondlar o'rnatilgan. Zondlar sifatida qattiq metall (mas: vo'lfram, molibden, osmiy...) simlar yoki qotishmalardan yasalgan simlar ishlatiladi. Solishtirma qarshilikning qiymati quyidagicha aniqlanadi: Namunadan tok manbai orqali I tok o'tkaziladi va u A- ampermetr bilan o'lchanadi, zondlar orasidagi kuchlanish potensiometrda konpensatsiya usulida o'lchanadi va unda galvonometrdan oqayotgan tokning ta'sirini yo'qotishga erishiladi. Bu xolda potensiometrdagi kuchlanish U_p ikki zond orasidagi namuna bo'lagiga tushayotgan kuchlanish - U ga teng bo'ladi. Bunda ham solishtirma qarshilikni $\rho = \frac{US}{Il}$ fo'rmuladan foydalanib topiladi, bu yerda R-namunaning ikki zond orasidagi qarshiligi, L-zondlar orasidagi masofa. Bundagi asosiy g'oya kuchlanish – U, konpensatsiya usulida o'lchanganda , kontakt qarshiligining o'lchov natijalariga ta'siri to'la yo'qotiladi deb qaraladi.

b) solishtirma qarshilikni o'lchashning bir zondli usuli: Bir zondli usul ham ikki zondli usulning bir ko'rinishidir. Solishtirma qarshlikni bir zondli usulda o'lchash uchun quyidagi sxema asosida zanjir tuziladi:



(3-rasm)

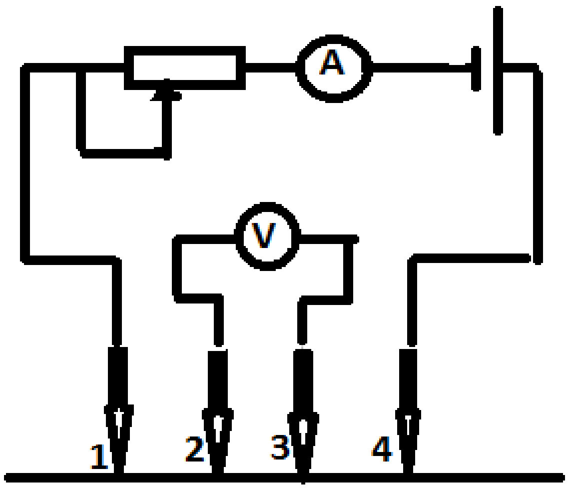
Bunda potensiometrning bir uchi to'k o'tkazuvchi kontaktlardan biri, masalan K_1 bilan ulanadi, sirtdagi zond qo'zg'aluvchan bo'ladi. Bu bilan K_1 kontaktgacha masofani o'zgartirish mumkin bo'ladi. Masofaning ikki qiymatida zond bilan K_1 – kontakt orasidagi kuchlanish o'lchanib, solishtirma qarshilik aniqlanadi:

$$\rho = \frac{S}{I} * \frac{U(X_{z1}) - U(X_{z2})}{X_{z1} - X_{z2}} \quad (3)$$

bunda U_x - namunadan o'tayotgan tok I ning K_1 kontaktdan zondgacha bo'lgan qismida xosil qilgan kuchlanishi. Bunda kontaktning solishtirma qarshilik natijasiga ta'siri ikki zondli usuldagidek bo'ladi. Bu usul namunalarni bir jinslilikka tekshirishda , bir jinsli bo'lmagan namunalarda solishtirma qarshilikning namuna uzunligi x bo'yicha taqsimotini aniqlashda, kontaktlarni O'm kontaktiga tekshirishda, tok o'tkazuvchi kontaktlar qarshiligini topishda qo'llash mumkin.

Namunalarning solishtirma qarshiligini to'rt zondli usul bilan aniqlash

Yarimo'tkazgich namunalarning solishtirma qarshiligini aniqlashda boshqa usullardan ancha afzal bo'lgan usul- to'rt zondli usul keng qo'llanadi. Bunga sabab qilib, o'lchash ko'rsatkichining yuqoriligi, o'lchash uchun namunalarga O'm kontakti olish shart emasligi, bir tomoni yassi tekislikdan iborat shakli va o'lchamlari har xil hajmiy yarimo'tkazgich namunalarni hamda ko'p qavatli strukturalarda epitaksial, diffusion qatlam solishtirma qarshiliklarini o'lchash mumkinligini ko'rsatish mumkin. Bu usul hajmiy monokristallarda plastika shaklidagi namunalarda solishtirma qarshilikni 10^{-4} dan 10^{-3} O'm*sm gacha oraliqda , epitaksial, diffuzion sirt qarshiligini 10^5 dan $5*10^5$ O'm*sm oraliqda o'lchash imkonini beradi. To'rt zondli usulning bir ko'rinishi quyidagi keltiramiz: Bir tomoni yassi tekis sirt bilan chegaralangan yarim cheksiz namunaning sirtiga bir chiziqda joylashgan to'rtta uchi ingichkalashtirilgan metal zondlar (elektrodlar) joylashtirilgan. Ikki chetki zonddan tok o'tkaziladi va o'rta zondlardan



(4-rasm)

kuchlanish o'lchanadi. Kuchlanish va tok kuchi orqali solioshtirma qarshilikni aniqlaymiz. Bu usul nazaryasi 1954-yilda Valdes tomonidan yaratilgan bo'lib, yarimo'tkazgich va zondni kichik yuzasi bilan kontaktlashgan nuqtasidan tokning yarimo'tkazgichda tarqalishiga asoslangan. Bu usul bo'ycha solishtirma qarshilikni qanday aniqlanishini ko'rmasdan oldin to'rt zondli usulda aniqlash shartlarini ko'rib o'taylik:

- O'lchov bir jinsli namunaning yassi tekis sirtida bajarili kerak.
- Kontakt orqali asosiy bo'lmagan zaryad tashuvchilarning injeksiyasi bo'lmasligi kerak. Bu sirt rekombinatsiya tezligi katta bo'lgan namunalarda kuzatiladi, bu sirtga ma'lum ishlov berish bilan ishlatiladi.
- Tokning sirt boyicha sirqib oqishi bo'lmasligi kerak.
- Zondlar namuna sirti bilan nuqtada kontaklashgan bo'lishi va bir chiziqda yotishi kerak.
- Tok otkazuvchi zondlar bilan yarimo'tkazgich namuna sirti chegarasida zondlar kichik radiusli yarimshar ko'rinishida bo'lishi kerak.
- Zondlarni namuna sirti bilan kontaklashgan yuzasining diametrizondlar orasidagi masofadan juda kichik bo'lishi kerak.

Bu usulda solishtirma qarshiliknining tok va kuchlanishga bog'liq ifodasi qanday ekanligini topish uchun yarim cheksiz (o'lchamlari zondlar orasidagi masofa S dan juda katta) namunaning yarim sirti bilan kontaklashgan aloxida olingan nuqtaviy zond chegarasidan yarimo'tkazgichga tok tarqalishi masalasini qarash kerak. Yarim cheksiz namunalarda nuqtaviy kontaklashgan zond bilan yarimo'tkazgich chegarasidan tarqalayotgan tok, potensial taqsimoti sferik simmetriyaga ega bo'ladi. Bu hol uchun O'm qonuni

$$\boldsymbol{j} = \boldsymbol{\sigma E} = -\frac{1}{\rho} * \frac{d\varphi}{dr} \quad \textbf{(4)} \text{ va to'k zichligining } \quad \boldsymbol{j(r)} = \frac{I}{2\pi r^2} \quad \textbf{(5)}$$

ifodalaridan foydalanib, namunada potensial taqsimlanishini topamiz:

$$\boldsymbol{\varphi(r)} = \frac{I\rho}{2\pi r} + A \quad \textbf{(6)}$$

bu yerda A – o'zgarma kattalik. Potensial ishorasi tok yo'nalishi bilan aniqlanadi, istalgan nuqtadagi potensial har bir tok zondlarining xosil qilgan potensiallarining yig'indisidan iborat. Namunaga kirgan tokning xosil qilgan potensiali musbat, chiqayotgan tokning xosil qilayotgan potensiali esa manfiy bo'ladi. Demak , o'lchov zondlarining kontaktlaridagi 2 va 3 potensiallari 1 va 4 zondlar xosil qilayotgan potensiallar yig'indisiga teng . To'k yonalishi , ya'ni 1 va 4 tok manbalari xosil qilgan potensiallarini nazarda tutganda 2 va 3 nuqtalardagi potensiallar ifodasi (6) ga ko'ra quyidagi ko'rinishda bo'ladi:

$$\varphi_2 = \frac{I\rho}{2\pi}\left(\frac{1}{S_1} - \frac{1}{S_2+S_3}\right) \quad \textbf{(7)} \quad \text{va} \quad \varphi_3 = \frac{I\rho}{2\pi}\left(\frac{1}{S_1+S_2} - \frac{1}{S_3}\right) \quad \textbf{(8)} \quad ;$$

Ikki ichki (2 va 3) zondlardagi potensiallar ayirmasining kuchlanish tushuvi U_{23} quyidagicha bo'ladi:

$$U_{23} = \varphi_2 - \varphi_3 = \frac{I\rho}{2\pi}\left(\frac{1}{S_1} - \frac{1}{S_2+S_3} - \frac{1}{S_1+S_2} + \frac{1}{S_3}\right) \quad \textbf{(9) ;}$$

Agar xususan, zondlar orasidagi masofa bir-biriga teng bo'lganda , ya'ni $S_1=S_2=S_3=S_4=S$ bo'lsa, solishtirma qarshilikning ifodasi quyidagicha bo'ladi:

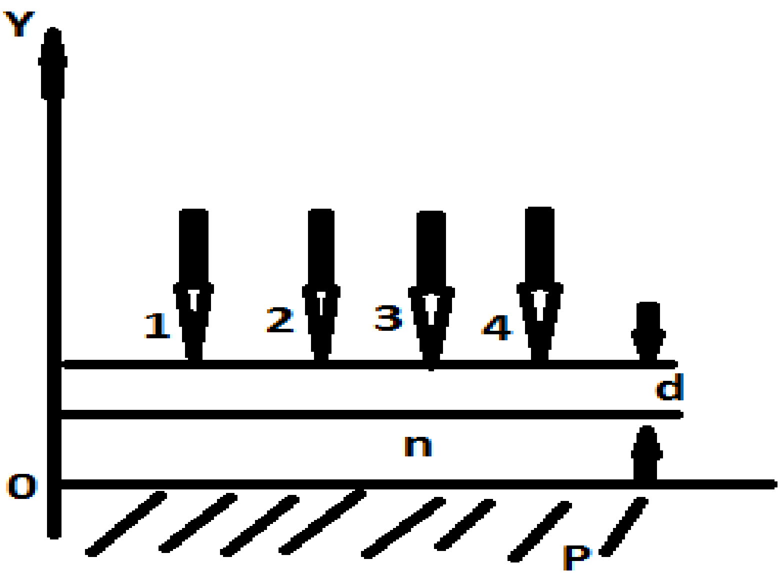
$$\rho = \frac{U_{23}}{I_{14}} * 2\pi S \quad \textbf{(10)}$$

Shuni aytish kerakki , ko'p xollarda yarimo'tkazgich namunalari aniq geometric o'lchamlarga ega bo'ladi va zondlar bilan namuna qirrasi orasidagi masofa L zondlar orasidagi masofa tartibi bilan bir qatorda bo'ladi, bu tok zichligining potensial taqsimotida sferik simmmetriyaning buzilishiga olib keladi. Natijada (10) fo'rmula bilan aniqlangan solishtirma qarshilikning qiymati haqiqiy qiymatidan farqli bo'ladi . Buni tuzatish uchun yarimcheksiz namunalar uchun o'rinli bo'lgan namuna o'lchovlariga va zondlarning namuna sirtida joylanishiga bog'liq bo'lgan tuzatish funksiyasi kiritiladi. Ba'zi hollar uchun bunday funksiyalar topilgan.

Solishtirma qarshilikni nuqtaviy kontaktning tarqalgan qarshilik usuli bo'yicha aniqlash.

Bu usul yarimo'tkazgich va uning yassi (tekis) sirtiga tik joylashgan zonddan iborat bo'lgan struktura qarshiligini o'lchashga asoslangan . Agar metall zond yarimo'tkazgichning yassi sirti bilan kichik yuzachali O'm kontakti xosil qilsa , shu kontaktdan tok o'tkazib o'lchangan qarshilik tarqalgan (yoyilgan qarshlik) deb ataladi. Yarimo'tkazgichda kontakt qarshiligi kichik bo'lsa katta yuzali $S_0 >> \pi r^2$ ikkinchi kontakt ham bor va u metall zonddan uzoqda $L >> r_0$ katta masofada joylashgan deb faraz qilinadi. Bu usul keng tarqalgan bo'lib, bir jinsli yarimo'tkazgichlarda , epitaksial strukturalarning hamma turlarida , diffuzion qatlamlarda solishtirma qarshilikni 0.001 dan 100 O'm*sm gacha oraliqda va qarshilikning qatlam bo'yicha taqsimotini aniqlashda qo'llanadi, uning afzalliklaridan yana biri namunaing muayyan nuqtasidagi kichik hajmlarda qarshilikni o'lchash mumkinligidir. Tarqalgan qarshilik usulining nazaryasi yarimcheksiz yarimo'tkazgich namunalaridan nuqtaviy zond kontakti tok o'tganda xosil qilgan potensialining taqsimlanishiga asoslangan.

Quyidagi 5- rasmga qarang.



(5-rasm)

Ma'lumki , bunday hollar uchun potensial taqsimoti (6) fo'rmuladan aniqlanadi. Ravshanki zondning yarimo'tkazgich bilan xosil qilgan kontaktining diametri $2r_0$ yarimshar ko'rinishida bo'lgan holida ham potensial taqsimoti (6) ga o'xshash bo'ladi. Kontakt r_0 bo'lganda namunadagi ikki zond orasidagi kuchlanish tushuvi zondning elektr potensialiga teng bo'ladi:

$$U = \varphi_0(r_0) - \varphi(l) \approx \frac{I\rho}{2\pi r_0} \approx \varphi(r_0) \quad \textbf{(11)}$$

Yarimcheksiz namunalarda elektr potensialining tarqalishi qonunidan, tarqalgan qarshilik (11) fo'rmulaga ko'ra $R_p = \frac{U}{I} = \frac{\rho}{2\pi r_0}$ **(12)** ekanligi kelib chiqadi. Yarimo'tkazgich sirtidagi oksid qatlami va sirt o'tkazuvchanligining struktura qarshiligiga ta'siri kichik bo'lsa , uni tarqalgan qarshilik sifatida olish mumkin. Ma'lumki, zond va yarimo'tkazgichlarning deformatsiyalanishlari tufayli , zond bilan yarimo'tkazgich orasidagi kontaktning haqiqiy shakli va o'lchamini aniqlash juda qiyin. Shu bilan birga , u zond kontakti radiusiga materiallarining mexanik xossalariga, zondga qo'yilgan kuchga bog'liq.

