Size and quantum effects in InN nanodomains

Justification of work

- InN intrinsic semiconductor
- Band gap 0.6-0.8 eV
- Electric surface effects

→ high density of surface states →high density of surface electrons→ electron confinement in nanodomains

Applications

- Semiconductors
- Solar shells
- Charge memory devices
- Size and quantum effects in 2-D InN nanotextures

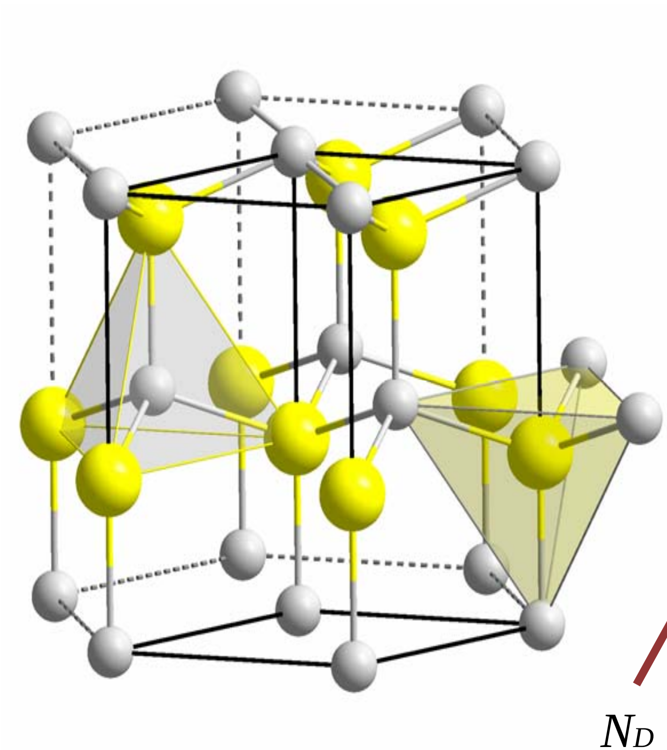
Overview

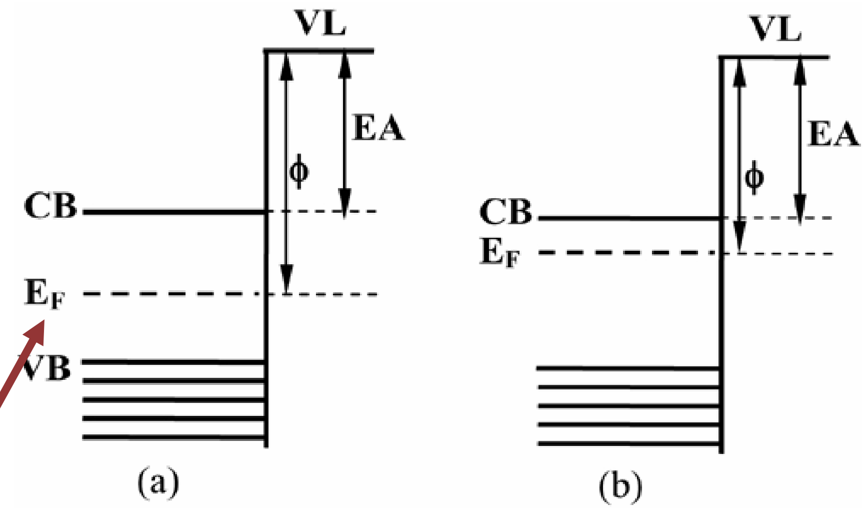
- Physical principles
- Methodology of growing 2-D InN nanotextures (10nm).

Demonstrate

- Schottky diode (metal-semiconductor-metal): operation with C-AFM.
- Charge memory effects (I-V, hysterisis loop).
- → Electron confinement on boundary of nanodomains → Scattering of wavefunctions on 2-D InN boundaries.

InN semiconductor





1)BG=CB-VB=0.6-0.8 eV

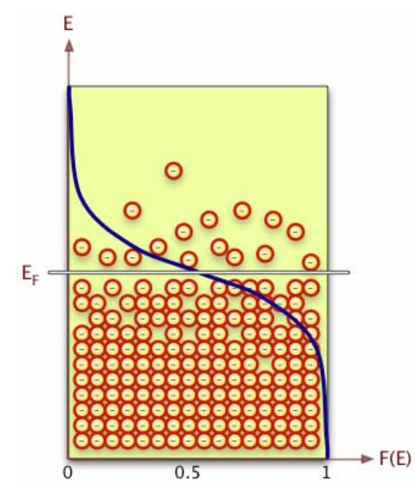
2)Degenerate CB+5kT<E_F<CB-kT

$$N_D : n(el/cm^3) \approx 10^{19} \exp\left(-\frac{E_c - E_F}{kT}\right)$$

$$\Delta E_F = 0.3eV \Rightarrow \Delta n(el/cm^3) = 10^{16}$$

$$D : n(el/cm^3) \approx 10^{19} \left(\frac{|E_F - E_c|}{kT}\right)^{3/2}$$

$$\Delta E_F = 6kT \Rightarrow \Delta n(el/cm^3) = 10^{21}$$

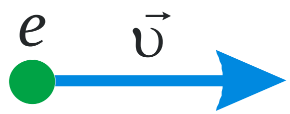


Surface charge effects

2-D nanotextures

→Breaking of translational symmetry
→ charge accumulation on the boundaries →charge confinement →charge memory effects