Ko'rilayotgan usulning to'rt zondli usuldan farqi shundaki, bunda kontakt shakli qandaydir r_0 radiusga ega bo'lgan yassi aylanadan iborat. Ikki materialning yung moduli va zondga qo'yilgan kuchlarni bilgan holda kontaktning radiusini hisoblash mumkin. Radiusi r_0 bo'lgan yassi kontaktning yarimcheksiz namunalarda elektr potensialining taqsimlanishi Laplas tenglamasi aniqlanadi. Bunday struktura (tuzilma)ning tarqalgan qarshiligi $R_p = \frac{\rho}{4r_0}$ **(13)** fo'rmula bilan aniqlanadi. Tajribada tarqalgan qarshilik odatda ikki, uch zondli chizmalar bilan o'lchanadi. Uch zondli chizma bilan o'lchanganda zondlarning bir xil bo'lishi talab etilmaydi, lekin bir qancha sabablar borki, metall - yarimo'tkazgich strukturalaridagi qarshilikni ideal strukturalardagi tarqalgan qarshilikdan farqli bo'lishiga olib keladi. Metall - yarimo'tkazgich orasida potensial to'siq paydo bo'lsa , ya'ni ularning chiqish ishlari xar hil bo'lgan holda zaryad tashuvchilar bilan boyigan yoki kambag'allashgan qatlam hosil qiladi. Omik bo'lmagan kontaktdan tok o'tganda , kuchlanishning teskari yo'nalishida potensial to'siq sohasi qatlamining qarshiligi ortadi, kuchlanishning to'g'ri yo’nalishida injeksiya tufayli kontakt qarshilik qiymati kichiklashadi. Bular bilan bir qatorda kontaktdan tok o’tganda kontakt sohasining qizishi va termo E.Yu.K xosil bo’lishi qarshilikning o’zgarishiga olib keladi. Qarshilikning o’zgarishiga sabablardan yana biri bu – kontaktning kichik yuzachaga ega bo’lishi va kontakt sohasida elektr maydon kuchlanganligini katta bo’lishligi harakatchanlikning kamayishiga , ya’ni qarshilikning o’zgarishiga olib kelishi mumkin. Bu ko’rilgan hodisalar tarqalgan qarshilikni hisoblashda qabul qilingan yarimo’tkazgichning bir jinsli va O’m kontaktli bo’lsin deb qabul qilingan farazlarning buzilishiga olib keladi. Shuning uchun strukturaning tarqalgan qarshiligi haqiqiy qiymati bilan farq qiladi, ya’ni xatolik mavjud bo’ladi. Tarqalgan qarshilikni kichik toklarda **(10^{-7} – 10^{-2} A)** , kichik kuchlanishlarda (U = kT/e) o’lchash bilan yuqorida qayd etilgan ba’zi bir hodisalarning ta’sirini kamaytirish – minimumga keltirish mumkin. Xisoblashlarning ko’rsatishicha, kremniy namunalarida zond kontakti radiusi 4mkm, kuchlanish U<15mV bo’lganda kontakt sohasi temperaturasining o’zgarishi 0.1 ^{0}C dan oshmaydi, elektr maydon kuchlanganligi zaryad tashuvchilar harakatchanligining maydonga bog’liqlik sohasidan kichik **(E<1000V/sm)** bo’ladi.

Yupqa, qarshiligi katta namunalarda sirt holatlari hosil qilgan sirt o’tkazuvchanlikning tarqalgan qarshilikka ta’sirini qo’yilgan kuchlanishni kamaytirgan bilan yo’qolmaydi , shuning uchun o’lchangan struktura qarshiligi **(13)** fo’rmula bo’yicha hisoblagan qiymatimizdan biroz farq qiladi. Shuning uchun 13 formulaga xatolikni to’g’irlash uchun emperik koeffitsent K(ρ) orqali o’lchangan struktura qarshiligi quyidagicha ifodalanadi: $\boldsymbol{R_{o\prime}} = \boldsymbol{k}(\boldsymbol{\rho})\frac{\boldsymbol{\rho}}{\mathbf{4r_0}}$ **(14)**

Bu hodisalar kontakt radiusining haqiqiy qiymatini to’g’ridan-to’g’ri aniqlash mumkin emasligi, tarqalgan qarshilikni solishtirma qarshiligi aniq bo’lgan namunalardan foydalanib darajalash zaruriyatini tug’diradi, ya’ni R = f(ρ) bog’lanishni topish kerak bo’ladi. O’lchov natijalari aniq va takrorlanuvchan bo'lishi uchun solishtirma qarshiligi o'lchanayotgan va etalon namunalarning sirti bir xil ishlovdan o'tishi va uning sifati sirt ishlovining ma'lum bir standart talabiga javob berishi kerak. Zond manipulyatori tuzilishi va zond o'lchami kontakt yuzasining har doim birday bo'lishini ta'minlashi kerak. Ko'p xollarda zondlar sifatida uchiga osmiydan yarimshar ko'rinishida qoplangan qattiq materiallar, ruteniy qotishmalarining simlari ishlatiladi. Zondlar uchidagi yarimshar ko'rinishidagi osmiydan iborat poynak ning radiusi 25mkm chamasida bo'lganida , kontakt radiusi taxminan 4mkm ni tashkil etadi. Poynakka yuqori aniqlikda ishlov beriladi. Kontakt xossalarining takrorlanishi uchun zondlarga qo'yilgan kuchlanish, ya'ni yuza birligiga qo'yilgan kuch 100-10^4 N/sm^2 oraliqda o'zgartiriladi. Bunda zondga qo'yilgan yuk bir xil saqlanishi va zondlarni oxista tik ko'tarishiga erishish kerak. Yuqorida keltirilgan bosim zondlar namuna sirtidagi oksid qatlamni teshishga yetarli bo'lgan qoniqarli O'm kontakti hosil qiladi. Bu usul bilan ajratilgan muayyan joydagi , asosan qalingi bir necha kontakt radiusiga teng bo'lgan tarqalgan qarshiligini, ya'ni solishtirma qarshiligini o'lchash mumkin. Fazoviy ajratish qobilyati taxminan kontakt diametri (10mkm) ga teng. Solishtirma qarshiliki o'lchanayotgan sohaning hajmi taxminan 10^{-11} - 10^{-10} sm^3 tartibida bo'lsin. Bu holat kremniy va bosqa yarimo'tkazgich namunalarida solishtirma qarshilikning sirt va qalinlik bo'yicha fluktuatsiyasini o'rganishga imkon beradi. Solishtirma qarshilkni o'lchashdagi xatoliklar yarimo'tkazgich bilan yarimo'tkazgich bilan zond orasidagi masofani kontakt o'lchami xar xil bo'lishidan , oksidlangan qatlamning qatnashishidan , kontakt sohaning qizishidan , haraktchanlikning kuchli elektr maydonida kamayishi bilan sodir bo'lishi mumkin. Solishtirma qarshiligi katta namunalarda sirt sohasida bo'ladigan hajmiy zaryad sohasining va vaqt bo'yicha sirt potensialining o'zgarishining kuchli ta'sir ko'rsatishi mumkin. Xar xil yarimo'tkazgichlar uchun ularning sirtiga ishlov berish, namunani darajalashga tayyorlash va o'lchashdagi shart –

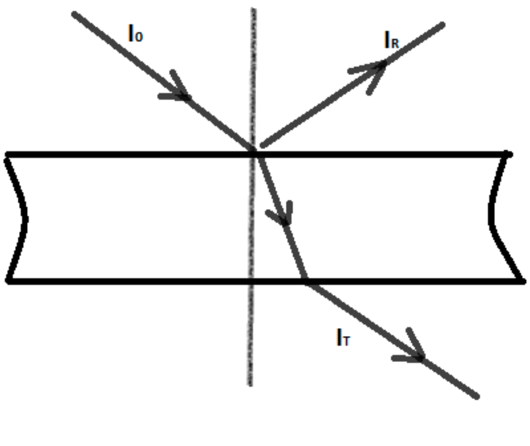
sharoitlar takliflari ishlab chiqilgan. Masalan, eng ko'p qo'llanadigan yarimo'tkazgich kremniy namuanalarini o'lchashga darajalashga tayyorlash uchun quyidagi variant taklif etilgan. Kremniy namunalarini kesgandan so'ng kaliy ishqorida 100 ^{0}C da 10 min davomida qaynatib , ikki tomonidan taxminan 15mkm qatlam edirib yuboriladi, so'ng unga mexanik kimyoviy ishlov berib , 25-35 mkm chamasida qatlam olib tashlanadi, so'ng peroksid – amiak eritmasida yuvilib, havoda 150 ^{0}C da 15 minut davomida ushlab turiladi. Shu usul bilan ishlovdan o'tgan namunalarda ishonch extimolligi 0.95 bo'lgani holda qarshilikni o'lchashdagi xatolik 3.5% dan oshmaydi. Bundan tashqari, kremniy namunalarida yaxshi natijalarga erishish uchun ketma – ket ikki texnologik bosqichni o'z ichiga olgan ishlov qo'llaniladi: olmos pastasi AP – 2 bilan silliqlash , so'ng ishqorli eritmaga SiO_2 kukuni solingan suspenziyada yaltiratiladi, ya'ni sayqal beriladi yoki vodorod xlorid (HCl) kislotasi bug'idan sirtni edirish uchun foydalaniladi. Bu usul bilan ishlangan namunalarda solishtirma qarshilik 0.001 - 10 O'm*sm oraliqda o'lchanganda va ishonch ehtimoli 0.95 bo'lganida, xatolik 5% dan oshmaydi.

1.3-§ Yarimo'tkazgichlarning parametrlarini optik usullar bilan o'lchash usullari

Yarimo'tkazgichlarning optik parametrlari haqida. Yarimo'tkazgichlarda optik xodisalar asosida elektromagnit to'lqinlarning bog'langan valent elektronlar, bog'lanmagan erkin zaryad tashuvchilar, kristall panjara va kirishma atomlari, elektron-kovak plazmalari bilan o'zaro ta'siri yotadi. Shuning uchun optik xodisalar yarimtkazgichli kristallarda to'lqin uzunligi 0,2 mkm - 100 mkm oralig'ida bo'lgan elektromagnit to'lqinlar ta'sirida sodir bo'ladigan keng jarayonlarni o'z ichiga oladi.Yarimo'tkazgich sirtiga tushgan yorug'lik uch qismga ajraladi: bir qismi qaytadi, bir qismi sinib namunaga kiradi, uning bir qismi yutilib, bir qismi esa namunadan o'tadi (6-rasm). Namunadan qaytgan I_R, o'tgan I_T va namunada yutilgan I_α yorug'lik intensivliklarining ularga tushgan yorug'lik intensivligi I_0 ga nisbati bilan aniqlanadigan kattaliklar

$$R_v = \frac{I_R}{I_0}; \quad T_v = \frac{I_T}{I_0}; \quad A_v = \frac{I_\alpha}{I_0}$$

mos ravishda namunaning yorug'likni qaytarish va o'tkazish (shaffoflik, tiniqlik) koeffisientlari, A_v - yutish qobiliyati deb ataladi. Bu kattaliklar namunadan yorug'lik oqimining qanday qismi qaytishini, o'tishini va namunada yutilishini ko'rsatadi. Energiyaning saqlanish konuniga muvofiq: $\mathbf{R_v + T_v + A_v = 1}$ **(15)** buladi.



(6-rasm)

Optika kurslaridan ma'lumki, T_v, R_v, A_v lar bilan optik konstantalar orasidagi munosabatlar elektr o'tkazuvchan muhitda (solishtirma elektr o'tkazuvchanligi $\sigma \neq 0$ bo'lganda) kompleks nur sindirish ko'rsatkichi bilan aniqlanadi:

$$\mathbf{n^2 = c^2\mu_0\left(\mu\varepsilon\varepsilon_0 - i\mu\frac{\sigma}{\omega}\right) = (n - i\chi)^2} \qquad \mathbf{(16)}$$

Bu yerda nur sindirish ko'rsatkichi n ning haqiqiy qismi n = c/u bo'lib, u yorug'likning vaquumda tarqalish tezligini yarimo'tkazgichdagi tarqalish tezligiga nisbati bilan aniqdanadigan kattalikdir. Mavhum qismi χ elektromagnit to'lqinlarining muhitda sinishini ko'rsatadigan kattalikdir. Shuning uchun χ - yutilish ko'rsatkichi yoki ekstensiya koeffisienti deb yuritiladi, $\varepsilon_0 = 8.85*10^{-12}$ F/m – vakuumning dielektrik singdiruvchanligi, $\mu_0=4\pi*10^{-7}$ Gn/m - vakuumning magnit singdiruvchanligi, ε – namunaning dielektrik singdiruvchan ligi, σ - solishtirma elektr o'tkazuvchanlik. Umumiy xolda yarimo'tkazgich kristallarida ε , σ , μ - tenzor kattaliklardir, ya'ni ular elektromagnit to'lqinlarining kristall o'qlariga nisbatan tarqalish yo'nalishiga bog'lik bo'lgan kattaliklar. Kub shaklidagi kristallarda kristall panjarasi optik hodisalar parametrlarini skalyar kattaliklar deb hisoblash mumkin. ev o, ju - pa- rametrlar namunaga tushayotgan yorug'lik chastotasining funksiyalaridir. Elektromagnit to'lqinlarning muhitda tarqalishi Maksvell tenglamalari tizimining yechimi asosida o'rganiladi. O'tkazuvchan muhitda Maksvell tenglamalari tizimining yechimiga ko'ra z o'qi yo'nalishda tarqalayotgan elektromagnit to'lqinlaring elektr maydon kuchlanganligi

$$\boldsymbol{E_z = E_0 \exp\left(-\frac{\omega\chi}{c}z\right)\exp\left(i\omega t - \frac{nz}{c}\right)} \qquad \mathbf{(17)}$$

ko'rinishdagi ifoda bilan aniqlanadi. Bu formula amplitudasi eksponensial qonun bo'yicha sunuvchi yassi elektromagnit to'lqinlarning elektr maydon kuchlanganligini ifodalaydi. Odatda optic asboblarda elektr maydon kuchlanganligi amplitudasi kvadratiga proporsional bo'lgan yorug'lik intensivligi (I_υ) o'lchanadi. Shunga ko'ra, (3) dan

$I_v \sim E_0^2 \exp(-\frac{2\omega\chi z}{c})$ **(18)** $\Longrightarrow$ $I_v = I_0 exp(-\alpha z)$ **(19)** (bu yerda $\alpha = 2\omega\chi/c$ ga teng va uni yutilish koeffitsienti deb ataladi) ko'rinishdagi ifodasi yorug'likning muhitda yutilishini ko'rsatuvchi Buger-Lambert qonuni deb yuritiladi. Yarimo'tkazgichlarning optik xossalarini yoritishda n va χ bilan bir qatorda, kompleks dielektrik singdiruvchanlik ham qo'llaniladi: $\varepsilon = \varepsilon_1 - i\varepsilon_2$ **(20);** n bilan ε orasidagi bog'lanish $n = \sqrt{\varepsilon\mu}$ **(21)** formula bilan aniqlanadi. Elektromagnit to'lqinlarning to'lqin uzunligi λ=0,2 - 100 mkm sohasida yarimo'tkazgichlar kuchsiz magnit xossalariga ega bo'lib, magnit singdiruvchanligi birga yaqin bo'ladi. Bu vaqtda yuqoridagi tenglamalardan $\varepsilon_1 = n^2 - \chi^2$, $\varepsilon_2 = 2n\chi = \sigma/(\varepsilon_0\ \omega)$, $\alpha(\omega) = \varepsilon_2\ \omega/\ (nc)$ **(22)** bo'lishligini ko'ramiz. Yarimo'tkazgichlarning optik xossalarini ε_1, va ε_2 orqali hisoblashga zaruriyat bo'lgan vaqtda n va χ parametrlarga o'tish unchalik qiyinchilik tug'dirmaydi. Nur sindirish ko'rsatkichlari n_1 va n_2 bo'lgan muhit chegarasiga tushgan yorug'lik ikkiga ajraladi: bir qismi qaytadi, bir qismi esa sinib, namunaga kiradi. Ma'lumki, qutblangan yorug'lik ikki muhit chegarasiga tushganda qaytgan (E'), singan (E") to'lqinlarning elektr maydon kuchlanganliklari amplitudalari Frenel tenglamalari orqali aniqlanadi. Bunda $\mu_1 = \mu_2 = 1$ bo'lganda , E' va E" lar quyidagi ifodalar orqali topiladi: $E'_{vp} = E_{vp}\frac{tg(\varphi-\varphi'')}{tg(\varphi+\varphi'')}$;

$E''_{vs} = E_{vs}\frac{tg(\varphi''-\varphi)}{tg(\varphi+\varphi'')}$; **(23)**

Bu yerda φ - tushish, φ'' – sinish burchaklari. E_p, E_s - tushayotgan to'lqinlarning elektr maydon kuchlanganliklari amplitudasi. P va S - indekslar elektr maydon kuchlanganligini yorug'likning tushish tekisligiga parallel va unga tik tekislikda yotishini mos ravishsa ko'rsatadi. Qutblangan yorug'likning namunadan qaytish koeffisientlari o'tish koeffisientlari (shaffoflik koeffisientlari) quyidagi ifodalar bilan aniqlanadi:

$T_{vs} = (\frac{E''_{vs}}{E_{vs}})^2$; $T_{vp} = (\frac{E''_{vp}}{E_{vp}})^2$ **(24)**

Frenel tenglamalaridan ko'rinadiki, yorug'likning namunadan qaytish va o'tish koeffisientlari yorug'likning tushish burchagiga , optic konstantalariga, elektr maydon kuchlanganligi vektorining yo'nalishiga bog'liq. Eslatib o'tamiz, Frenel tenglamalari muhitning nur sindirish ko'rsatkichi kompleks bo'lgan hol uchun ham o'rinlidir. Bunda sinish qonuni $\frac{n^*}{n_1} = \frac{sin\varphi}{sin\varphi''}$ **(25)** ko'rinishda bo'ladi. Birinchi muhit havo bo'lganda $n_1=1$ bo'lib, sinish burchagi kompleks bo'ladi. Yorug'lik havodan yarimo'tkazgich sirtiga tik tushganda $\varphi = \varphi'' = 0$ bo'ladi. Frenel munosabatlariga ko'ra, havo-yarimo'tkazgich chegarasidan yorug'likning qaytish koeffisientining optik konstantalar (n va χ) bilan bog'lanishi quyidagi ko'rinishni oladi: $\boldsymbol{R_v = R_{sv} = R_{pv}} = \frac{(n-1)^2+\chi^2}{(n+1)^2+\chi^2}$ **(26)**. (26) dan ko'rinadiki, qaytish koeffisienti yorug'lik tik tushganda uning qaanday kutblanganligiga bog'liq bo'lmaydi. Qaytish koeffisientining tushish burchagiga bog'liqligi shuni ko'rsatadiki, tushish burchagining φ = 0 - 17° oshirilsa deyarli o'zgarmaydi, shuning uchun amaliyotda tushish burchagining 0 - 17° oralig'ida o'lchangan qaytish koeffisientini tik tushgandagi kabi qarash mumkin, (26) tenglamadan ko'rinadiki, qaytish koeffisientini o'lchash bilan bir vaqtda ikki parametr (n va χ) ni aniqlash mumkin emas. Ko'p yarimo'tkazgichlarda nur sindirish ko'rsatkichining yetarlicha katta bo'lishi tufayli, ularda yutish ko'rsatkichi χ=0 bo'lganda xam qaytish koeffisientlari katta R= 30 - 40% bo'ladi. Namunalarda nur sindirish ko'rsatkichi katta n>> χ bo'lganda qaytish koeffitsienti xam katta bo'ladi ($R \approx 1$).

1.4-§ Zaryad tashuvchilar konsentratsiyasi va harakatchanligini o'lchash

Nomuvozanat zaryad tashuvchilar parametrlari - Yarim o'tkazgichlar tashqi ta'sir ostida, yani yorug'lik, rentgen, γ - kvantlar, tezlantirilgan neytral, zaryadlangan zarrachalar hamda p – n o'tish orqali injeksiya, elektr maydonda zarbdan ionlanish, tunnel jarayonlari tufayli nomuvozanat zaryad tashuvchilarning paydo bo'lishi, generatsiyalanishi mumkin. Nomuvozanat zaryad tashuvchilar yarimo'tkazgich materiallari va asboblarining elektrofizik, fotoelektrik xossalarini aniklaydi. Nomuvozanat zaryad tashuvchilarning dreyf harakatchanligi (m) diffuziya koeffitsienti (D), diffuzion uzunlik (L), yashash vaqti (t), sirtiy rekombinasiya tezligi (5) kabi parametrlar bilan tavsiflanadi. Bu parametrlarni aniklash usullari elektron, kavak uzluksizlik tenglamalarining ba'zi bir soddalashtiruvchi farazlar bilan berilgan boshlang'ich, chegaraviy shartlarni qanoatlantiruvchi yechimini topishga asoslangan. Yarim o'tkazgich namunalarda nomuvozanat zaryad tashuvchilar xususiya tok (tabiati, xatti-harakati) quyidagi

1. Elektron, kavak tok zichliklari

$$\gamma_n = e\mu_n nE + e\partial_n gradn \quad \textbf{(27)}$$

$$\gamma_p = e\mu_p pE + e\partial_p gradp \quad \textbf{(28)}$$

2. Uzluksizlik

$$\frac{\partial n}{\partial z} = g_n - \frac{\Delta n}{\tau_n} + \frac{1}{e}\mathrm{div}j_n \quad \textbf{(29)}$$

$$\frac{\partial p}{\partial z} = g_p - \frac{\Delta p}{\tau_p} + \frac{1}{e}\mathrm{div}j_p \quad \textbf{(30)}$$

tenglamalari sistemasi yechimi bilan tavsiflanadi:

Bu yerda $n = n_0 + \Delta n$ va $p = p_0 + \Delta p$ - nomuvozanat xolatdagi zaryad tashuvchilar (elektron, kovak) to'la konsentrasiyasi n_0, p_0- muvozanatdagi zaryad tashuvchilar elektron, kavak konsentrasiyasi; Δl, Δp - nomuvozanat zaryad tashuvchilar elektron, kavakning muvozanat xolatdagisiga nisbatan ortiqcha konsentrasiyasi, Δn, Δp - elektron, kavak diffuziya koeffitsientlari; μ_n, μ_p - elektron, kavak harakatchanliklari; τ_n, τ_p- elektron, kavak yashash vaktlari; g_n, g_p- elektron, kavakni generasiyalash tezliklari.

Fotoinjeksiya (yorug'lik orkali) nomuvozanat xolatdagi zaryad tashuvchilarni xosil qilganda generasiya tezligi

$$g = \alpha\beta I_n e^{-\alpha x}(1 - R_\nu)/h\nu = g_0 e^{-\alpha x} \qquad \textbf{(31)}$$

ifoda bilan topiladi. Bu yerda α – yorug'likning yarim o'tkazgichda yutilish koeffitsienti, R_ν- yorug'likning namunadan kaytish koeffitsienti, hv- foton energnyasi, β - zaryad tashuvchilarning kvant chikish koeffitsienti – yorug'lik intensivligi. (29) va (30) tenglamalardan ko'rinadiki, nomuvozanat xolatdagi zaryad tashuvchilar konsentrasiyalarining o'zgarish tezliklarini $\frac{\partial n}{\partial t}$, $\frac{\partial p}{\partial t}$ ni zaryad tashuvchilarning rekombinatsiya, geniratsiya, dreyf-diffuziya jarayonlari aniqlaydi. Zaryad tashuvchilar konsentrasiyasi fakat bir yunalishda, masalan, x – o'qi bo'yicha o'zgaradi va elektr maydon kuchlanganligi $\vec{E}$ x o'qi bo'yicha yo'nalgan bo'lsin deb olingan xol uchun, (29) va (30) tenglamalar (27) va (28) ni nazarda tutganda, quyidagi ko'rinishni oladi:

$$\frac{\partial \Delta p}{\partial t} = g_p - \frac{\Delta p}{\tau p} + D_p \frac{\partial^2 \Delta p}{\partial x^2} - \mu_p p \frac{\partial E}{\partial x} - \mu_p E \frac{\partial \Delta p}{\partial x} \qquad \textbf{(32)}$$

$$\frac{\partial \Delta n}{\partial t} = g_n - \frac{\Delta n}{\tau n} + D_n \frac{\partial^2 \Delta n}{\partial x^2} + \mu_n n \frac{\partial E}{\partial x} + \mu_n E \frac{\partial \Delta n}{\partial x} \qquad \textbf{(33)}$$

Bu yerda $\left(\frac{\partial E}{\partial x}\right)$ Puasson tenglamasi

$$\frac{\partial E}{\partial x} = \frac{e}{\varepsilon_0 \varepsilon}(\Delta p - \Delta n) \quad \textbf{(34)}$$

bilan ifodalanadi. Xajmiy zaryad vujudga kelmaganda, ya'ni namunada elektr neytrallik sharti Δp=Δn bajarilganda $\frac{\partial E}{\partial x}$=0 bo'ladi. Bu xol yaxshi o'tkazuvchanlikka ega bo'lgan yarimutkazgichlarda kuzatiladi. Kirishmali yarim o'tkazgichning biror joyida qaysi usul bilan bo'lmasin asosiy bo'lmagan zaryad tashuvchilar injeksiyalansin. Paydo bo'lgan xajmiy zaryad bunda ikki usul bilan: bu sohadan asosiy bo'lmagan zaryad tashuvchilarni chiqarib tashlash orqali, yoki xajmiy zaryadni boshka tipdagi zaryad orqali, yani asosiy zaryad tashuvchilar bilan kompensatiyalanishi mumkin. Asosiy zaryad tashuvchilarning katta konsentrasiyalarida elektr neytrallikni *tiklash* uchun ularning qayta taqsimlanishi juda tez, maksvell relaksasiya vaqti

$$\boldsymbol{\tau_n = \varepsilon_0 \varepsilon / \sigma} \quad \textbf{(35)}$$

ichida sodir bo'lishi kerak. ε_0,ε- vakkum, yarimo'tkazgichning dielektrik singdiruvchanliklari, τ – yarimo'tkazgichning solishtirma o'tkazuvchanligi.Amaliyotda asosiy zaryad tashuvchilarning qayta taqsimlanishi xech qanday qiyinchilik tug'dirmaydi. Noasosiy zaryad tashuvchilarning diffuziya jarayoni o'z harakatchanligiga, diffuziya koeffisientiga ega bo'lgan ney-tral zarracha kabi sodir bo'ladi. Elektr maydonida asosiy bo'lmagan zaryad tashuvchilar zaryadlangan zarracha kabi dreyflanadi. Lekin asosiy zaryad tashuvchilarning tez qayta taqsimlanishi tufayli, hajmiy zaryad xosil bo'lmaydi. Demak, zaryad tashuvchilarning kichik konsentrasiyalarida, ikki ishorali zaryad tashuvchilarning fazoda qayta taqsimlanishi orqali, elektroneytrallikning tiklanishi sodir bo'ladi.

Δp=Δn bo'lganda $g_n = g_p$, $\sigma_n = \tau_p$bo'ladi. (32) ni $\tau_n = enm_n$ ga, (33) ni $\sigma_p = ep\mu_p$ ga ko'paytirib, o'xshash xadlarni qo'shib,

$$\frac{\partial \Delta p}{\partial t} = g_p - \frac{\Delta p}{\tau_p} + D\frac{\partial^2 \Delta p}{\partial x^2} - \mu_n E\frac{\partial \Delta p}{\partial x} \quad \textbf{(36)}$$

ko'rinishda bo'lgan uzluksizlik tenglamasini olamiz. Kichik elektr maydonlarida zaryad tashuvchilar dreyf harakatining diffuziyasiga nisbatan xisobga olinmas- ligi mumkin, shuning uchun (36) ni kichik elektr maydonda

$$\frac{\partial \Delta p}{\partial t} = g_p - \frac{\Delta p}{\tau_p} + D\frac{\partial^2 \Delta p}{\partial x^2} \quad \textbf{(37)}$$

ko'rinishda ifodalash mumkin. Bu yerda,

$$D = \frac{\sigma_n D_p + \sigma_p D_p}{\sigma_n + \sigma_p} = \frac{n+p}{n/D_p + p/D_n} \quad \textbf{(38)}$$

$$\mu_E = \frac{\tau_n \mu_p - \tau_p \mu_n}{\tau_n + \tau_p} = \frac{(n-p)}{(n/\mu_p + p/\mu_n)} \quad \textbf{(39)}$$

(37)tenglama (32) va (33) tenglamalarga teng kuchli bo’lib, elektroneytrallik sharti bajarilgan sharoitda, u zaryad tashuvchilar tabiatini ifodalaydi.

(37) dagi D - elektron-kavakning diffuziyasini aniqlaydi va zaryad tashuvchilarning biqutbiy diffuziya koeffisienti, (39) dagi μ_E esa biqutbiy dreyf harakatchanligi deb yuritiladi.n-tip kirishmali yarimo’tkazgichda $n>>p$ bo’lgani uchun (38) va (39) lardan **$D=D_p$; $\mu_E=\mu_p$** p-tip kirishmali yarimo’tkazgichda $p >> n$ bo’lgani uchun **$D=D_n$; $\mu_E=-\mu_n$** va xususiy yarimo’tkazgichda $n=p$ bo’lgani uchun $\boldsymbol{D=\frac{D_nD_p}{D_{n+}D_p}}$; **$\mu_E=0$** bo’lishligini ko’ramiz. Kirishmali yarimo’tkazgichlarda zaryad tashuvchilarning biqutbiy diffuziya koeffitsienti asosiy bo’lmagan zaryad tashuvchilar diffuziya koeffitsientiga teng bo’lishligini, biqutbiy dreyf harakatchanlik absolyut qiymati buyicha asosiy bo’lmagan zaryad tashuvchilar harakatchanligiga mos kelishini ko’rdik. Bundan tashqari, elektron kovak konsentrasiyalari n va p-larning nisbatiga qarab μ_E -ishorasini o’zgartiradi: $n=p$ va $\mu_E=0$ bo’lishligini guvohi bo’lamiz. Agar biqutbiy diffuziya koefftisienti (38)ni Eynshteyn munosabati

$$\boldsymbol{D=\frac{KT}{e}\mu_D} \quad \textbf{(40a)}$$

orqali ifodalasak, harakatchanlikning yana bir ifodasini, yani zaryad tashuvchilarning biqutbiy diffuzion harakatchanilik ifodasini olamiz.

$$\boldsymbol{\mu_D=\frac{n+p}{\frac{p}{\mu_n}+\frac{n}{\mu_p}}} \quad \textbf{(40b)}$$

Kirishmali yarimo’tkazgichlarda $n>>p$ yoki $p>>n$ o’rinli bo’lganda μ_D qiymati μ_E ga teng bo’lib, uning ishorasi xamma vaqt musbat bo’ladi. Xususiy yarimo’tkazgichlarda

$$\boldsymbol{\mu_D=2\frac{\mu_n\mu_p}{\mu_n+\mu_p}} \quad \text{dir } \textbf{(40c)}$$

Uzluksizlik tenglamalari (40b) ning bazi bir sodda xollardagi yechimini taxlil qilaylik.

1.Faraz qilaylik, elektr maydon quyilmagan ($\boldsymbol{E}=0$) va namunada nomuvozanatdagi zaryad tashuvchilar tekis $\boldsymbol{g_n=\alpha\beta I_n e^{-\alpha x}(1-R_v)}$

geniratsiyalansin. Namuna erkin sirtlarida sirtiy rekombinasiya sodir bo'lmasin (S=0). Bu xolda dreyf, diffuziya jarayonlari bo'lmaydi, shuning uchun (36) tenglama

$$\frac{\partial \Delta p}{\partial t} = g - \frac{\Delta p}{\tau_p} = (1 - R_v)\alpha\beta I_{0v} - \frac{\Delta p}{\tau_p} \quad \textbf{(41)}$$

ko'rinishni oladi. Nomuvozanat zaryad tashuvchilar konsentrasiyasining vaqt bo'yicha o'zgarishini faqat generasiya va rekombinasiya jarayonlari aniqlaydi. Yopishish (tutqich) markazlar bo'lmaganda generasiya tezligi $g_0 = \alpha\beta I_{0v}(1 - R_v)$ - ga mos Δp_{bosh}- boshlang'ich konsentrasiya to'g'ri kelsin. Agar t = 0 da generasiya jarayoni to'xtatilsa, t> 0 da g=0 bo'lgandagi (41)ning..yechimi

$$\Delta p = p(t) - p_0 = \Delta p_{bosh} \exp\left(-\frac{t}{\tau_p}\right) = (1 - R_v)\alpha\beta I_{0v}\tau_p e^{-\frac{t}{\tau_p}} \quad \textbf{(42)}$$

bo'ladi. Tekis generasiya bilan vujudga kelgan asosiy bo'lmagan zaryad tashuvchilar konsentrasiyasining so'nishi yorug'lik intensivligi I_{ov} (uygotish darajasi) kichik Δn , $\Delta p \ll n_0 + p_0$ yoki juda katta I_{ov} da, ya'ni katta darajali injeksiya , $\Delta p \gg n_0 + p_0$ bo'lganda eksponenta qonuni bilan sodir bo'ladi. Bundan foydalanib, nomuvozanat zaryad tashuvchilarning yashash vaqtini aniqlash mumkin. Bu yerdagi τ – vaqti yarimo'tkazgichga kiritilgan noasosiy zaryad tashuvchilar konsentrasiyasini e- marta kamayishiga ketgan vaqt deb qarash mumkin.