Translational symmetry in space



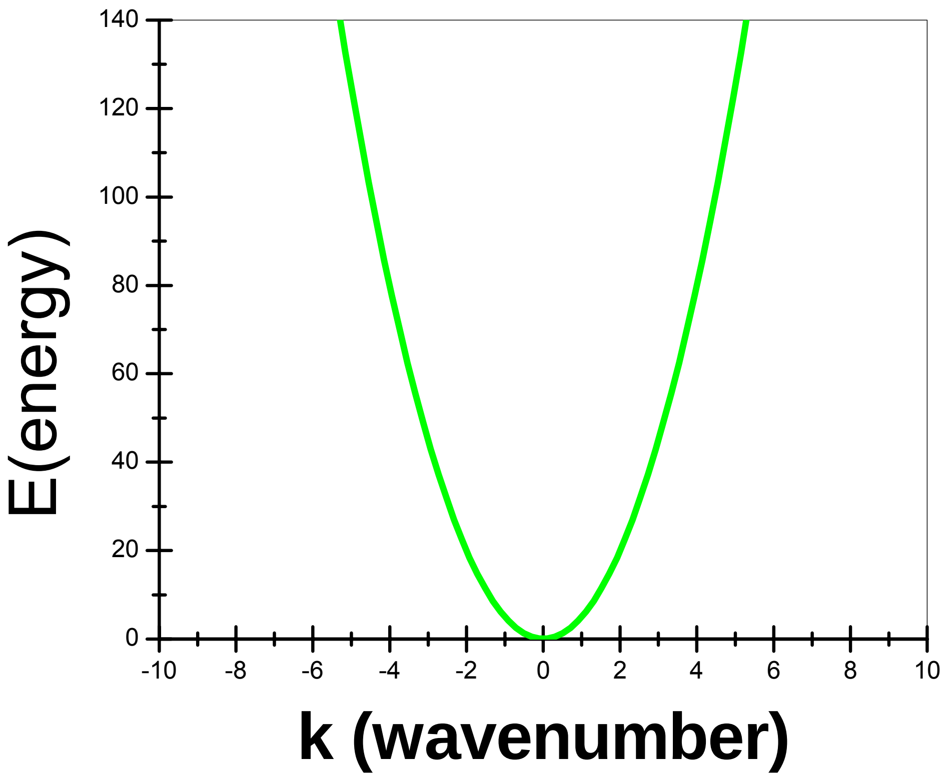
Space homogenuity

$$\hat{T}\psi(\vec{r}) = \psi(\vec{r} + \vec{a})$$

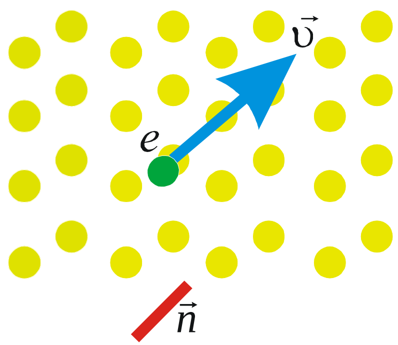
$$\psi_k(\vec{r}) = \psi_{0k}(\vec{r})\exp i(\vec{\kappa} \bullet \vec{r})$$

$$\vec{P} = \hbar\vec{\kappa}$$

$$E(k) = \frac{\hbar k^2}{2m}$$



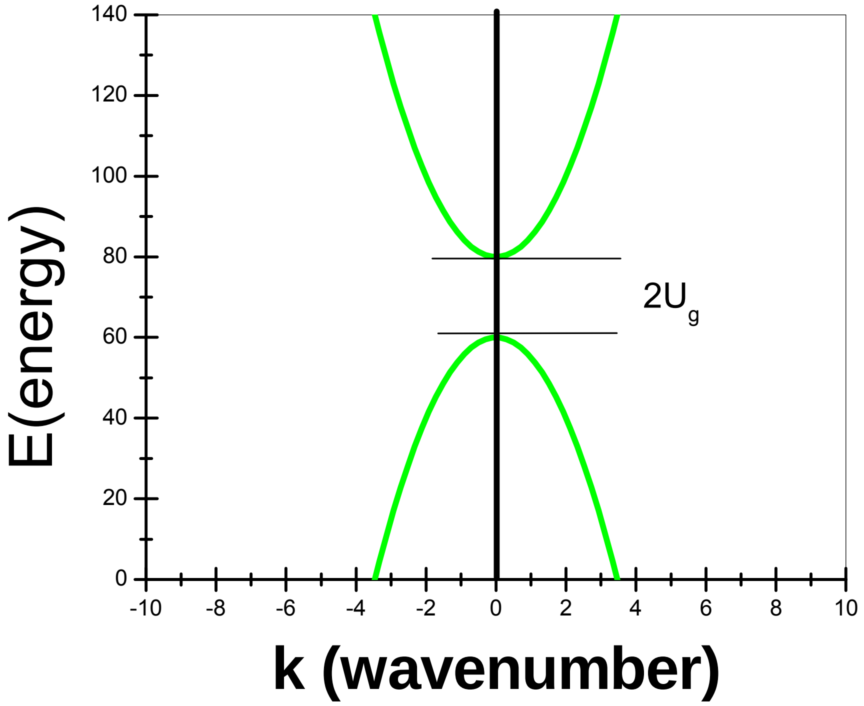
Translational symmetry in crystals



$$\widehat{T}\psi(\vec{r}) = \psi(\vec{r} + \vec{n})$$

$$\psi_k(\vec{r}) = \varphi_k(\vec{r}) \exp i(\vec{\kappa} \bullet \vec{r})$$

$$E(\vec{k}) = E(\vec{k}_0) \pm \sum_{i=1}^{3} \frac{\hbar^2}{2m}\left(1 \pm \frac{\pi^2\hbar^2 g^2}{m|U_g|}\right)(k_i - k_{01})^2$$



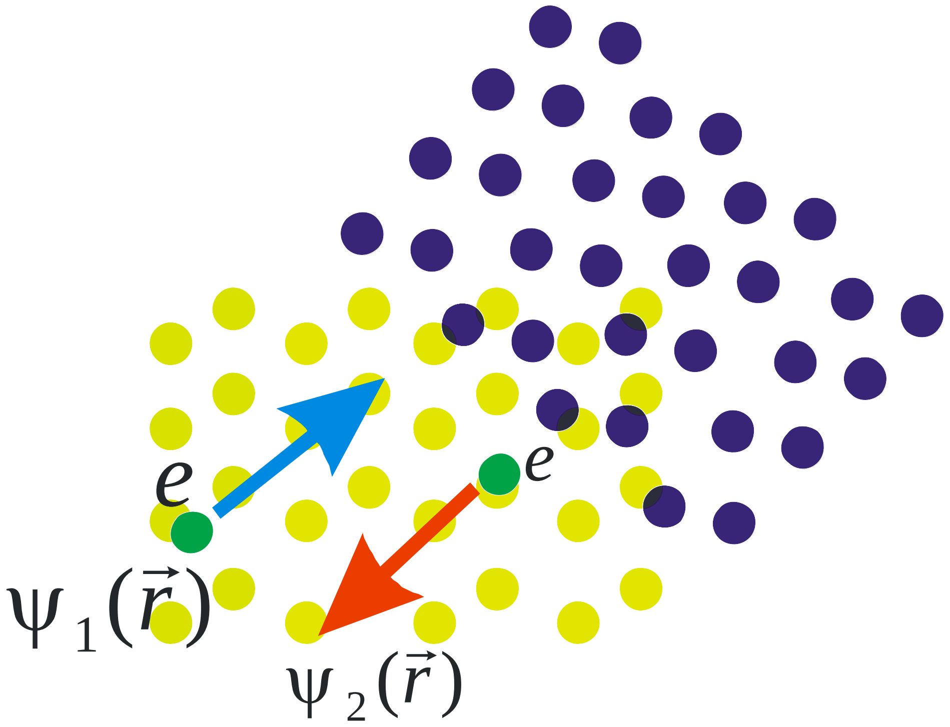
Real wavenumber

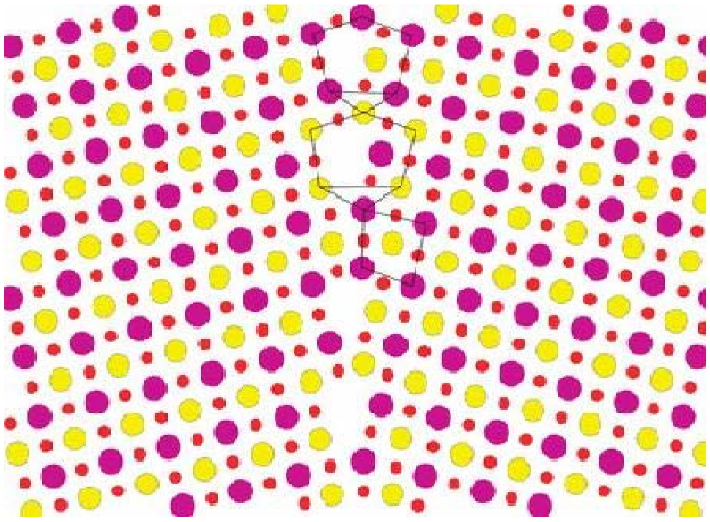
Breaking of translational symmetry

Complex wavenumber

$$k = ik_1 + k_2$$

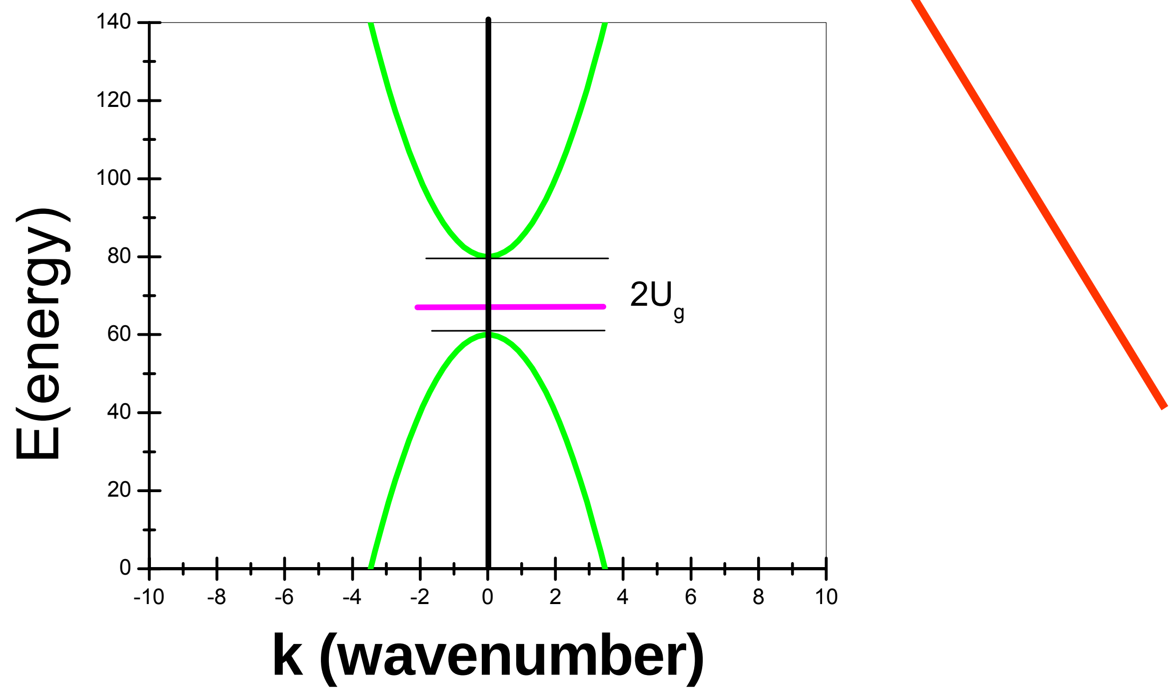
$$\psi(\vec{r}) = A\psi_1(\vec{r}) + B\psi_2(\vec{r}) = A\exp(ik_1)\varphi_k(\vec{r})\exp(-k_2\vec{r}) + B\exp(-ik_1)\varphi_k(\vec{r})$$



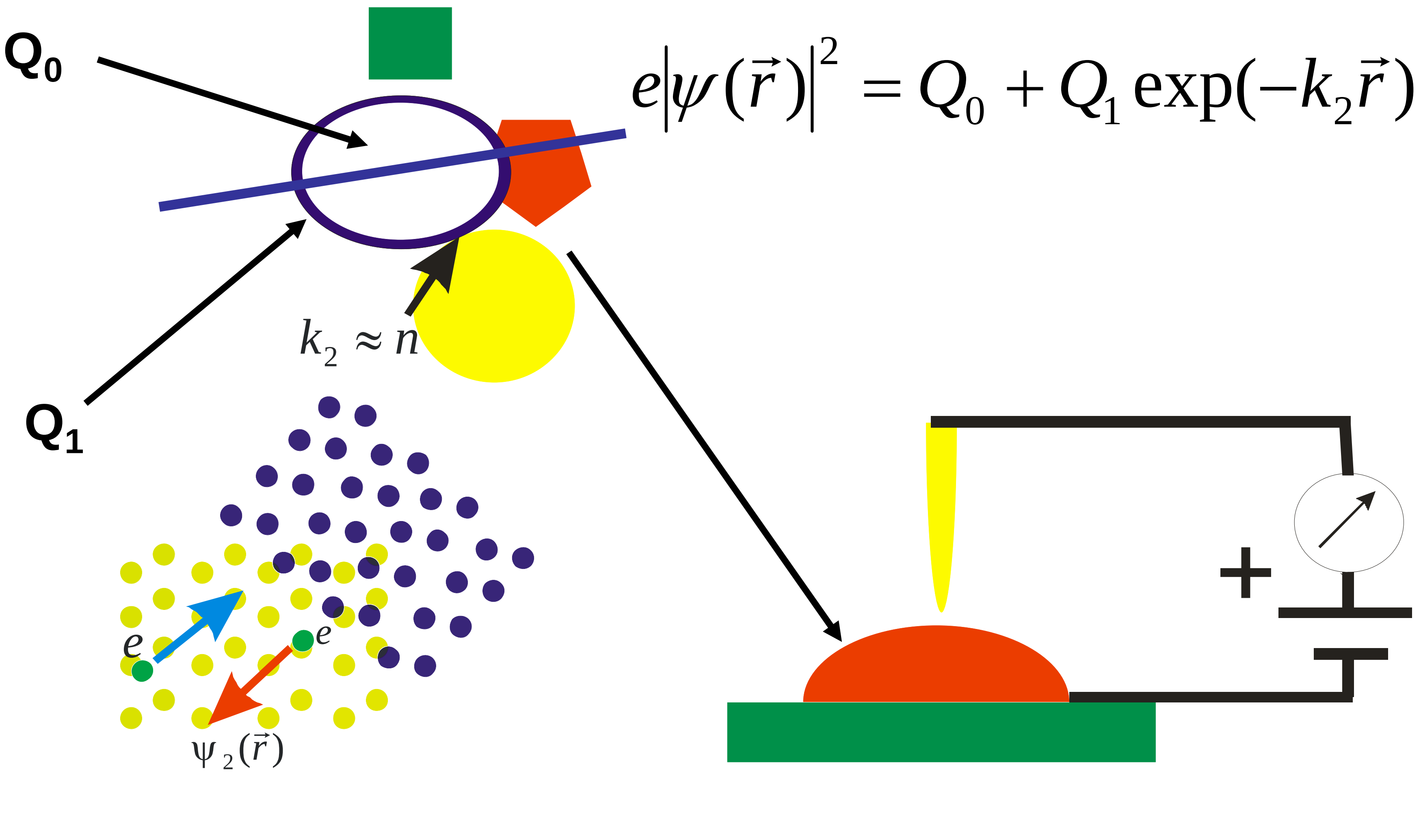


Boundary energy states

$$E(\vec{k}) = E(\vec{k}_0) \pm \sum_{i=1}^{3} \frac{\hbar^2}{2m}\left(1 \pm \frac{\pi^2 \hbar^2 g^2}{m|U_g|}\right)(k_{i2} - k_{01} - \lambda)^2$$