2.Stasionar holni $\frac{d\Delta p}{dt} = 0$ ko'raylik. Elektr maydoni bo'lmaganda va yarimcheksiz namunaning x – o'qi bo'yicha nomuvozanat zaryad tashuvchilar notekis geniratsiyalanib, hajm bo'yicha t=0 da g_p= 0 deb faraz qilinganda, uzluksizlik tenglama $\frac{d^2 \Delta p}{dx^2} - \frac{\Delta p}{\partial \tau} = 0$ **(43)** ko'rinishda bo'ladi. Bu tenglamaning $p_{x=0} = \Delta p(0) + p_0$; $p_{x\to\infty} = p_0$ chegara shartlarini qanoatlantiruvchi yechimi

$$\Delta p(x) = p(x) - p_0 = \Delta p(0) \exp\left(-\frac{x}{L}\right) \quad \textbf{(44)}$$

bo’ladi. Bu yechimdan foydalanib, yarimo’tkazgich namunalarida asosiy bo’lmagan zaryad tashuvchilar diffuzion uzunligi $L=(D\tau)^{0.5}$ ni aniqlash mumkin. L ni asosiy bo’lmagan zaryad tashuvchilar diffuziyasi sodir bo’lganda ular konsentrasiyasining e - marta kamayadigan masofasi deb qarash mumkin. Taqiqlangan zonadagi yopishish (tushish) markazlarida ushlangan zaryadlar, zaryad tashuvchilarning diffuzion oqimiga xissa qo’shmaydi. Shuning uchun diffuzion uzunlik orqali yashash vaqtini aniqlaganda, yopishish markazlari nomuvozanat, asosiy bo’lmagan zaryad tashuvchilar yashash vaqtiga ta'sir ko’rsatmaydi. 3. Stasionar, nostasionar masalalarni ko’rshda, ba'zi bir hollarda, chegaraviy shartlar, $\boldsymbol{j_{px}} = \boldsymbol{eD}\,\frac{\partial\Delta p}{Dx}/_{x=0}$, **a** $=\pm \boldsymbol{S}(\boldsymbol{p}-\boldsymbol{p_0})/_{x=0}$, **a** ko’rinishda berilishi mumkin. Bu yerda, S – o’lchamligi tezlik birligi bilan aniqlanadigan kattalik, u sirtiy rekombinasiya tezligi deb ataladi. Mazkur chegaraviy shartning ma'nosi shundan iboratki, u S tezlik bilan sirtga oqib kirayotgan zaryad tashuvchilar oqimini anglatadi. S ning eng katta qiymati zaryad tashuvchilar tezligi 10^7 sm/s ning to’rtdan biriga teng bo’lib, germaniy va kremniylar uchun uy sharoitida $2*10^6$ sm/s tartibida bo’ladi. Agar namunada yopishish markazi mavjud bo’lsa, asosiy, noasosiy zaryad tashuvchilarning yashash vaqtlari bir-biridan juda katta farq qiladi . Yopishish markazlarida ushlangan zaryad tashuvchilar konsentrasiyasi oshiqcha nomuvazanat zaryad tashuvchilar konsentrasiyasidan katta bo’lsa, asosiy zaryad tashuvchilar yashash vaqti nomuvozanat asosiy bo’lmagan zaryad tashuvchilar yashash vaqtidan juda katta bo’ladi. n – tip materiallarda $\tau_n >> \tau_p$, p - tipda esa $\tau_n << \tau_p$ bo’ladi. Bu holda bitta namuna uchun zaryad tashuvchilarning yashash vaqti o’lchash usullariga qarab har xil qiymatga ega bulishi mumkin. Tekshirishlar shuni ko’rsatadiki, nomuvozanat zaryad tashuvchilar konsentrasiyasini, ya'ni nomuvozanat o’tkazuvchanlikning vaqt bo’yicha so’nishiga asoslangan hamma τ ni o’lchash usullari yopishish (tutqich) markazlarining holatiga, konsentrasiyasiga bog’liq bo’lgan zaryad tashuvchilar vaqtini beradi.

Diffuzion uzunlikni o'lchashga asoslangan zaryad tashuvchilar yashash vaqtini aniqlashning hamma usullari yarimo'tkazgich namunalarida yopishish (tushich) markazlarini bor yoki yo'q bo'lishiga, ularning xolatiga bog'lik; bo'lmagan asosiy zaryad, tashuvchilar yashash vaqtini beradilar. Yarimo'tkazgich namunalarida zaryad tashuvchilarning yashash vaqtini, diffuzion uzunligini aniqlashning juda ko'p usullari mavjud. U yoki bu usulni qo'llash yarimo'tkazgich materiallari va asboblarining ishlashini aniqlaydigan zaryad tashuvchilar yashash vaqtiga qarab tanlanadi. Yarimo'tkazgichlarda nomuvozanat zaryad tashuvchilarni generasiyalash usullariga qarab, tashuvchilar yashash vaqtini, diffuzion uzunligini o'lchashning stasionar, nostasionar usullari tavsiya etilgan. 3-turkum usullar sifatida p-n o'tishni qo'llashga asoslangan usullarni ko'rsatish mumkin. Oxirgi yillarda yorug'lik intensivligi katta bo'lgan impulsli lazerlarning yaratilishi munosabati bilan zaryad tashuvchilar yashash vaqtini katta $\Delta n\,,\Delta p \gg n_0 + p_0$ darajali injeksiyada o'lchash imkoni tug'ildi. Nurlanishli, nurlanishsiz rekombinasiyalar zaryad tashuvchilarning yashash vaqtini, diffuzion uzunligini aniqlovchi jarayonlardir. Bundan tashqari, τ, L namunalarni olish sharoitiga, issiqlik ishlovlariga va temperaturaga bog'liq parametrlardir.

Endi nomuvozanat zaryad tashuvchilar parametrlarini o'lchashning nostasionar usullari haqida so'z yuritamiz - Nomuvozanat zaryad tashuvchilar parametrlarini o'lchash usuli nazariyasi . Malumki, zaryad tashuvchilar generasiyalanishining qanday sodir bo'lishiga, namuna o'lchamlariga, sirt ishloviga qarab zaryad tashuvchilar konsentrasiyasi (fotoo'tkazuvchanlik)ning vaqt bo'yicha o'zgarishini, yani relaksasiyalarini aniqlovchi rekombinasiya, dreyf, diffuziya jarayonlari xar xil kechadi. Shuning uchun 2.4.1 da keltirilgan Δn (x, y, z, t) yoki ΔG(x, y, z, t) larning so'nishidan aniqlash mumkinligi to'g'risidagi g'oyani amaliyotga tadbiq etish uchun qayd etilgan omillar va jarayonlarni Δn (x, y, z, t) va ΔG(x, y, z, t) relaksatsiyalariga tasirini batafsilroq taxlil qilaylik. Oldin namuna to'g'ri burchakli yolg'iz (yakka) yoki davriy yorug'lik impulsi bilan yoritilgan xolni qarab chiqaylik. Foton energygiyasi hω≥ E bo'lgan yorug'lik impulsi davomiyligi ichida nomuvozanat zaryad tashuvchilar namuna hajmi bo'yicha tekis generatsiyalangan va erkin sirtlari shunday ishlovdan o'tkazilganki, sirtiy rekombinasiya kichik (boshqacha aytganda, kuzatilmasin) deb faraz qilamiz. Bu holda zaryad tashuvchilarning diffuziyasi vujudga kelmaydi.Δn=Δp da chiziqli rekambinasiya $\left(\frac{\Delta p}{\tau_p}\right)$ mavjud bo'lganda $\vec{E}$=0 da uzluksizlik tenglamasi (41) ko'rinishda bo'ladi. Kichik intensivlivdagi (Δn, Δp≤n_0+p_0) amplitudasi $I_{0\upsilon}$, davomiyligi T bo'lgan to'g'ri burchakli yorug'lik impulsi bilan yoritilganda, impulsning davomiyligi oralig'ida 0≤t = T (41) ning yechimi

$$\Delta p = \alpha\beta I_0\tau_p\left(1 - e^{-\frac{t}{\tau_p}}\right)(1 - R_v) \quad \textbf{(45)}$$

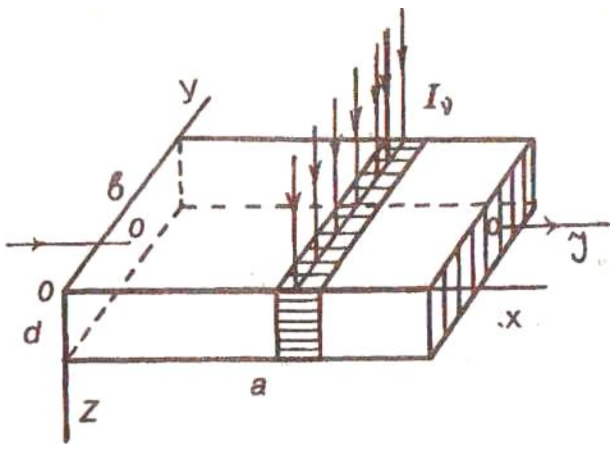
va impuls tugagandan so'ng T≤t da

$$\Delta p = \alpha\beta I_0\tau_p\left(1 - e^{-\frac{T}{\tau}p}\right)e^{-\frac{t-T}{\tau_p}}(1 - R_v) \quad \textbf{(46)}$$

bo'ladi. Agar yorug'lik impulsining davomiyligi zaryad tashuvchilar yashash vaqtidan katta (T≫ τ_p) bo'lsa , zaryad tashuvchilarning konsentrasiyasi stasionar

$$\Delta n_{em} = \alpha I_{0v}\beta\tau_p(1 - R_v) \quad \textbf{(47)}$$

qiymatga erishib ulguradi. Shunday qilib, ko'rilayotgan xolda zaryad tashuvchilarning konsentrasiyasi (Δn,Δp) xamda ularga proporsional bo'lgan fotoo'tkazuvchanlik, impuls davomiyligi oralig'ida



7-rasm. Yarimo'tkazgichning namunaviy modeli.

$$\Delta G \sim \Delta p \sim \left(1 - e^{-\frac{t}{\tau_p}}\right) \quad \textbf{(48)}$$

Impuls tugagandan so'ng

$$\Delta G \sim \Delta p \sim e^{-\frac{t-T}{\tau_p}} \quad \textbf{(49)}$$

qonuniyatlari bo'yicha o'zgaradi. Endi fotoo'tkazuvchanlikning so'nishida diffuziya, dreyf rekombinasiya jarayonlari qatnashadigan murakkabroq xolni ko'raylik. Namuna X=0, X=2A, Y= O, Y=2B Z= O, Z=2C dan o'tgan tekis-liklar bilan cheklangan to'g'ri burchakli parallelopiped shaklida bulsin (7-rasm). Aytaylik, namuna n - tipli yarimo'tkazgich bo'lsin, u xolda nomuvozanatiy zaryad tashuvchilarning diffuziyasini asosiy bo'lmagan zaryad tashuvchi, yani kovak aniqlaydi. Zaryad tashuvchilar tekis generatsiyalangan namunani sirtlarida, zaryad tashuvchilarning sirtiy rekombinasiyasi sodir bo'lganda, sirtga tomon yo'nalgan zaryad tashuvchilar oqimi vujudga keladi. Bu bilan hajm bo'yicha zaryad tashuvchilarning notekis taqsimlanishiga va natijada ularning diffuziyasi sodir bo'ladi. Faraz qilaylik, namunada yopishish markazlari yo'q, yorug'lik impulsining uyg'otish darajasi (intensivligi) kichik $\Delta n, \Delta p \ll n_0 + p_0$ bo'lsin. Impuls davomiyligi shunday kichik bo'lsinki, uning tugash vaqtini vaqt xisobining boshlanishini (t =0) deb qabul qilish mumkin bo'lsin. t =0 da xajm bo'yicha bir xil (tekis) tarqalgan nomuvozanat elektron, kavaklarning

diffuziya, rekombinasiya jarayonlari boshlanadi. O'tkazuvchanlikni o'lchash uchun zarur bo'lgan X – yo'nalishda elektr maydoni mavjud bo'lgan xolda uzluksizlik tenglama (30) si, yani,

$$\frac{\partial \Delta p}{\partial t} = -\frac{\Delta p}{\tau_p} - \mu E \frac{\partial \Delta p}{\partial x} + D\,div\,grad\,\Delta p(x, y, z, t) \quad \textbf{(50)}$$

bilan ifodalanadi. Uzluksizlik (50) tenglamani boshlang'ich

$$\Delta p(x, y, z, t)/_{t=0} = \Delta p_{bosh} \quad \textbf{(51)}$$

va sirtiy rekombinasiyani xisobga oluvchi

x = 0, x = 2A sirtlarida $D\frac{\Delta p}{\Delta x} = \pm S_a \Delta p$

y=0, y=2B sirtlarida $D\frac{\Delta p}{\Delta y} = \pm S_b \Delta p$ **(52)**

$$z=0,\ z=2C \text{ sirtlarida } D\frac{\Delta p}{\Delta z} = \pm S_c \Delta p$$

chegaraviy shartlarni qanoatlantiruvchi yechimi

$$\Delta p = \sum_{ijk} \Delta p_{ijk} = \sum_{ijk} G_{ijk} \cos\left(\frac{\xi_i x}{A}\right) \cos\left(\frac{\xi_j y}{B}\right) \cos\left(\frac{\xi_k z}{C}\right) x *$$

$$* \exp\left(-\frac{\mu E x}{2D}\right) exp\left\{-\left[\frac{1}{\tau} + \gamma_{ijk} + \frac{(\mu E)^2}{4D}\right]\right\} \quad \mathbf{(53)}$$

ko'rinishda bo'ladi. Bu yerda

$$\gamma_{ijk} = D\left(\frac{\varepsilon_i^2}{A^2} + \frac{\eta_j^2}{B^2} + \frac{\xi_n^2}{C^2}\right) \quad \mathbf{(54)}$$

(54) Δp_{ijk} - amplitudasi G_{ijk} bo'lgan garmonika konsentrasiyasi, berilgan xususiy funksiyasi bilan aniqlanadigan oshiqcha zaryad tashuvchilar konsentrasiyasining qismi. G_{ijk} – boshlang'ich shartdan, yani zaryad tashuvchilarning t =0 dagi taqsimotidan topiladigan kattalik. (53) yechimga xususiy funksiyalarning chiziqli kombinasiyasi deb qarash mumkin. Undan ko'rinadiki, Δp_{ijk}- ning vaqtga bog'lanishi uchta eksponensial tashkil etuvchilarni o'z ichiga oladi.

$\exp\left(-\frac{t}{ap}\right)$-namuna hajmida zaryad tashuvchilar rekombinasiyasi tufayli,

$\exp(-\gamma_{ijk} t)$- sirtiy rekombinasiya tufayli,

$\exp\left(-\frac{(\mu E)^2}{4D}\right)$ - zaryad tashuvchilar taqsimotiga maydon tasiri tufayli vujudga kelgan tashkil etuvchilardir, zaryad tashuvchilar yashash vaqtini, sirtiy rekombinatsiya tezligini o'lchashda vaqt doimiyligining oxirgi tashkil etuvchisi shunday kichik bo'lsinki, tashqi elektr maydoni fotoo'tkazuvchanlikning pasayishiga tasir ko'rsatmasin. Bunga erishish uchun, $-\frac{(\mu E)^2}{4D} < \frac{1}{\tau} + \gamma_{ijk}$ **(55)** shart bajarilishi kerak. Odatda bu shart elektr maydon kuchlanganligining bir necha V/sm dan katta bo'lmagan qiymatlarida bajariladi. Agar (50) tenglamada elektr maydon kuchlanganligini kichik deb, uni inobatga olmasak va unda (52) chegaraviy shartlarni qo'llasak, ε_i,η_j,ξ_k-kattaliklarni sirtiy rekombinasiya tezliklari S diffuziya koeffitsient D ni namuna o’lchamlari bilan bog’laydigan,

$$\frac{S_a A}{D} = \varepsilon_i tg\varepsilon; \quad \frac{S_b B}{B} = \eta_j tg\eta; \ \frac{S_c C}{C} = \xi k tg\xi_k; \qquad \textbf{(56)}$$

yechimlari bo’ladi. Shuning uchun Δp_{ijk} ning asosiy garmonikasi ε_i,η_j,ξ_k-larning eng kichik xususiy qiymatlariga mos kelib, effektiv vaqt doimiysi,

$$\tau_{eff} = (\frac{1}{\tau} + \gamma_{ijk})^{-1} \quad \textbf{(57)}$$ bilan aniqlanadi.