Charge confinement on boundaries of nanodomains



Growth of InN 2-D nanotextures by pulsed laser deposition at 157 nm

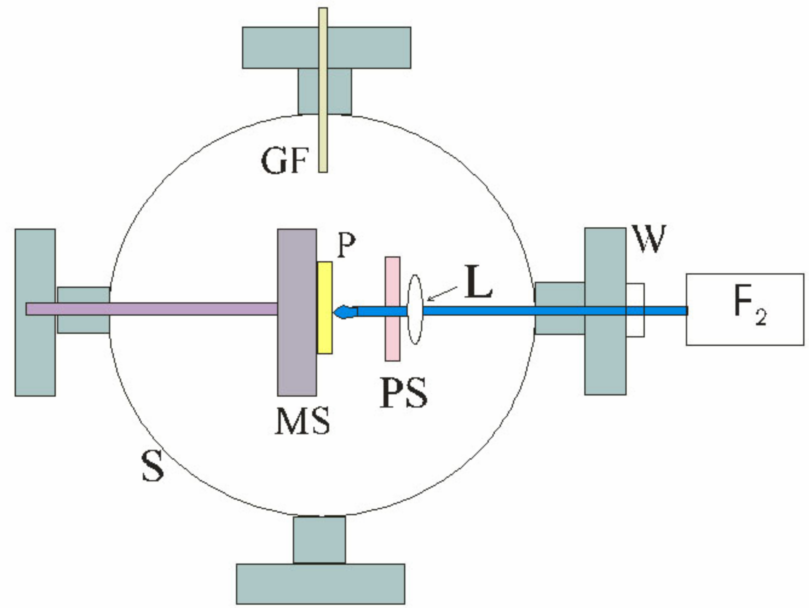
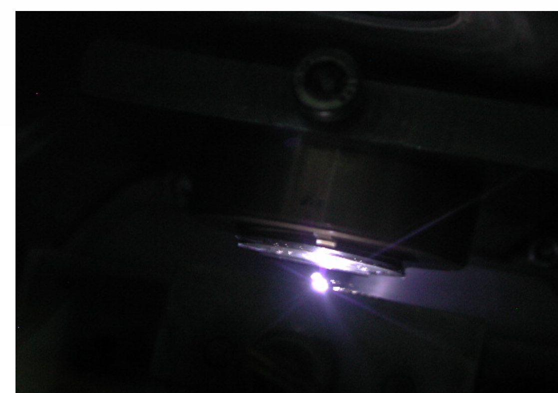
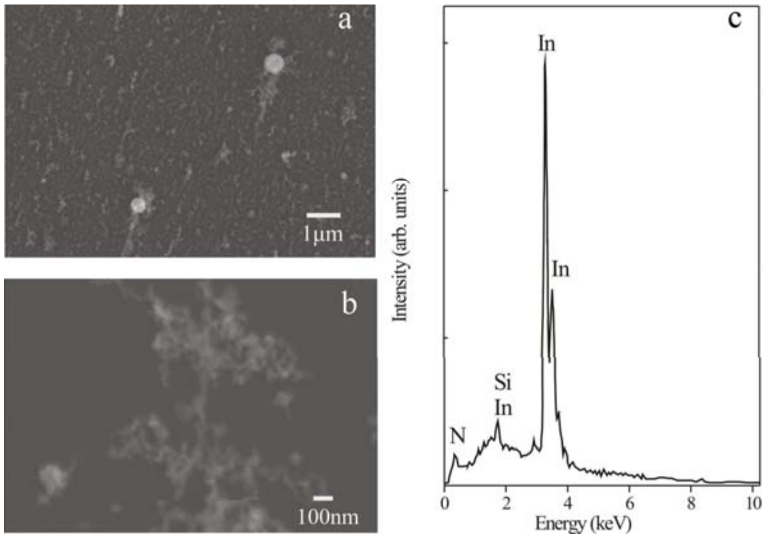