Bu yerda $$\gamma_{ijk} = D\left[\frac{\varepsilon_i^2}{A^2} + \frac{\eta_j^2}{B^2} + \frac{\xi_n^2}{C^2}\right] \qquad \textbf{(58)}$$

γ_{ijk} - sirt rekombinasiyasi tezligiga, namuna geometrik o’lchamlariga bog’liq. γ_{ijk}-ni qabul qilishi mumkin bo’lgan qiymatining kichigidir. Termodinamik muvozanatni tiklash jarayonlari bilan bog’liq asosiy garmonikaning kamayishi (pasayishi) qolgan garmonikalardan ustunlik qiladi, chunki u eng katta vaqt doimiysiga ega. $\upsilon_{ijk} + \frac{1}{\tau}$ kattalikni $(\frac{1}{\tau} + \gamma_{ijk})$ ga yaqin qiymatni qabul qilguncha ketgan vaqt oralig’i garmonikalar amplitudalari G_{ijk} ning o’zaro nisbatiga bog’liq. Eng sodda xolda δ (delta funksiya) – ko’rinishdagi yorug’lik impulsi bilan yoritilgan, boshlang’ich xolatda tekis taqsimlangan zaryad tashuvchilar kamayishining boshlanishida S⟶ ∞, 2B=2C<<2A bo’lganda, asosiy garmonika nomuvozanatiy oshiqcha zaryad tashuvchilar 2/3 qismining relaksasiyasini ifoda- laydi, bu nisbiy vaqt o’tishi bilan ortib boradi va tez chegaraviy qiymatga yaqinlashadi. Demak, bu xolda fotoo’tkazuvchanlik relaksasiyasining asosiy qismi nisbatan katta bo’lmagan boshlang’ich qismidan tashqarida

$$\Delta\sigma(t) = \Delta\sigma_0 exp\left[-\left(\frac{1}{\tau} + \gamma_{ijk}\right) t\right] \quad \textbf{(59)}$$

orqali ifodalanadi. Namunaning geometric o’lchamlari qancha katta bo’lsa, erkin sirtlarda sirt rekombinasiya tezligi qancha past bo’lsa, vaqt doimiysi (57) ga sirt rekombinasiyasining ta’siri shuncha kichik bo’ladi. γ_{ijk}- sodda fo’rmulalar bilan ifodalanadigan ba’zi bir xususiy xollarni ko’raylik.Agar x=0 va x=2A qirralari (yoqlari)da sirt rekombinasiyasi tezliklari cheksiz katta

S⟶ ∞ (odatda bu omik kontaktlarda amalga oshadi) va boshqa sirtlarida S= 0 deb qabul qilsak, u

$$\gamma_{III} = \gamma_{100} = \frac{\pi^2}{4A^2} \qquad \textbf{(60)}$$

ko'rinishda ifodalanadi. (60) formulani shubhasiz zaryad tashuvchilar hajmiy yashash vaqtini aniqlashga qo'llash mumkin. Effektiv yashash vaqti τ_{eff} tajribadan o'lchash bilan aniqlangan bo'lsa, hajmiy yashash vaqti bilan

$$\frac{1}{\tau} = \frac{1}{\tau_{ef}} - \frac{\pi^2 D}{4A^2} \quad \textbf{(61)}$$

aniqlanadi. qachonki, hamma sirtlarda sirt rekombinasiyasi tezligi juda katta bo'lib, ma'lum bo'lsa, $\frac{1}{\tau} = \frac{1}{\tau_{ef}} - \frac{\pi^2 D}{4A^2}\left(\frac{1}{A^2} + \frac{1}{B^2} + \frac{1}{C^2}\right)$ **(62)** bunday imkoniyat yana tug'iladi. Agar yorug'lik impulsi bilan rekombinasiya jarayoniga omik kontaktlari ta'sir etmaydigan masofada bo'lgan bir qismi yoritilgan bo'lsa, unda bo'ladi. Namuna erkin sirtlarida sirt rekombinasiyasi tezliklari bir xil chekli kichik qiymatlarni qabul qilgan holda

$$\frac{SB}{D} = \eta^2 , \frac{CS}{D} = \xi^2 \quad \textbf{(63a)} \text{ va } \frac{1}{\tau_{eff}} = \frac{1}{\tau} - S\left(\frac{1}{B} + \frac{1}{C}\right) \quad \textbf{(63b)}$$

bo'lishligini ko'ramiz. Endi bu keltirilgan (63a) va (63b) ifodalarni qo'llab S, g, D parametrlarni tajribadan aniqlash ustida to'xtalamiz. Sirt rekombinasiyasi tezligini (63b) asosida o'lchash uchun fotoo'tkazuvchanlikning kamayish jarayonida sirtiy rekombinasiya asosiy aniqlovchi jarayon, ya'ni (63b) da

$$S\left(\frac{1}{B} + \frac{1}{C}\right) \gg \frac{1}{\tau} \qquad \textbf{(64)}$$

bo'lishi kerak. Agar namuna o'lchamlaridan biri juda kichik bo'lsa, C< B, ya'ni yupqa plastinka shaklidagi namuna qo'llanilsa, bunga erishish mumkin. (64) shartni, katta sirtiy rekombinasiya tezligi bo'lganda qanoatlantirish oson, lekin (64) munosabat bajarilmaydi, bu xolda (58) umumiy formulani (56) bilan qo'llash kerak. (57) dan ko'rinadiki, kvadrat qavsdagi ko'paytmaga chizikqli bog'langan, $1/\tau_{ef}$ funksiyaning grafigi sirtiy rekombinasiyani o'zgarmas qiymatida to'g'ri chiziq bo'lib, u vertical o'qni $1/\tau$ da kesadigan, uning og'ish burchagi tangensi, diffuziya koeffisientiga teng bo'ladi.

$$tg\varphi = D = \frac{\Delta\left(\frac{1}{\tau_{ef}}\right)}{\Delta\left[\frac{n^2}{B^2}+\frac{\varepsilon^2}{c^2}\right]}$$ **(65)** ifoda bilan aniqlanadi.

τ_s ning zaryad tashuvchilarning hajmdagi yashash vaqtiga ta'sirini kremniy misolida ko'raylik. Buning uchun kremniy namunalarining sathlari ikki xil, ya'ni: a) mexanik - kimyoviy ishlovdan va b) yedirish (kislota yoki ishkorlar bilan sirtini yuvish) ishlovidan o'tgan sirtlardir. Bu sirt ishlovlariga mos ravishda rekombinasiya tezliklarining 10^4 sm/s, 10^3 sm/s qiymatlari turri keladi. Quyidagi jadvalada τ_s ning, har xil qalinlikda namunalar uchun qiymatlari keltirilgan.

1-jadval

Namuna qalingi(mkm)	$\tau_S = \frac{d^2}{4D\xi^2}$			
d	p-tip, D_n=39 sm^2/s		n-tip, D_n=15.5 sm^2/s	
	S=10^4 sm/s	S=10^3 sm/s	S=10^4 sm/s	S=10^3 sm/s
0.4	6	24	12	29
1	31	72	70	110
5	670	880	1700	1960
10	2700	3100	6800	7100
15	5900	6500	10000	11000
20	10500	11000	27000	27000

τ_s ning qiymatlari tahlilidan ko'rinadiki, τ ni ΔG ning so'nishi bo'yicha aniqlashda zaryad tashuvchilar hajmiy yashash vaqtini 10% dan katta bo'lmagan xatolik bilan o'lchash uchun, $\mathbf{1/\tau_{eff} = 1/\tau + 1/\tau_s}$ ga ko'ra, shunday qalinlikdagi namunani tanlash kerakki, unda τ_s ning qiymati τ ga nisbatan kamida (bir tartibda) 10 marta katta bo'lishi kerak. Masalan, diametri 76 mm, qalinligi 0,4 mm bo'lgan kremniy namunasida τ ni 10% dan katta bo'lmagan xatolik bilan o'lchash uchun x ning qiymati 1-2 mks dan kichik bo'lishi kerak. Elektron sanoati rivojlanishi bilan keyingi yillarda zaryad tashuvchilar parametrlarini kontaktsiz aniqlash usullariga talab ortdi. Shu boisdan bir qancha usullar yaratildi. Bu usullar asosida namunaga injeksiyalangan zaryad tashuvchilar konsentrasiyasining so'nishi bilan bog'liq xodisalar yotadi. Masalan, yorug'lik impulsi bilan generatsiyalangan erkin zaryad tashuvchilarda yorug'lik yutilish koeffisientining so'nishiga asoslangan usulni ko'rsatish mumkin.

2 - BOB. TAJRIBA NATIJALARI VA HISOBLASHLAR

2.1-§ Tajribalar uchun namunalar tayyorlash texnologiyasi

Kremniy taqiqlangan zonasida chuqur sathlar hosil qiladigan kirishmalarni turli usullar bilan kiritish mumkin:

1.Monokristallarni o'stirish chog'ida eritmaga kirishma qo'shilishi orqali.

2. Epitaksial texnologiya bo'yicha.

3. Ionlar implantasiyasi vositasida.

4. Diffuziya vositasida.

Kremniyda chuqur sathli kirishmalar turli xossa va parametrlarini o'rganish uchun

monokristallarni o'stirish chog'ida eritmaga kirishma qo'shilishi orqali va diffuziya vositasida kiritish qo'llaniladi. Chuqur sathli kirishmalar kremniyda ancha katta diffuziya koeffisientlariga (D=10-8-10-5 sm^2 /s ushbu 800 - 1300 ^{0}C tempearaturalarda), kichik segregasiya koeffisientlariga ((10-5 10-7) va temperaturaga kuchli bog'lik chekli eruvchanlikka egadir. Odatda chuqur sathli kirishmalar diffuziyasi dissosiativ mexanizm bo'yicha ketadi, avval kremniy tugunlari oralig'idan tezkor diffuziya bo'ladi, keyin kirishmaning tugunlar oralig'idagi atomlari o'rin almashish oqibatida panjara tugunlariga o'tadilar. Natijada ancha qalin kristallarda kam kirishmaning yetarlicha tekis taqsimlanishi yuz beradi. Shuning uchun diffuziya koeffisienti yetarli katta kirishmalarni kiritish uchun diffuziya usuli qulay hisoblanadi. Kremniyni o'stirish chog'ida eritmaga zarur kirishma qo'shilishi orqali kirishma kiritish ancha kichik diffuziya koeffisientli elementlar uchun afzaldir. Ushbu ishda tadqiqotlar uchun namunalar diffuziya usulida kiritilgan. Taqqoslash uchungina o'stirish chog'ida eritmaga marganes qo'shilishi orqali kirishma kiritilgan namunalar ham foydalanildi.

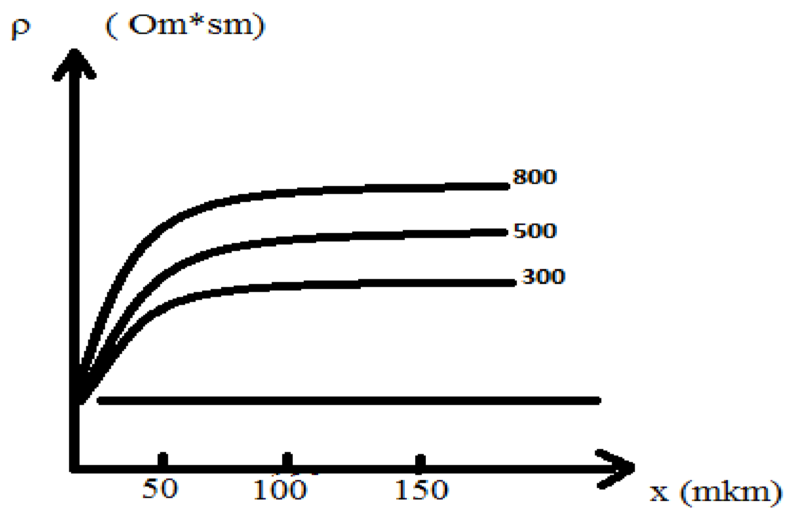
Marganesli namunalar diffuziya usulida olinishi quyidagi sxemada amalga oshirildi. Dastlabki material sifatida Si<Mn> namunalarni olish uchun n- va p-tur o'tkazuvchanlikli solishtirma qarshiliklari 0.3-100 Om·sm kremniy monokristalli olindi. Namunalar disklaridan parallelepiped shaklida kesib olindi va dona o'lchamlari markalari M - 20, M - 14, M - 10, M -5 kremniy karbid kukuni suspenziyasi vositasida ketma-ket silliqlandi. Bundan keyin namunalar distillangan suvda o'ta yaxshi yuvilgach, organik eritmada qaynatildi. Keyingi bosqichda kislotali - perekisli yuvish jarayonida tozalandi .

1. Toluolda yuvish (1.3 min. ikki marta yoki ikkinchisi asetonda yuvish).
2. HNO3 da 10 min.davomida qaynatish
3. 3 HF + 5 HNO + CH COON o'yuvchida yedirilish.
4. Uch marta (HNO + 3HC1) - eritmada qaynatish.
5. HF da yuvish (30 sek).
6. Perekisli yuvish - 10 min.davomida HC1 + 2H2O2 + 7H2O2 eritmada qaynatish. Kislotali yuvishning har bosqichidan keyin namunalar bir necha marta distillangan suvda yuvildi. Bunday tayyorlangan namunalar maxsus (HC1 + HNO, 3 : 1), da yuvib tozalangan va T > T dif. qizdirilgan kvars ampulalarga joylashtiriladi. Diffuziya qilinuvchi modda sifatida tozaligi 99, 999 % bo'lgan metall marganes qo'llanildi. Mn diffuziyasi kremniyda uning sirtiga bug'lantirib o'tirilgan marganes qatlamidan amalga oshirildi. Kristallarni yuqori temperaturada kuydirish 900 – 1250 ^{0}C intervalda temperatura avtomatik

ravishda ± 5 ^{0}C aniqlikda ushlab turiladigan SUOL - 4 gorizontal elektropechda amalga oshirildi. Temperatura bevosita ampula yonidagi darajalangan platina-rodiyli termojuft (termopara) yordamida o'lchandi. Diffuziya jarayoni t dif. = 0.5-100 soatlar oralig'ida amalga oshirildi. Diffuziya jarayoni havosi 2·10-2 mm. s. ust. gacha so'rib olingan kvars ampulalarda amalga oshirildi. Diffuziyadan keyin namunalar ampulalardan suvga yoki yog'ga tashlash orqali sovutildi. Yuqori temperaturalarda ishlov berishning kremniyga ta'sirini o'rganish uchun diffuziya o'tkazilgan trubalarga Si monokristallidan kesib olingan namunalar (kirishmasiz) joylashtirilib kuydirildi. Markalari KEF va KDB hamda solishtirma qarshiliklari 0.3 dan 100 Om·sm gacha bo'lgan kremniyga kirishmalar havosi so'rilgan kvars ampulalar yoki ochiq trubada diffuziya usulida kiritildi. Diffuziyadan keyin namunalar yog'da yoki suvda sovutildi. Diffuziya jarayonidan keyin kremniy sirtidan jilvirlash yo'li bilan mavjud shikastlangan va buzilgan sohalar hisobidan 80-100 mkm qalinlikdagi qatlam olib tashlanib, undan keyingina o'tkazuvchanlik turi aniqlanib, solishtirma qarshilik o'lchandi. Diffuziya T=900-1250 ^{0}C temperaturalarda 0,5-10 soat davomida o'tkazilgach namunalar sekin va tez sovutildi. Diod strukturalar sifatida diffuziya jarayonida olingan p-n o'tish qo'llanildi, yana Shottki to'siqlari sifatida kremniy yassi plastinalariga vakuumda Au, Sb changlantirilgan namunalardan foydalanildi.