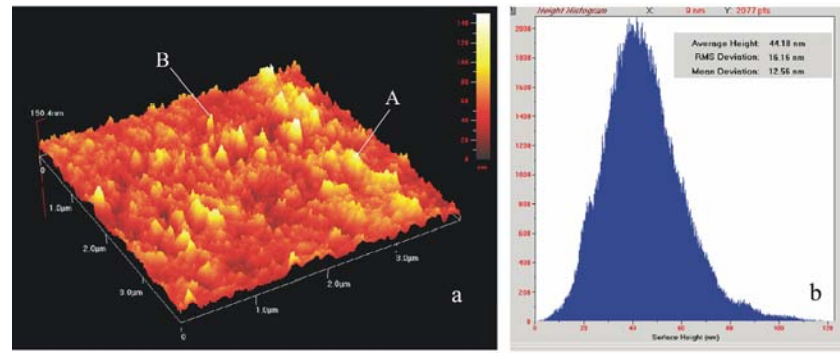
Fig. 1

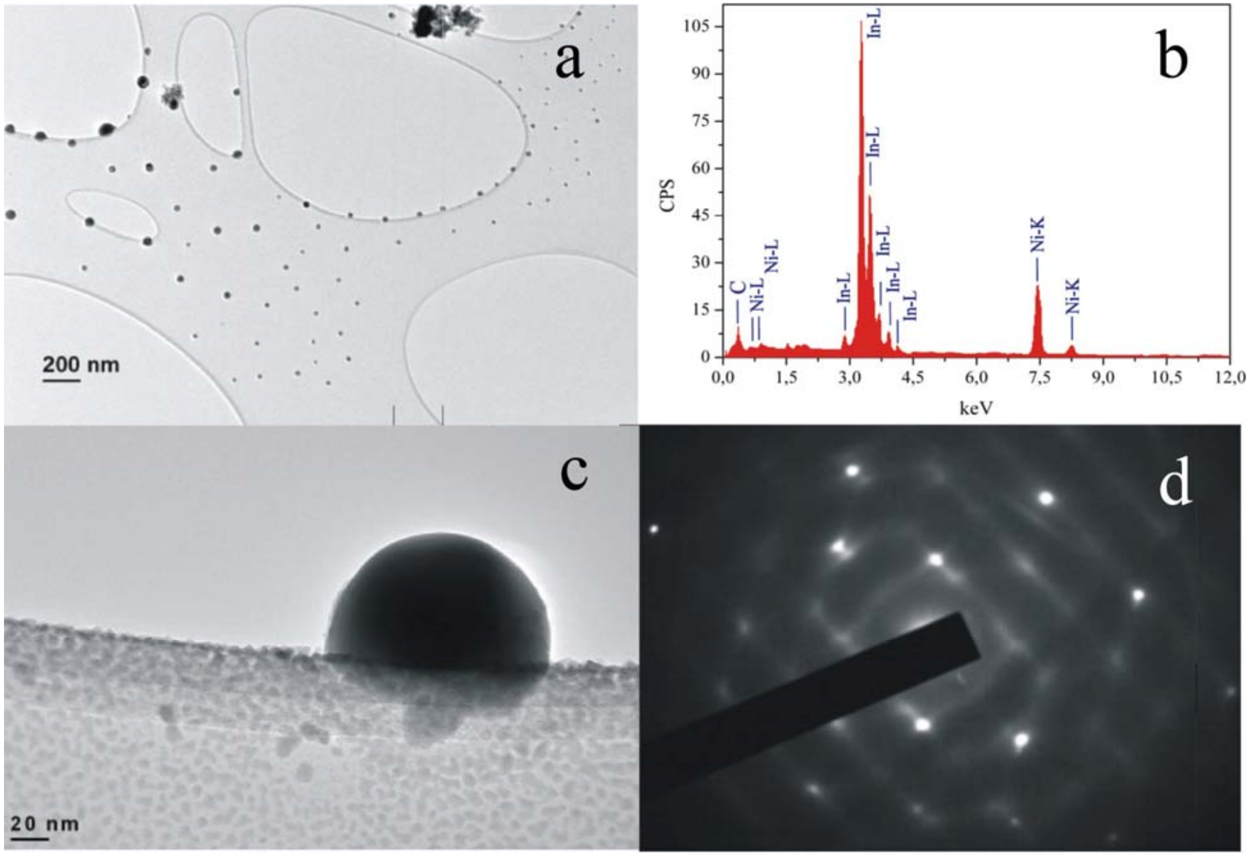


F_2 Laser:157 *nm*, E =20 *mJ/pulse*, 15 Hz rep.rate
Target : InN
Substrate : Si / Ta
Distance between target and substrate 0.3 *cm*
Background gas: N_2 105 Pa Growth rate of the film : 170 *nm / h*

InN film morphology





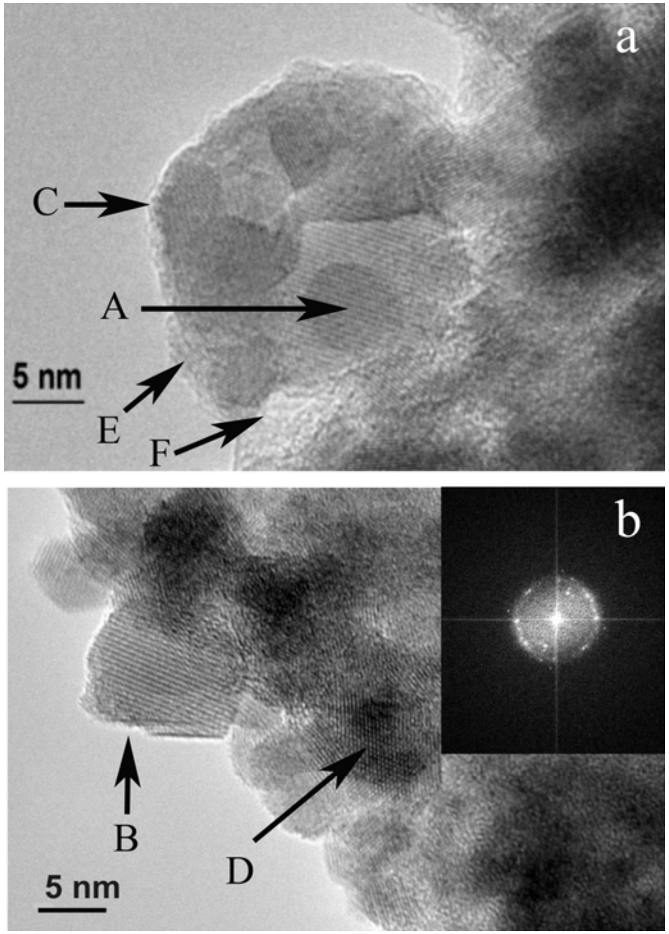


(a) TEM image of destroyed nanocrystalline domains deposited on Ni grids following electron irradiation.

(b) (b) EDXS of the e-beam irradiated crystal nanodomains. Only an indium peak is recorded.

(c) (c) Indium nanocrystalline sphere of tetragonal structure formed after e-beam irradiation.

(d) (d) SAED of the nanosphere with the tetragonal crystalline structure of pure indium

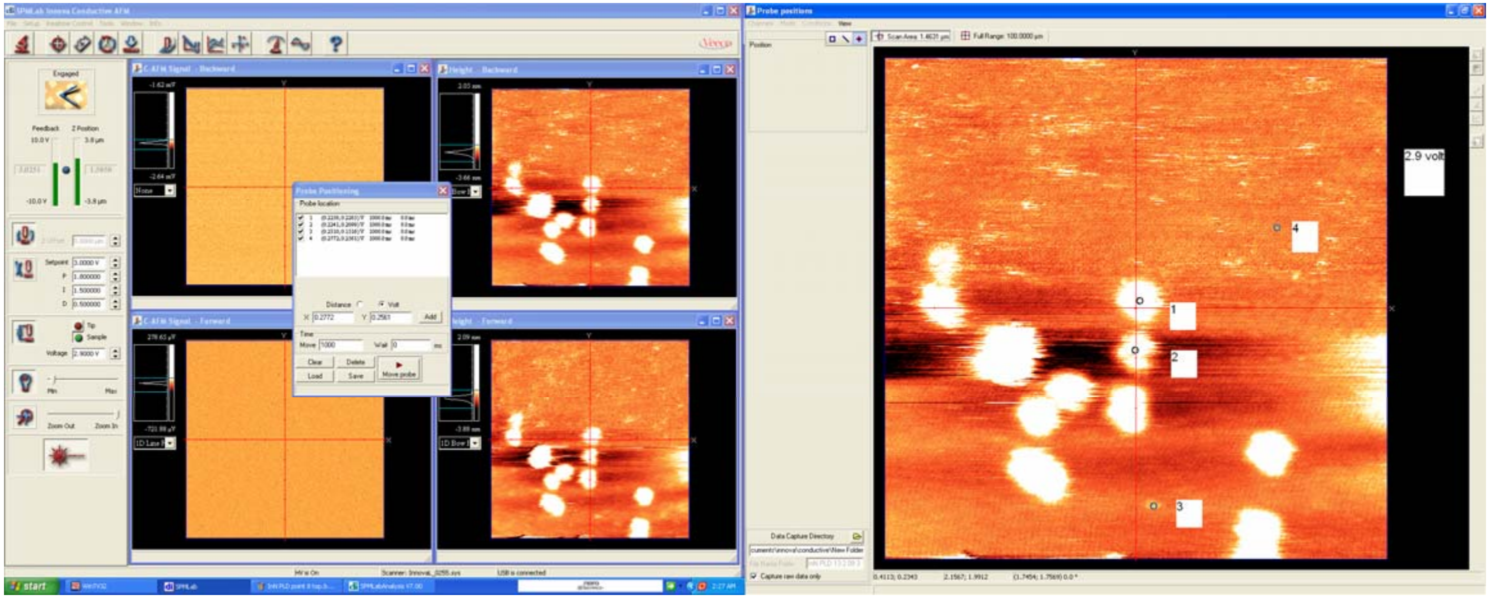


Morphology of InN nanostructures on Ta substrate by 157 nm PLD.

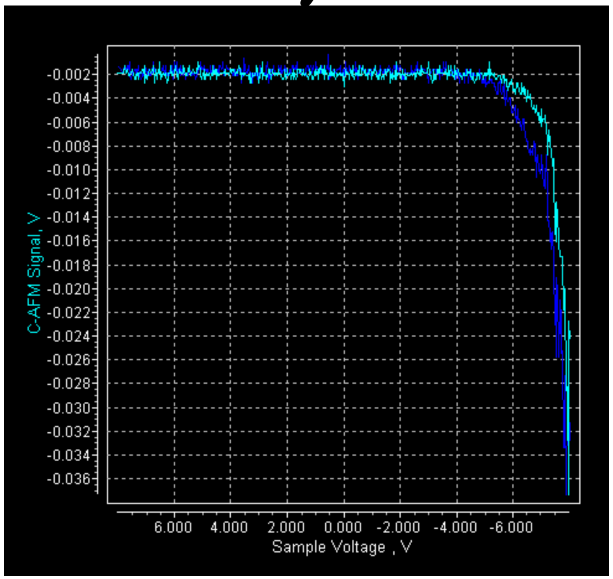
(a) 5 nm crystal domains (A), 40 nm crystal domains (C), amorphus oxinitrile In-O_y-N_x phase (E), boundary between amoprhus and crystal phase (F).

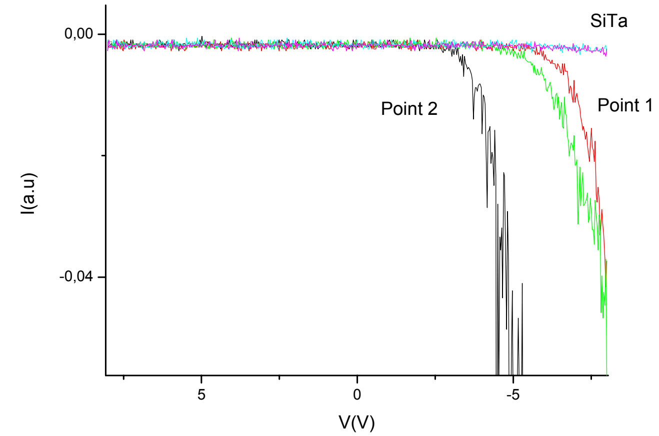
(b) Crystal cubic In_2O_3 [112] nanodomains. 25 nm crystal domains (B), Crystal 2-D nanostructures rotated with respect to each other (D).