2.2-§ Solishtrima qarshilikni o’lchash natijalari

Marganes bilan 1200 ^{0}C temperaturada 42 soat diffuziya jarayonidan keyin n - va p - tur o’tkazuvchanlikli namunalar solishtirma qarshiliklari to’rt zondli usulda nazorat qilinib, dastlabki qiymatlar bilan solishtirildi. To’rt seriya bo’lgan turli o’tkazuvchanlikli namunalar solishtirma qarshiliklari o’lchandi. Ushbu o’lchashlar natijalari barcha n - tur o’tkazuvchanlikli namunalarda marganes kiritilgandan keyin o’tkazuvchanlik turi o’zgarishi va solishtirma qarshiliklari keskin oshishi kuzatildi. p - tur o’tkazuvchanlikli namunalarda u o’zgarmay, solishtirma qarshiliklarining biroz kamayishi kuzatildi. Taqqoslash uchun shunday - solishtirma qarshiliklari 20 Om·sm bo’lgan n - va p - tur o’tkazuvchanlikli namunalar 1200 ^{0}C temperaturada 42 soat davomida nazorat kuydirish o’tkazildi. O’lchash natijalari n - Si va p-Si o’tkazuvchanlikli namunalar o’tkazuvchanligi nazorat kuydirishda saqlanishini ko’rsatdi. Biroq n-tur namunalarda solishtirma qarshiliklarining biroz kamayishi, shu bilan bir vaqtda p-tur o’tkazuvchanlikli namunalar solishtirma qarshiliklari, aksincha biroz oshishi kuzatildi. Marganes diffuziyada kiritilgan va nazorat kuydirishiga duchor qilingan kremniy o’tkazuvchanlikli namunalar solishtirma qarshiliklari namuna sirtdan boshlab ichkari tomon o’lchandi. Quyidagi rasmda marganes kiritilgan va nazorat (marganes kirishmasiz) namunalar solishtirma qarshiliklari taqsimot kesimi ko’rsatilgan:



Marganes kiritilgan (2) va nazorat (1) namunalar solishtirma qarshiliklari sirtidan ichkariga taqsimot funksiyasi.

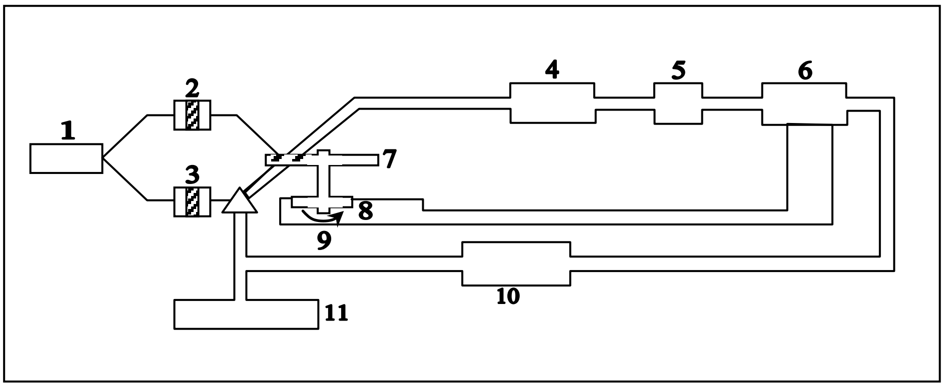
Rasmda marganes diffuziya yordamida kiritilgan Si<Mn> namunalar solishtirma qarshiliklari taqsimot kesimi erfc-funksiya bilan tasvirlanmay ikki sohadan iboratligi kuzatiladi: dastlab ~ 70 mkm qalinlikkacha keskin o'sish kuzatilsa, keyin qiymati barqarorlashib namuna ichkarisiga tomon oshishi kuzatilmaydi to'yinadi. Shuni qayd qilish kerakki, solishtirma qarshiliklari namuna sirtdan boshlab ichkariga bunday taqsimoti kremniyda Ni, Mn kabi o'tish guruhi metallari uchun kuzatilgan. Dastlabki sirt oldi sohaning keskin 4-5 daraja oshishi bilan tavsiflansa, ikkinchisi esa namuna hajmida amalda bir tekis taqsimotini bilan tavsiflanadi. Bunda solishtirma qarshilik nazorat (marganes bo'lmaganda) namunalarida sirtdan ichkari tomon sezilarli o'zgarmaganini qayd qilish kerak.

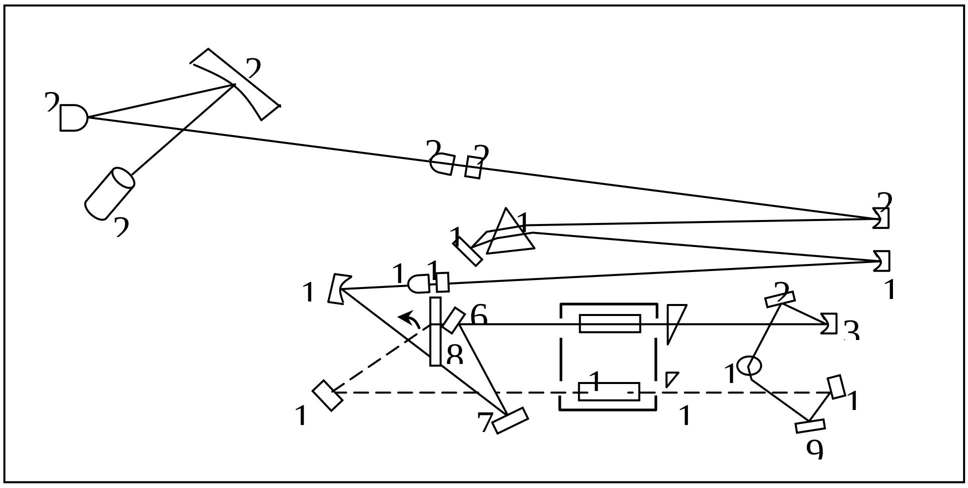
2.3-§ Infraqizil yutilish spektri

1. Nurlar yutilish spektrlarini o'lchashlardan kislorod va uglerod konsentrasiyasini aniqlash. Kremniyda har doim katta miqdorda mavjud kirishmalar - kislorod va uglerod atomlari konsentrasiyasini aniqlash uchun ikki nurli sxemada ishlovchi Specord - IR - 72 qo'llaniladi. Infraqizil nurlar yutilish spektrlarini o'lchash prinsipi quyidagicha. Specord - IR - 72 spektrofotometri namunadan o'tayotgan infraqizil nurlar 1200 dan 400 sm gacha bo'lgan qismini to'lqin soniga bog'lanish spektri kabi yozadi. To'lqin sonining bu diapazonida deyarlik barcha atom guruhlari asosiy tebranishlari joylashgan, shunga ko'ra yozib olingan spektr kristallar va ko'p organik birikmalar strukturasini aniqlash va tozaligini sinash imkonini beradi. Nurni o'tkazish koeffisientini o'lchash qurilma nulini optik tekislash prinsipi bo'yicha ikki nurli metod bo'yicha amalga oshiriladi .

Bir manbadan chiquvchi ikki nur dastasi o'lchanuvchi va etalon-namunadan o'tib navbatma – navbat aylanayotgan sektorli oynadan o'tib monoxromator kirish tirqishiga tushadi. Monoxromator chiqish tirqishidan chiqayotgan nurning qismi nur qabul qilgich (termoelement)da fokuslanadi. Davriy sxema bo'yicha qabul qilgich nur ikki oqimidan birinining o'lchanuvchi yoki etalonlardan o'tuvchi monoxromatik qismini tutadi. Agar o'lchanayotgan nur bir xil intensivlikka ega bo'lsa qabul qilgich o'zgaruvchan kuchlanish beradi, chunki taqqoslovchi nur dastlab o'zining odatdagi intensivligiga ega bo'ladi, o'lchanuvchi nur esa susaygan bo'ladi. O'zgaruvchan kuchlanish signali kuchaytiriladi, faza bo'yicha to'g'rilanib , qayta o'zgartirishlardan keyin servodvigatelni boshqarish uchun foydalaniladi, u esa o'lchash tirqishini taqqoslovchi nurga tomon buradi. Taqqoslovchi nur intensivligi o'lchanuvchi nur kamaygan intensivligiga mos kelguncha diafragma burilaveradi.

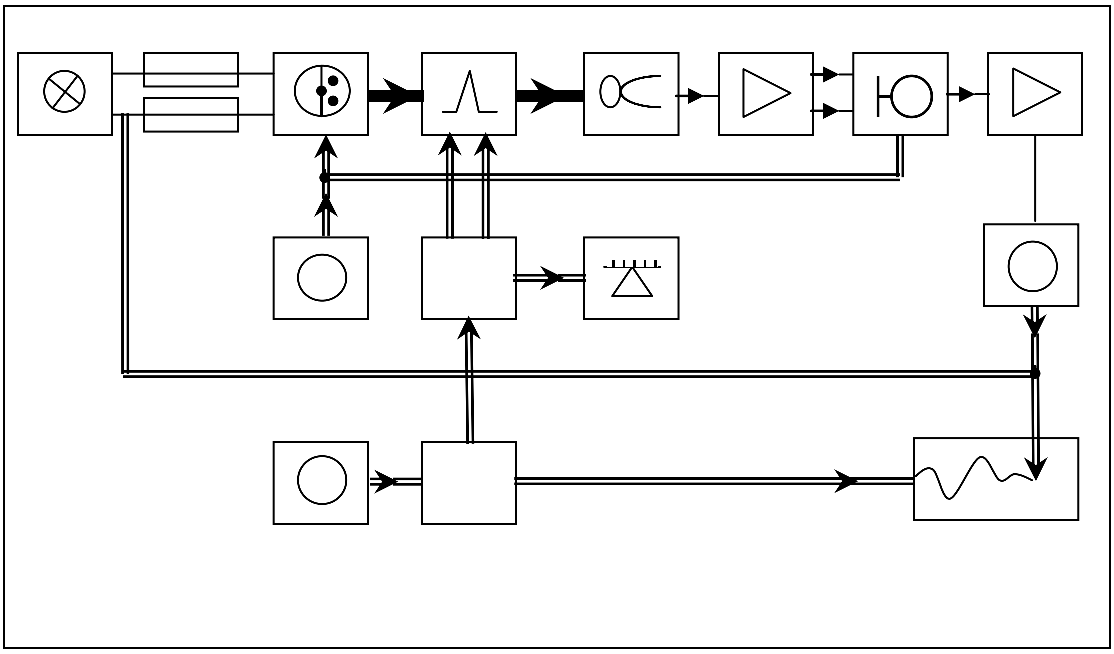
Spesord - IR - 72 asbobining optik konstruksiyasi sxematik ravishda quyidagi rasmlarda tasvirlangan. Shtrixlangan chiziqlar elektr, ikkilangan chiziqlar mexanikaviy birlashtiruvlarga mos keladi. Nurlanish manbasidan chiqqach , ikki nur dastasi o'lchanuvchi namunani joylashtirish uchun xizmat qiladigan kyuvetali kameradan o'tadi. Bundan tashqari, taqqoslovchi nur yo'lida yozuvchi qism va o'ta aniq bo'lgan potensiometr bilan mexanik bog'langan o'lchovchi diafragma bo'lib, u o'lchanuvchi kattaliklarni ikkilamchi indikatorga chiqishini ta'minlaydi quyidagi rasmda sistema eng muhim optik, elektr va mexanik qismlari blok sxemasi keltirilgan. O'lchanuvchi nur qo'shimcha 100% tog'rilovchi diafragma bilan susaytiriladi. Bu diafragmaning o'tkazishi siljuvchi tugunli diskda shunday programmalashtirilishi mumkinki, to'lqin soniga bog'liq holda, taqqoslovchi nur orasidagi intensivlik kompensasiyalanadi, va shu tarzda to'lqin uzunligi bo'ylab 100% - boshqarish ning tekis bo'lishi amalga oshiriladi.





Spektroskop - IR - 72 asbob optik sxemasi

Quyidagi rasmda eng muhim optik, elektr va mexanik qismlarning blok - sxemasi berilgan.



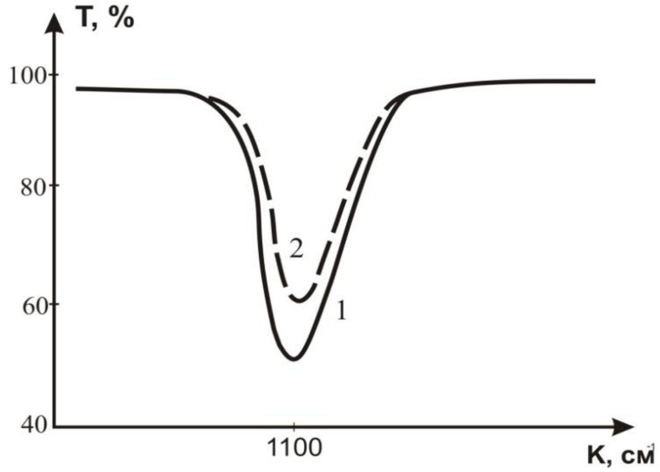
Nur qabul qilgich yorug'lik signallarini elektr kuchlanishiga o'zgartiradi, bunda elektr signal dastlabki bosqich kuchaytirgichi va asosiy kuchaytirgich yordamida kuchaytiriladi va qayta o'zgartiriladi. O'tkazish spektrlarini o'lchash va kislorod va uglerod konsentrasiyasini aniqlash uchun namunalar quyidagicha tayyorlandi: dastlab ular markalari M 14 i M 15 bo'lgan karborund poroshoklar vositasida jilvirlanib, keyin esa olmos pastasi yordamida mexanik ravishda oynaday (ko'zguday) silliqlandi. Namuna ikki yon tomoni paralelligi buzilmasligi uchun maxsus namunani ushlab turish qurilmasi qo'llanildi. Bunday ishlovdan keyin namunalar yuzasi haqiqatda ko'zguday yaltiroq bo'ladi. Bu silliqlash jarayon sifati namuna sirtiga nur dastasi tushirish bilan nazorat qilinadi. Agar silliqlangan sirt nurni yaxshi qaytarsa, bu ishlov berish sifati yaxshi bo'lgan deb hisoblanadi.Yuzasi yaxshi silliqlangan namunalarda IQ nurlar yutilish spektrlarini to'lqin sonining 1200 - 400 sm-1 intervalida o'lchangandan keyin kislorod N_1 va uglerod N_2 konsentrasiyalari hisoblanadi. Optik faol kislorod N_1 va uglerod N_2 konsentrasiyalarini hisoblash uchun:

N_{oopt} (2-1) Ncopt (2-2 ifodalari qo'llanildi , bunda I_1 – o'tgan nur intensivligi I_2 - yutilgan nur intensivligi; D - namuna qalinligi.

Marganes yuqori temperaturali diffuziyada kremniyga kiritilganda hosil bo'lgan chuqur sathlar energiyaviy spektrini o'rganganda ChS ning hosil bo'lish samaradorligi texnologik rejimlar - diffuziya temperaturasi va undan keyingi sovutish tezligiga bog'likligi ko'rsatildi. Marganesning chuqur sathlar hosil bo'lish samaradorligi texnologik deyiluvchi kirishmalar - kislorod va uglerodning dastlabki kremniydagi miqdoriga bog'likligini aniqlash uchun shu seriyali namunalarda Infraqizil nurlar yutilish spektrlari o'lchandi. Tadqiqotlar uchun dastlabki namunalar sifatida Choxralskiy usulida o'stirilib, kislorod va uglerod optik faol konsentrasiyalari tegishlicha N $=6\cdot10^{17}$ $1.2\cdot10^{18}$ sm^{-3} i $N_{sopt} = 2\cdot10^{16}$ sm^{-3} bo'lgan n va p- tur o'tkazuvchanlikli kremniy olindi. Bu dastlabki namunalar solishtirma qarshiliklari 1-100 Om·sm oralig'ida bo'lib, oynaday silliqlangan namunalar qalinliklari qo'yilgan vazifaga mos holda 1 1.5 mm. ni tashkil qiladi .

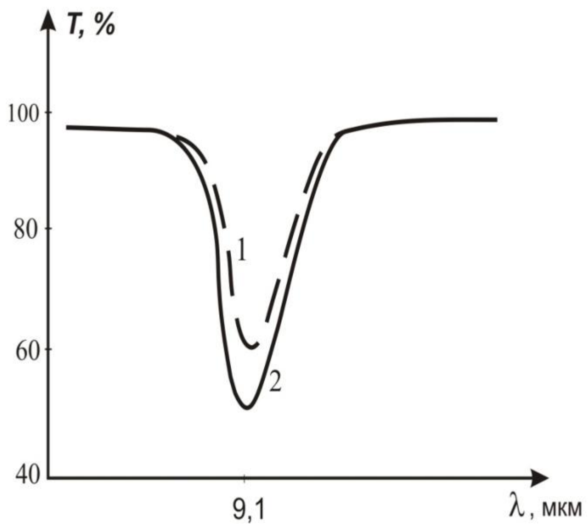
Kislorod N va uglerod N miqdorini baholash 1100 sm-1 (kislorod polosasi) va 610 sm-1 (uglerod polosasi) sohalardagi nurlar yutilish spektrlarini Specord - IR-75 infraqizil spektrofotometrda ikki nurli sxemada 300 K temperaturada o'lchash orqali amalga oshirildi.

Nazorat uchun namuna (etalon) sifatida shunday qalinlikdagi $N_{0opt} =10^{16}$ sm^{-3}, $N_{sopt} =5*10^{15}$ sm^{-3} oynaday silliqlangan kislorodsiz kremniy olindi.



Dastlabki namunalarda N_{0opt} va N_{sopt} o’lchangach, vakuumda bug’latib o’tkazilgan yuqori tozalikli metal - marganes qatlamidan ularga Mg diffuziya usulida kiritildi.

Namunalarga marganes diffuziya qilingach aynan shularda N0opt I IQ yutilish spektrlari o’rganildi. Ushbu o’lchashlar natijalari rasmda keltirilgan. 3 n-Si<Mg> diffuziyasida 1200 ^{0}C (2) va nazorat namunasida (1) Infraqizil nurlar yutilish spektrlari . Ushbu natijalar tahlili marganes kiritilgandan keyin n-, hamda p- tur o’tkazuvchanlikli Si da optic faol kislorod konsentrasiyasi, marganes diffuziyasi temperaturasida kuydirilgan (marganessiz) namunalarga nisbatan 20 - 35 % kamayishi kuzatildi. Yana optik faol uglerodning kremniyda nur yutishiga mos - 16,4 mkm to’lqin uzunligida IQ nurlar yutish spektri olindi. Marganes diffuziyada kiritilgan va nazorat namunalarida optik faol uglerodning kamayishi kuzatilmadi. Kristallni o’stirish jarayonida marganes kiritilgan kremniy va aynan shu namunalarni yuqori temperaturalarda turlicha qizdirilish jarayonlaridagi hollarda IQ - nurlar yutilish spektrlari o’rganildi.



900 – 1200 ^{0}C temperaturalarda kuydirishgacha va undan keyin namunalarda IQ - nurlar yutish spektrining n-Si<Mn> larni YuTQ natijasida optik faol kislorod konsentrasiyasining oshganligini ko’rsatdi. YuTQ gacha va 1000 ^{0}C temperaturada kuydirilgandan keyin namunalardan olingan odatiy tur IQ - nurlar yutish spektrlari keltirilgan, ulardan n-Si<Mn> namunalarini 1000 ^{0}C qizdirilib, so’ng juda tez sovutilgani optik faol kislorod konsentrasiyasini 8 - 10% oshishiga olib kelar ekan. Kuydirish temperaturasi oshganda bu Noopt ortishi kuchliroq namoyon bo’ladi va T=1200 ^{0}C temperaturada kuydirib so’ngra tez sovutilsa Noopt ortishi 25 - 30% ni tashkil qiladi. O’stirish chog’ida marganes kiritilgan n-Si namunalarning (1) va YuTQ dan keying (2) IQ nur yutish spektrlari.

Xulosa

Kremniy n-tur o'tkazuvchanlikli namunalarda marganes kiritilgandan keyin o'tkazuvchanlik turi o'zgarishi va solishtirma qarshiliklari keskin oshishi kuzatilishi belgilandi p - tur o'tkazuvchanlikli namunalarda, solishtirma qarshiliklarida ρ biroz kamayadi, lekin o'tkazuvchanlik turi o'zgarmaydi. Ushbu natijalar asosida marganesning diffuziya vositasida kiritilgani akseptor sathlar hosil bo'lishiga olib kelishi taxmin qilinadi. Si<Mn> namunalarida solishtirma qarshilikning taqsimot kesimi ikki sohadan iboratligi ko'rsatildi: dastlab ~ 65 mkm gacha bo'lgan sohada ρ qiymati keskin oshadi, keyin qiymat barqarorlashadi (to'yinadi) va namuna keyingi chuqurliklarda ρ ning sezilarli o'zgarishi kuzatilmaydi. Si<Mn> namunalarida E_s-0.23 eV sath kuydirish oqibatida kelib chiqadigan nuqson bo'lishi kerakligi ko'rsatilgan, chunki u nazorat qizdirilgan namunalarda kam kuzatiladi, bunda ushbu ChS konsentrasiyasi NEE kiritilgan Si dagiga qaraganda 1-1,5 daraja katta. Mn mavjudligi kremniy qizdirilganda nuqson hosil bo'lish samaradorligini kamaytirishi faraz qilingan. Infraqizil nurlar yutilish spektrlaridan n- ham p-o'tkazuvchanlikli Si- larga marganes kiritilishi optik faol kislorod konsentrasiyasini shu marganes diffuziyasidagidek sharoitlarda qizdirilgan nazorat namunalariga nisbatan 10-20% kamaytirishi belgilangan. O'stirish chog'ida kremniy hajmiga kiritilgan namunalarida NFT (Neytron faollashtirish taxlil) ma'lumotlari Si hajmida Mn kirishmasining haqiqatda borligi va katta miqdorda ekanligini (10^{15} dan 10^{17} sm^{-3} gacha) aniqlangan. O'stirish chog'ida marganes kiritilgan Si namunalari turli rejimlarda qizdirishgacha va undan keyin YuTQ davomiyligi oshishi bilan ortishiga olib kelish ko'rsatilgan, bu marganes kirishmali Si da kompensasiya -lovchi markazlar kiritilishidan kelib chiqadi. Marganes atomlarining YuTQ faollashib kremniyda hosil qiladigan ChS akseptor xarakterga ekanligi xulosa qilingan . 900 -1250 ^{0}C temperaturalar oralig'ida yuqori temperaturada qizdirishlar (YuTQ) o'stirish chog'ida kiritilgan atomlarini faollashtirishi belgilangan.

Yuqori xaroratli ishlov berish optik faol kislorod konsentrasiyasi Noopt ning ortishiga olib kelishi belgilangan, bu qizdirilish jarayonida marganesning kislorod bilan kompleksining parchalanishi bilan faollashishi bilan bog'likligi ehtimol. O'stirish chog'ida marganes kiritilgan n - Si namunalariga qo'shimcha nikel kiritilishi Ni diffuziyada kiritilgan namunalar uchun xarakterli bo'lgan optik shaffoflikni yo'qotishi va Noopt keskin kamayishiga olib kelmasligi belgilangan. Bu n-Si<Mn>+YuTQ vai n-Si<Mn+Ni> namunalarda kislorod miqdori ko'p farq qilmaydi, Bu holda n-Si<Mn> namunalari YuTQ yoki nikelning diffuziya vositasida kiritilishi ta'sirida Noopt oshishi yuz beradi. Mn atomlarining Si da mavjudligi radiasion nuqsonlar hosil bo'lish jarayonlarini sekinlashishiga olib kelishi belgilangan: A - markaz va E - markaz kiritilish samaradorligi bu holda odatdagi kremniyga qaraganda 1 - 1.5 daraja kam. Bunda tomlarining konsentrasiyasi qancha katta bo'lsa, nurlanish nuqsonlari konsentrasiyasi shuncha kam, bu esa kremniyda Mn nurlanish nuqsonlari bilan ta'sirlashish xususiyatlari bilan bog'liq.

Foydalanilgan adabiyotlar ro’yxati

1. Karimov I.A. "Jaxon moliyaviy iqtisodiy inqirozi. O’zbekiston sharoitida uni bartaraf etish yo’llari va choralari". Toshkent "O’zbekiston" 2009.
2. KarimovI.A. "O’zbekiston mustaqillikka erishish ostonasida". Toshkent. "Iqtisodiyot" 2011.
3. Zaynobiddinov.S, Teshaboev.A - "Yarim o’tkazgichlar fizikasi " Toshkent, "O’qituvchi" 1999-yil.
4. Teshaboev.A - "Yarim o’tkazgichlar fizikasiga kirish" Toshkent, "ToshDU" 1986-yil.
5. Zaynobiddinov.S, Akromov.X - “Yarimo’tkazgichlar parametrlarini aniqlash usullari” Toshkent “O’zbekiston” 2001-yil
6. Akramov, S. Zaynobiddinov, A.Teshaboev "Yarim o’tkazgichlarda fotoelektrik hodisalar " Toshkent, "O’zbekiston" 1994 yil.
7. Azizov.M -Yarimo’tkazgichlar fizikasi Toshkent 1974-yil
8. Fistul V.I. “Atomi legiruyushix primesey v poluprovodnikax”. M., Fizmatlit, 2004 g.
9. Milns L. Primesi s glubokimi urovnyami v poluprovodnikax. - M., Mir, 1977, 547 s.
10. Milvidskiy M.G., Osvenskiy V.B. Strukturnie defekti v monokristallax poluprovodnikov. M., Metallurgiya, 1984, 256 s.
11. Reyvi. K - Defekti i primesi v poluprovodnikovom kremni. Per. s angl.- M., Mir, 1984 .
12. Burguen J. Lanno M. Tochechnie defekti v poluprovodnikax. Teoriya. M., Mir, 1984, 264 s.
13. Qalandarov .E Nomzodlik dissertasiya Avtoreferati Toshkent 2008 yil
14. Zaynobiddinov.S Daliev.X "Defektoobrazovanie v kremnii" Toshkent Universitet 1993 - yil 194 b.
15. Zaynobiddinov.S - “Fizicheskie osnova obrazovaniya glubokix urovney v kremnii Toshkent” "FAN" 1984 yil 97 b.

16. Vigdorovich V.N. Ochistka metallov i poluprovodnikov kristallizasiey. M.: Metallurgiya, 1989. 296 s.
17. Fizika i materialovedenie poluprovodnikov s glubokimi urovnyami. Pod red. Fistulya V.I., M., Metallurgiya, 1987, 232 s.
18. Bagraev N.T. Bochkarev E.P. Vlasenko L.S. Issledovanie povedeniya primesey Ho, Gd, Yb v kremnii // Neorganicheskie materiali. Moskva, 1978. №4(14). S.614-617.
19. Neymash V.B, Siraskiy V.M., Shaxovsov V.I., Shindich V.A., Chesnokov S.N. Termicheskoe defektoobrazovanie v kremnii s primesyu gadoliniya. - UFJ, 1987, t.32, vip 10. S. 1550-1552. .
20. I.Xamidjanov- Nomzodlik dissertasiya Avtoreferati Toshkent 2003 yil
21. Potemkin A.Ya., Sasevich I.E. Vliyanie termicheskoy obrabotki na fizicheskie svoystva kremniya. M.: ONTI, GIREDMET, S. 1962. 132.
22. Mandelkorn J., Schwarts L., Broder J. et. al. Effect of impurities on radiation damage of silicon soZrr sells // J. Appl. Phys. 1964. N 7(35). P. 2258-2260.
23. Bagraev N.T., Vlasenko L.S., Volle V.M. i dr. Vozmojnost povisheniya termostabilnosti monokristallicheskogo kremniya dlya moshnix poluprovodnikovix priborov // Jurnal texnicheskoy fiziki. Sankt-Peterburg, 1984. v.5 (54). S. 917-928.
24. Glazov V.M., Potemkin A.Ya., Timoshina G.G., Mixaylova M.S. O vozmojnosti povisheniya termostabilnosti Si putem yego legirovaniya perexodnimi, libo redkozemelnimi elementami // Fizika i texnika poluprovodnikov. Sankt-Peterburg, 1997. v.9(31). S.1025-1028.
25. Nazirov D.E., Regel A.R., Kulikov G.S. Kremniy, legirovanniy redkozemelnimi elementami. - L.: Prepr.LFTI, 1987. 56 s.
26. Talipov F.M. Vliyanie itterbiya na radiasionnoe defektoobrazovanie v kremnii // Fizika i texnika poluprovodnikov. Sankt-Peterburg, 1997. v.6(31) S.728-729

Izog'li lug'at

1	Yarimo'tkazgich- A semiconductor . A semiconductor is a material with electrical conductivity intermediate in magnitude between that of a conductor and an insulator. This means a conductivity roughly in the range of 103 to 10−8 siemens per centimeter. Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Such devices include transistors, solar cells, many kinds of diodes including the light-emitting diode (LED), the silicon controlled rectifier, photo-diode, and digital and analog integrated circuits. Semiconductor solar photovoltaic panels directly convert light energy into electricity. In a metallic conductor, current is carried by the flow of electrons. Common semiconducting materials are crystalline solids—chips, but amorphous and liquid semiconductors are also known.
2	Energiya - Energy . Lightning is the electric breakdown of air by strong electric fields, which produce a force on charges. When these charges move through a distance, a flow of energy occurs. The electric potential energy in the atmosphere then is transformed into thermal energy, light, and sound, which are other forms of energy. The total energy contained in an object is identified with its mass, and energy (like mass), cannot be created or destroyed. When matter (ordinary material particles) is changed into energy (such as energy of motion, or into radiation), the mass of the system does not change through the transformation process. However, there may be mechanistic limits as to how much of the matter in an object may be changed into other types of energy and thus into work, on other systems. Energy, like mass, is a scalar physical quantity. In the International System of Units (SI), energy is measured in joules, but in many fields other units, such as kilowatt-hours and kilocalories, are customary. All of these units

	translate to units of work, which is always defined in terms of forces and the distances that the forces act through.
3	Metall - Frequency Three cyclically flashing lights, from lowest frequency (top) to highest frequency (bottom). f is the frequency in hertz (Hz), meaning the number of cycles per second. T is the period in seconds (s), meaning the number of seconds per cycle. T and f are reciprocals. Frequency is the number of occurrences of a repeating event per unit time. It is also referred to as temporal frequency. The period is the duration of one cycle in a repeating event, so the period is the reciprocal of the frequency. For example, if a newborn baby's heart beats at a frequency of 120 times a minute, its period (the interval between beats) is half a second.
4	Qarshilik - Electrical resistance and conductance The electrical resistance of an electrical element is the opposition to the passage of an electric current through that element; the inverse quantity is electrical conductance, the ease at which an electric current passes. Electrical resistance shares some conceptual parallels with the mechanical notion of friction. The SI unit of electrical resistance is the ohm (Ω), while electrical conductance is measured in siemens (S). An object of uniform cross section has a resistance proportional to its resistivity and length and inversely proportional to its cross-sectional area. All materials show some resistance, except for superconductors, which have a resistance of zero. The resistance of an object is defined as the ratio of voltage across it to current through it, while the conductance is the inverse:For a wide variety of materials and conditions, V and I are directly proportional to each other, and therefore R and G are constant (although they can depend on other factors like temperature or strain). This proportionality is called Ohm's