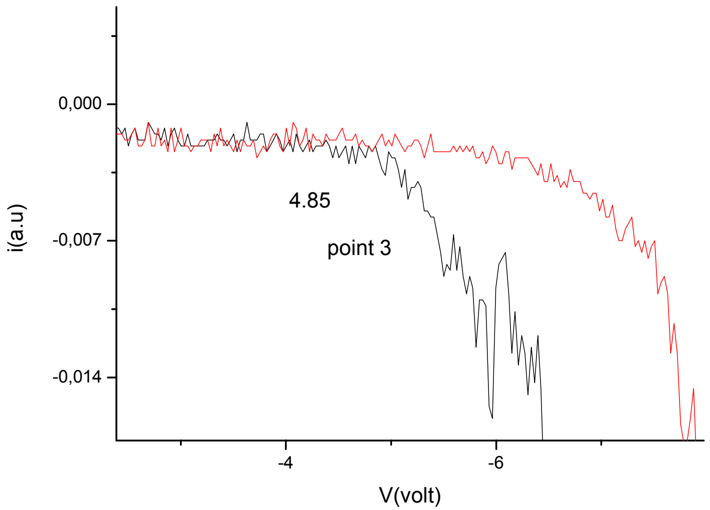
AFM and C-AFM images of InN film

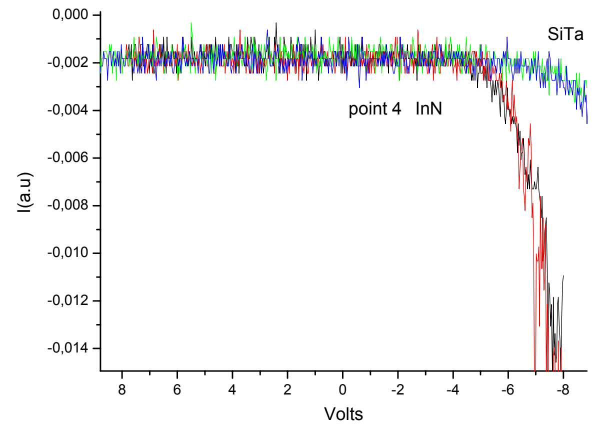


I-V response of InN nanodomains-Schottky diode charge memory effects

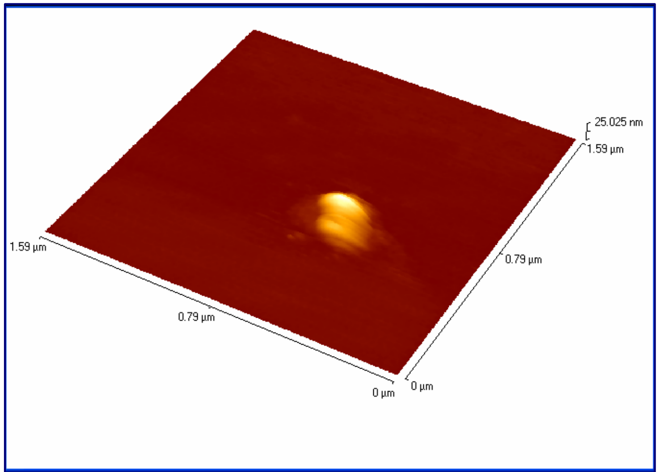


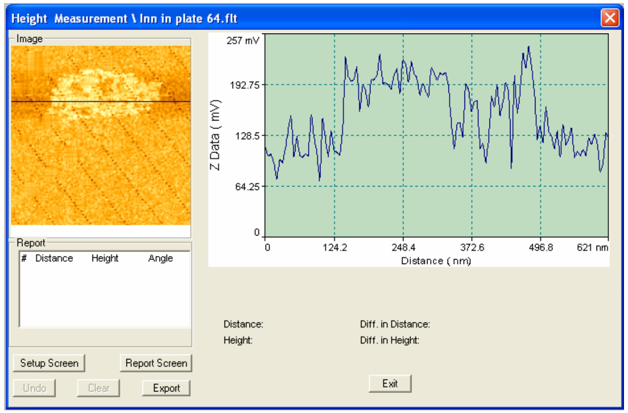


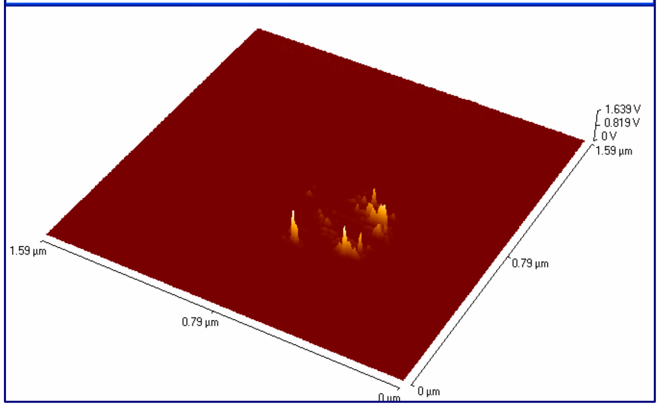


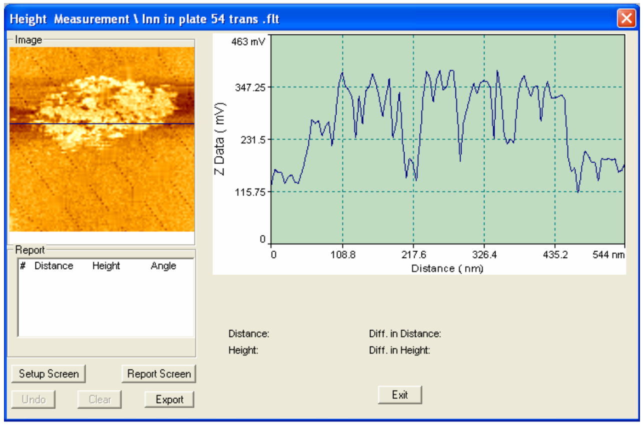


C-AFM of InN nanodomains

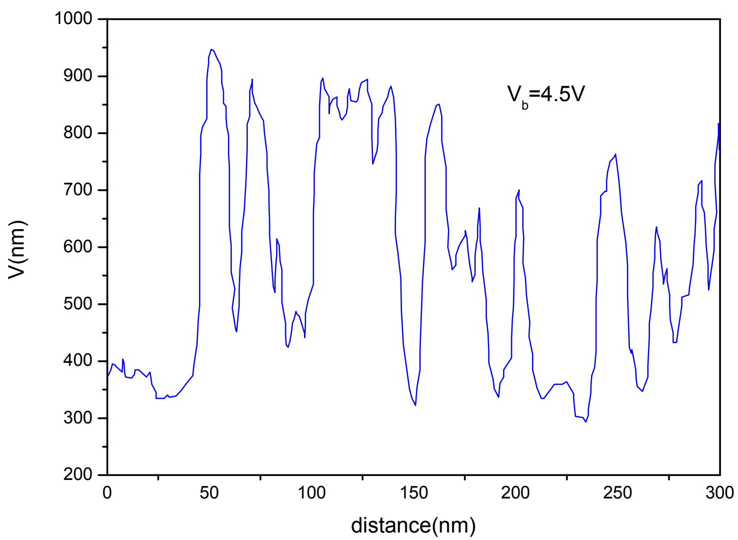


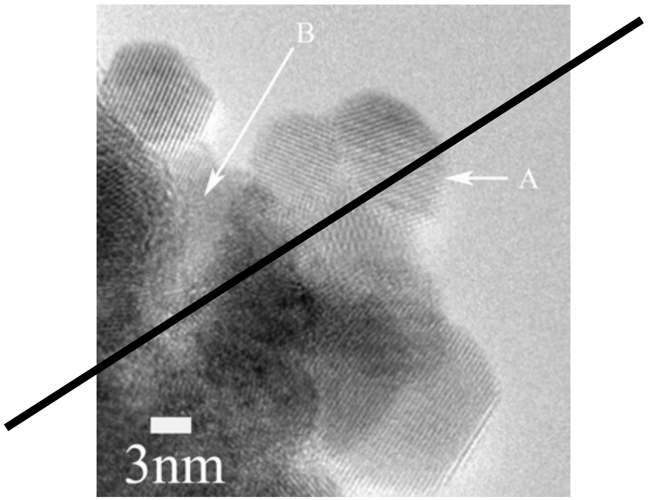






C-AFM scanning





Field effect in intrinsic InN semiconductors

$$\pm\left|\nabla(V(r)\right| = 2\left(\frac{2e^2 nkT}{\varepsilon\varepsilon_0}\right)^{1/2}\sinh\left(\frac{V(r)}{2kT}\right)$$

$$n(r) = \frac{\varepsilon\varepsilon_0}{e}\frac{d^2V(r)}{dr^2} \Rightarrow n_s(r) = -en_v(\exp(-\frac{V_s}{kT}) - \exp(\frac{V_s}{kT}))$$

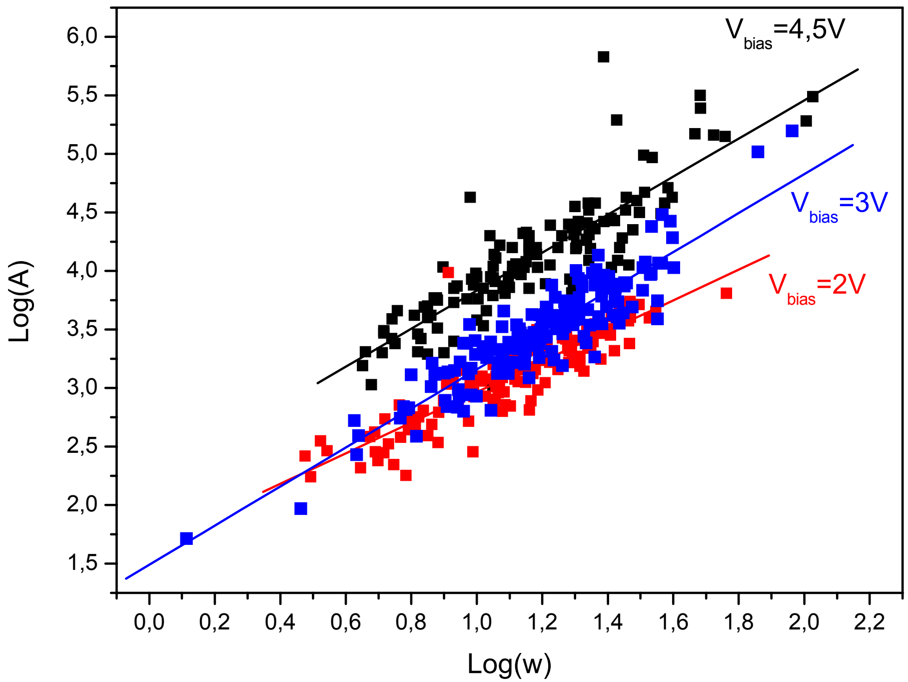
$$\log\left(\frac{4Q}{\pi w^2}\right) = \log(n_v) + \frac{V_s}{kT}$$

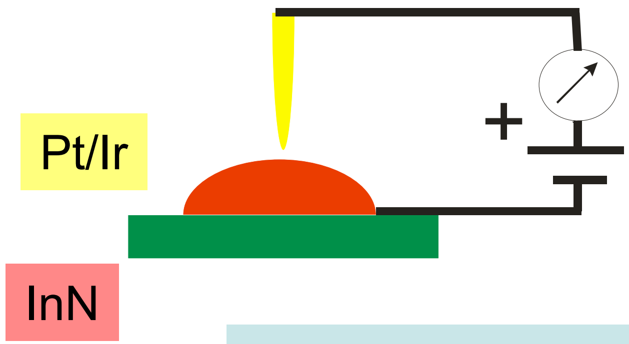
Field effect on InN nanodomains

$$Q = aA$$

$$A = \int_{-\infty}^{\infty} V(x)dx = \frac{\pi w V_{s\max}}{2}$$

$$\log A = C + 2\log w + \frac{V_s}{kT}$$





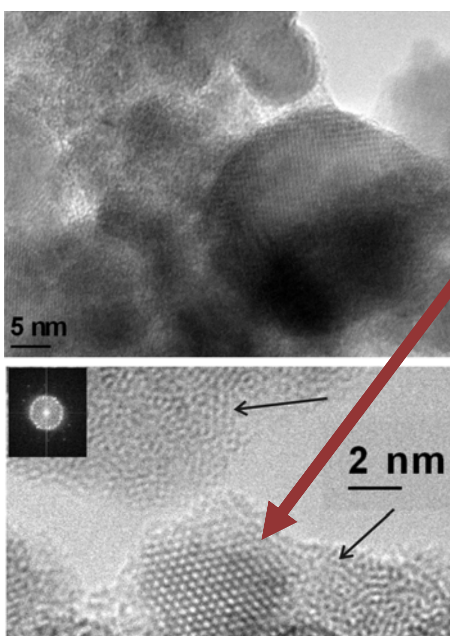
$$n(V_b), \quad \overline{n} = 1.6$$

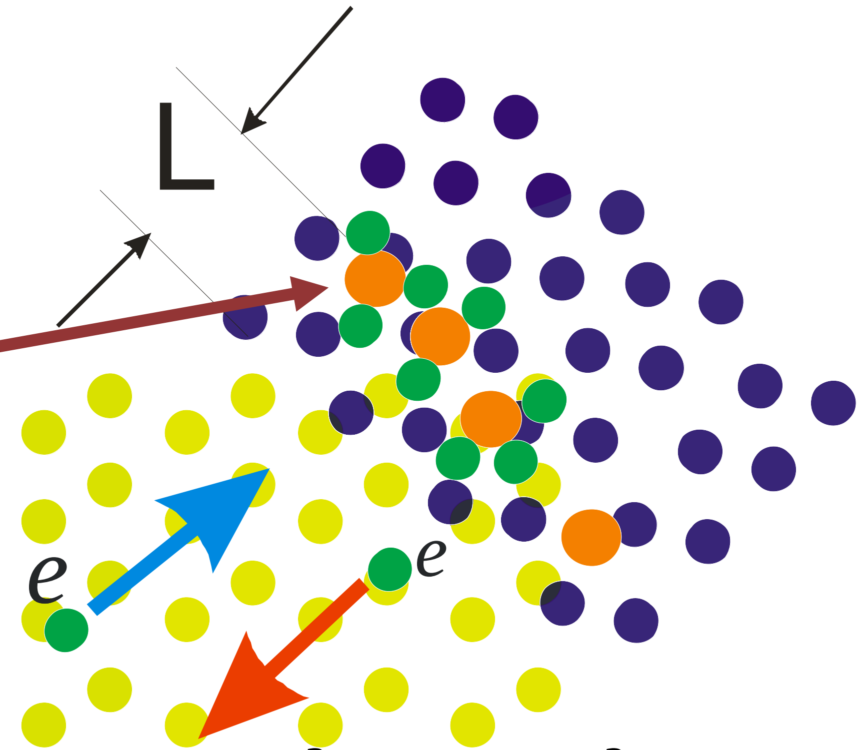
Surface distribution of charges (n=1.6)

Scattering of electrons on nanodomains

- ***Screening potential***
- ***Isotropic scattering***

$$V(r) = -\frac{Qe}{\varepsilon r}\exp(-k_0 r)$$





$$\frac{cn_s}{k^2}[\ln(1+\frac{4k^2}{k_0^2}) - \frac{4k^2}{k_0^2+4k^2}] \approx L$$

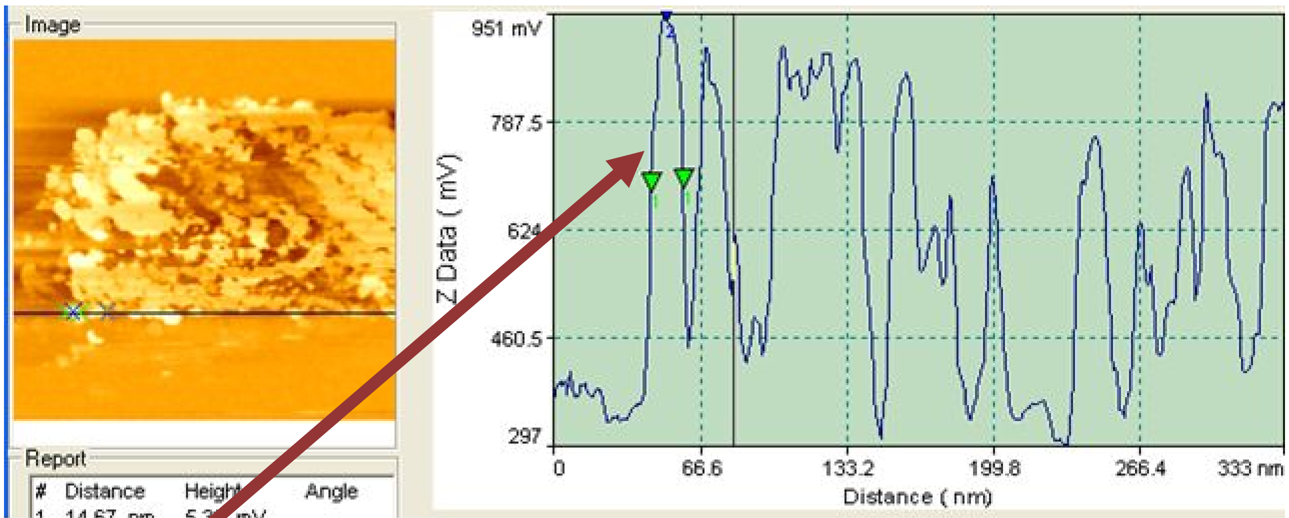
Electron concentration-screening action

n_s(el/cm^3)	10^{21}	10^{18}	10^{15}
L (nm)	1	10	100

Degenerate

Non-Degenerate

Scattering length



$$L = [(1.8 \pm 0.3 nm\ ) \Rightarrow n_s \sim 10^{21} - 10^{20} el / cm^3$$

$$L > 0.5 nm = \frac{1}{k_2}(translational\ symmetry)$$

conclusions

- 2-D (10 nm) InN nanotextures fabricated by PLD at 157 nm.
- Semiconductive (degenerate) response (Schottky)
- Charge memory effect (hysterisis).
- Accumulation of charges on the boundaries of nanotextures due to braking of translational symmetry and scattering of electron wavefunctions on screening

  potential of the boundary.