	law, and materials that satisfy it are called "Ohmic" materials.
5	Elektron - Electron The electron (symbol: e−) is a subatomic particle with a negative elementary electric charge. It has no known components or substructure; in other words, it is generally thought to be an elementary particle. An electron has a mass that is approximately 1/1836 that of the proton. The intrinsic angular momentum (spin) of the electron is a half-integer value in units of ħ, which means that it is a fermion. The antiparticle of the electron is called the positron; it is identical to the electron except that it carries electrical and other charges of the opposite sign. When an electron collides with a positron, both particles may be totally annihilated, producing gamma ray photons. Electrons, which belong to the first generation of the lepton particle family, participate in gravitational, electromagnetic and weak interactions. Electrons, like all matter, have quantum mechanical properties of both particles and waves, so they can collide with other particles and can be diffracted like light. However, this duality is best demonstrated in experiments with electrons, due to their tiny mass. Since an electron is a fermion, no two electrons can occupy the same quantum state, in accordance with the Pauli exclusion principle.
6	Atom - Atom . The atom is a basic unit of matter that consists of a dense central nucleus surrounded by a cloud of negatively charged electrons. The atomic nucleus contains a mix of positively charged protons and electrically neutral neutrons (except in the case of hydrogen-1, which is the only stable nuclide with no neutrons). The electrons of an atom are bound to the nucleus by the electromagnetic force. Likewise, a group of atoms can remain bound to each other, forming a molecule. An atom containing an equal number of protons and electrons is electrically neutral, otherwise it has a positive charge if

	there are fewer electrons (electron deficiency) or negative charge if there are more electrons (electron excess). A positively or negatively charged atom is known as an ion. An atom is classified according to the number of protons and neutrons in its nucleus: the number of protons determines the chemical element, and the number of neutrons determines the isotope of the element.
7	Dielektrik - Dielectric A dielectric is an electrical insulator that can be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material as they do in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization. Because of dielectric polarization, positive charges are displaced toward the field and negative charges shift in the opposite direction. This creates an internal electric field which reduces the overall field within the dielectric itself. If a dielectric is composed of weakly bonded molecules, those molecules not only become polarized, but also reorient so that their symmetry axis aligns to the field.
8	Zarralar konsentransiyai - Number density In physics, astronomy, and chemistry, number density (symbol: n) is an intensive quantity used to describe the degree of concentration of countable objects (particles, molecules, phonons, galaxies, etc.) in the three-dimensional physical space. Area number density (number of entities per unit surface area) and linear number density (number of entities per unit length) are defined analogously. The term number concentration (symbol: C) is sometimes used in chemistry for the same quantity, particularly when comparing with other concentrations.
9	Elektr yurituvchi kuch - Electromotive force In physics, electromotive force, emf (seldom capitalized), or

	electromotance (denoted and measured in volts) refers to voltage generated by a battery or by the magnetic force according to Faraday's Law, which states that a time varying magnetic field will induce an electric current. Electromotive "force" is not a force (measured in newtons) but a potential, or energy per unit of charge, measured in volts. Formally, emf is the external work expended per unit of charge to produce an electric potential difference across two open-circuited terminals. The electric potential difference produced is created by separating positive and negative charges, thereby generating an electric field. The created electrical potential difference drives current flow if a circuit is attached to the source of emf. When current flows, however, the voltage across the terminals of the source of emf is no longer the open-circuit value, due to voltage drops inside the device due to its internal resistance.
10	Chastota - Frequency Three cyclically flashing lights, from lowest frequency (top) to highest frequency (bottom). f is the frequency in hertz (Hz), meaning the number of cycles per second. T is the period in seconds (s), meaning the number of seconds per cycle. T and f are reciprocals. Frequency is the number of occurrences of a repeating event per unit time. It is also referred to as temporal frequency. The period is the duration of one cycle in a repeating event, so the period is the reciprocal of the frequency. For example, if a newborn baby's heart beats at a frequency of 120 times a minute, its period (the interval between beats) is half a second.
11	Kislorod - Acid . An acid (from the Latin acidus/acēre meaning sour) is a substance which reacts with a base. Commonly, acids can be identified as tasting sour, reacting with metals such as calcium, and bases like sodium carbonate. Aqueous acids have a pH of less than 7,

	where an acid of lower pH is typically stronger. Chemicals or substances having the property of an acid are said to be acidic.
12	Elektr toki - Electric current . Electric current is a flow of electric charge through a medium. This charge is typically carried by moving electrons in a conductor such as wire. It can also be carried by ions in an electrolyte, or by both ions and electrons in a plasma.The SI unit for measuring the rate of flow of electric charge is the ampere, which is charge flowing through some surface at the rate of one coulomb per second. Electric current is measured using an ammeter.
13	Zichlik - Density The mass density or density of a material is defined as its mass per unit volume. The symbol most often used for density is ρ (the lower case Greek letter rho). In some cases (for instance, in the United States oil and gas industry), density is also defined as its weight per unit volume; although, this quantity is more properly called specific weight. Different materials usually have different densities, so density is an important concept regarding buoyancy, purity and packaging. Osmium and iridium are the densest known metal elements at standard conditions for temperature and pressure but not the densest materials.
14	Monokristall - A single crystal or monocrystalline A single crystal or monocrystalline solid is a material in which the crystal lattice of the entire sample is continuous and unbroken to the edges of the sample, with no grain boundaries. The absence of the defects associated with grain boundaries can give monocrystals unique properties, particularly mechanical, optical and electrical, which can also be anisotropic, depending on the type of crystallographic structure. These properties, in addition to making them precious in some gems, are industrially used in technological applications, especially in optics and electronics.

15	Texnologiya - Technology By the mid 20th century, humans had achieved a mastery of technology sufficient to leave the atmosphere of the Earth for the first time and explore space. Technology is the making, usage, and knowledge of tools, machines, techniques, crafts, systems or methods of organization in order to solve a problem or perform a specific function. It can also refer to the collection of such tools, machinery, and procedures. Technologies significantly affect human as well as other animal species' ability to control and adapt to their natural environments. The word technology comes from Greek τεχνολογία (technología); from τέχνη (téchnē), meaning "art, skill, craft", and -λογία (-logía), meaning "study of-". The term can either be applied generally or to specific areas: examples include construction technology, medical technology, and information technology.
16	Elektr potensial - Electric potential In classical electromagnetism, the electric potential (a scalar quantity denoted by φ, φE or V and also called the electric field potential or the electrostatic potential) at a point is equal to the electric potential energy (measured in joules) of a charged particle at that location divided by the charge (measured in coulombs) of the particle. The electric potential is independent of the test particle's charge - it is determined by the electric field alone. The electric potential can be calculated at a point in either a static (time-invariant) electric field or in a dynamic (varying with time) electric field at a specific time, and has the units of joules per coulomb, or volts. There is also a generalized electric scalar potential that is used in electrodynamics when time-varying electromagnetic fields are present. This generalized electric potential cannot be simply interpreted as the ratio of potential energy to charge, however.

17	Ishora - Sign Not to be confused with sine. For other uses, see Sign (disambiguation). For how to sign your posts on Wikipedia talk pages, see Wikipedia:Signatures. This biohazard sign is a completely conventional symbol with no inherent relationship to what it represents. A sign is a representation of an object that implies a connection between itself and its object. A natural sign bears a causal relation to its object—for instance, thunder is a sign of storm. A conventional sign signifies by agreement, as a full stop signifies the end of a sentence. (This is in contrast to a symbol which stands for another thing, as a flag may be a symbol of a nation).
18	Kuchlanish - Voltage Voltage, otherwise known as electrical potential difference or electric tension (denoted ΔV and measured in volts, or joules per coulomb) is the potential difference between two points — or the difference in electric potential energy per unit charge between two points. Voltage is equal to the work which would have to be done, per unit charge, against a static electric field to move the charge between two points. A voltage may represent either a source of energy (electromotive force), or it may represent lost or stored energy (potential drop). A voltmeter can be used to measure the voltage (or potential difference) between two points in a system; usually a common reference potential such as the ground of the system is used as one of the points. Voltage can be caused by static electric fields, by electric current through a magnetic field, by time-varying magnetic fields, or a combination of all three.
19	Elektron donor - Electron donor An electron donor is a chemical entity that donates electrons to another compound. It is a reducing agent that, by virtue of its donating

	electrons, is itself oxidized in the process.Typical reducing agents undergo permanent chemical alteration through covalent or ionic reaction chemistry. This results in the complete and irreversible transfer of one or more electrons. In many chemical circumstances, however, the transfer of electronic charge to an electron acceptor may be only fractional, meaning an electron is not completely transferred, but results in an electron resonance between the donor and acceptor. This leads to the formation of charge transfer complexes in which the components largely retain their chemical identities.The electron donating power of a donor molecule is measured by its ionization potential which is the energy required to remove an electron from the highest occupied molecular orbital.The overall energy balance (ΔE), i.e., energy gained or lost, in an electron donor-acceptor transfer is determined by the difference between the acceptor's electron affinity (A) and the ionization potential
20	Material - Material Material is anything made of matter, constituted of one or more substances. Wood, cement, hydrogen, air and water are all examples of materials. Sometimes the term "material" is used more narrowly to refer to substances or components with certain physical properties that are used as inputs to production or manufacturing. In this sense, materials are the parts required to make something else, from buildings and art to stars and computers.
21	Технологик жараён Process (engineering) In engineering a process is a set of interrelated tasks that, together, transform inputs into outputs. These tasks may be carried out by people, nature, or machines using resources; so an engineering process must be considered in the context of the agents carrying out the tasks, and the resource attributes involved. Systems Engineering normative

	documents and those related to Maturity Models are typically based on processes. For example, System Engineering processes of the EIA-632 and processes involved in the Capability Maturity Model Integration (CMMI) institutionalization and improvement approach. Constraints imposed on the tasks and resources required to implement them are essential for executing the tasks mentioned.
22	Kristall - Crystal A crystal of amethyst quartz Microscopically, a single crystal has atoms in a near-perfect periodic arrangement; a polycrystal is composed of many microscopic crystals (called "crystallites" or "grains"); and an amorphous solid (such as glass) has no periodic arrangement even microscopically. A crystal or crystalline solid is a solid material whose constituent atoms, molecules, or ions are arranged in an orderly, repeating pattern extending in all three spatial dimensions. In addition to their microscopic structure, large crystals are usually identifiable by their macroscopic geometrical shape, consisting of flat faces with specific, characteristic orientations [citation needed] The scientific study of crystals and crystal formation is known as crystallography. The process of crystal formation via mechanisms of crystal growth is called crystallization or solidification. The word crystal is derived from the Ancient Greek word κρύσταλλος (krustallos), meaning both “ice” and “rock crystal”, from κρύος (kruos), "icy cold, frost". Common crystals include snowflakes, diamonds, and table salt; however, most common inorganic solids are polycrystals. Crystals are often symmetrically intergrown to form crystal twins
23	Panjara - Cell (biology) Allium cells in different phases of the cell cycle The cells of eukaryotes (left) and prokaryotes (right) The cell is the basic structural and functional unit of all known living organisms. It is the smallest unit of

	life that is classified as a living thing, and is often called the building block of life. Organisms can be classified as unicellular (consisting of a single cell; including most bacteria) or multicellular (including plants and animals). Humans contain about 10 trillion (1013) cells. Most plant and animal cells are between 1 and 100 μm and therefore are visible only under the microscope. The cell was discovered by Robert Hooke in 1665. In 1835, before the final cell theory was developed, Jan Evangelista Purkyně observed small "granules" while looking at the plant tissue through a microscope.
24	Ta'qiqlangan zona - Band gap In solid state physics, a band gap, also called an energy gap or bandgap, is an energy range in a solid where no electron states can exist. In graphs of the electronic band structure of solids, the band gap generally refers to the energy difference (in electron volts) between the top of the valence band and the bottom of the conduction band in insulators and semiconductors. This is equivalent to the energy required to free an outer shell electron from its orbit about the nucleus to become a mobile charge carrier, able to move freely within the solid material. So the band gap is a major factor determining the electrical conductivity of a solid. Substances with large band gaps are generally insulators, those with smaller band gaps are semiconductors, while conductors either have very small band gaps or none, because the valence and conduction bands overlap.
25	Elektromagnit maydon - Electromagnetic field An electromagnetic field (also EMF or EM field) is a physical field produced by moving electrically charged objects. It affects the behavior of charged objects in the vicinity of the field. The electromagnetic field

	extends indefinitely throughout space and describes the electromagnetic interaction. It is one of the four fundamental forces of nature (the others are gravitation, the weak interaction, and the strong interaction). The field can be viewed as the combination of an electric field and a magnetic field. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents); these two are often described as the sources of the field. The way in which charges and currents interact with the electromagnetic field is described by Maxwell's equations and the Lorentz force law.
26	Harakat - Motion (physics) . In physics, motion is a change in position of an object with respect to time. Motion is typically described in terms of velocity, acceleration, displacement, and time. Motion is observed by attaching a frame of reference to a body and measuring its change in position relative to another reference frame. A body which does not move is said to be at rest, motionless, immobile, stationary, or to have constant (time-invariant) position. An object's motion cannot change unless it is acted upon by a force, as described by Newton's first law. An object's momentum is directly related to the object's mass and velocity, and the total momentum of all objects in a closed system (one not affected by external forces) does not change with time, as described by the law of conservation of momentum. As there is no absolute frame of reference, absolute motion cannot be determined. Thus, everything in the universe can be considered to be moving.
27	Koeffitsient - Coefficient In mathematics, a coefficient is a multiplicative factor in some term of an expression (or of a series); it is usually a number, but in any case does not involve any variables of the expression. For instance in the first three terms respectively have the coefficients 7, −3, and 1.5 (in the third term the variables are hidden (raised to the 0 power), so the

	coefficient is the term itself; it is called the constant term or constant coefficient of this expression). The final term does not have any explicitly written coefficient, but is considered to have coefficient 1, since multiplying by that factor would not change the term. Often coefficients are numbers as in this example, although they could be parameters of the problem, as a, b, and c in when it is understood that these are not considered as variables.
28	Elektr zaryad - Electric charge Electric charge is a physical property of matter that causes it to experience a force when near other electrically charged matter. Electric charge comes in two types, called positive and negative. Two positively charged substances, or objects, experience a mutual repulsive force, as do two negatively charged objects. Positively charged objects and negatively charged objects experience an attractive force. The SI unit of electric charge is the coulomb (C), although in electrical engineering it is also common to use the ampere-hour (Ah). The study of how charged substances interact is classical electrodynamics, which is accurate insofar as quantum effects can be ignored. The electric charge is a fundamental conserved property of some subatomic particles, which determines their electromagnetic interaction. Electrically charged matter is influenced by, and produces, electromagnetic fields. The interaction between a moving charge and an electromagnetic field is the source of the electromagnetic force, which is one of the four fundamental forces (See also: magnetic field).
29	Kremniy - Silicon is the eighth most common element in the universe by mass, but very rarely occurs as the pure free element in nature. It is most widely distributed in dusts, sands, planetoids, and planets as various forms of silicon dioxide (silica) or silicates. Over 90% of the Earth's crust is composed of silicate minerals, making silicon the

	second most abundant element in the earth's crust (about 28% by mass) after oxygen. Most silicon is used commercially without being separated, and indeed often with little processing of compounds from nature. These include direct industrial building-use of clays, silica sand and stone. Silica is used in ceramic brick. Silicate goes into Portland cement for mortar and stucco, and when combined with silica sand and gravel, to make concrete. Silicates are also in whiteware ceramics such as porcelain, and in traditional quartz-based soda-lime glass. More modern silicon compounds such as silicon carbide form abrasives and high-strength ceramics. Silicon is the basis of the ubiquitous synthetic silicon-based polymers called silicones.
30	Germaniy - Germanium (/dʒ ər' meɪ niəm/ jər-MAY-nee-əm) is a chemical element with the symbol Ge and atomic number 32. It is a lustrous, hard, grayish-white metalloid in the carbon group, chemically similar to its group neighbors tin and silicon. Purified germanium is a semiconductor, with an appearance most similar to elemental silicon. Like silicon, germanium naturally reacts and forms complexes with oxygen in nature. Unlike silicon, it is too reactive to be found naturally on Earth in the free (native) state. Because very few minerals contain it in high concentration, germanium was discovered comparatively late in the history of chemistry. Germanium ranks near fiftieth in relative abundance of the elements in the Earth's crust. In 1869, Dmitri Mendeleev predicted its existence and some of its properties based on its position on his periodic table and called the element ekasilicon. Nearly two decades later, in 1886, Clemens Winkler found the new element along with silver and sulfur, in a rare mineral called argyrodite.