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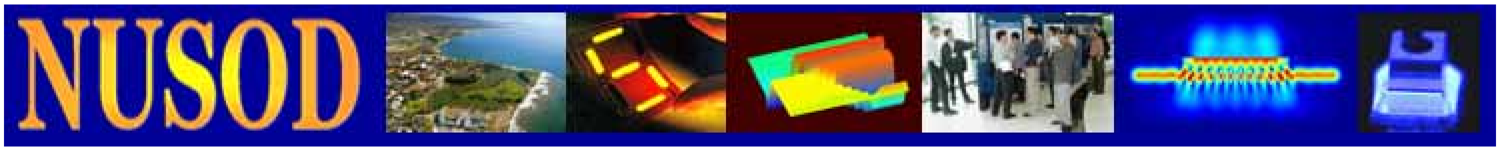

AlGaN/GaN based electroabsorption modulator operating at fiber-optics telecommunication wavelengths

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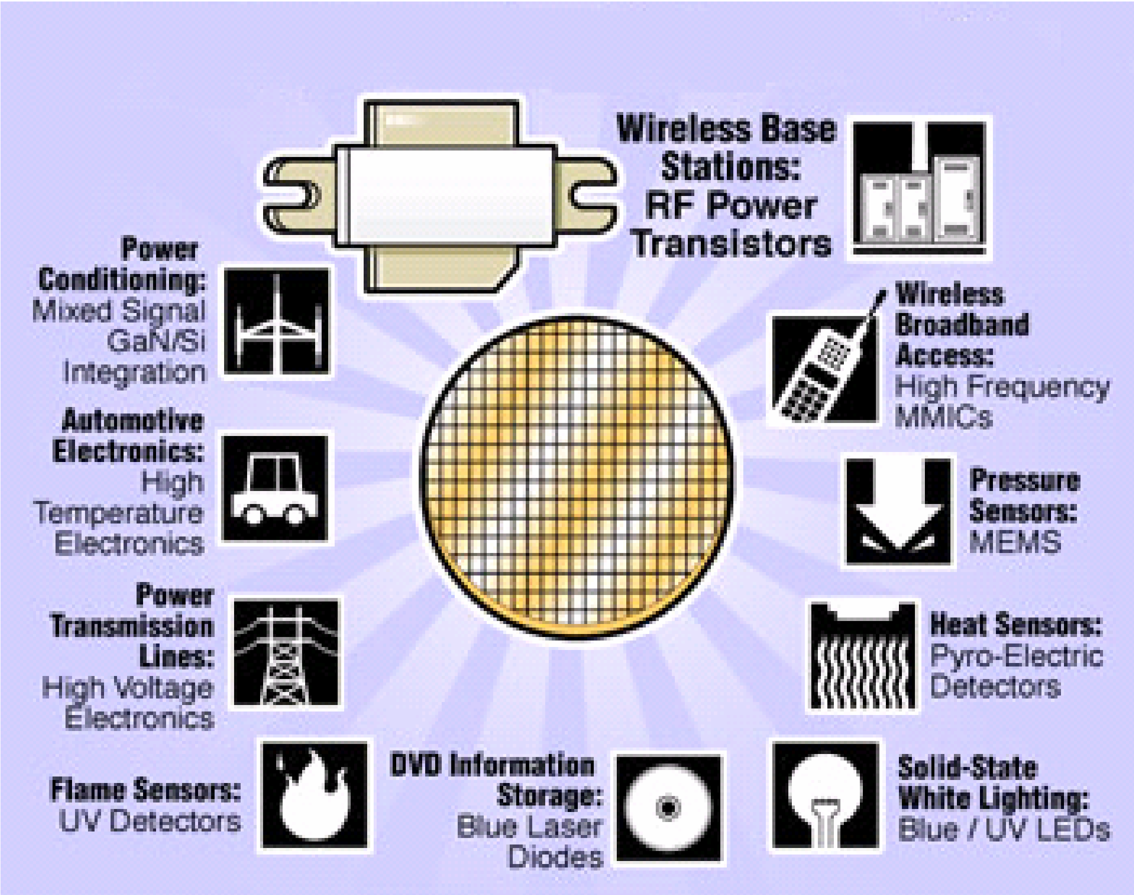
Outline

- INTRODUCTION
- MODELING AND DISCUSTIONS
  - ✓ Subband energy and MQW profile
  - ✓ The effects of electric field
- Summary

Applications for AlGaN / GaN



Introduction

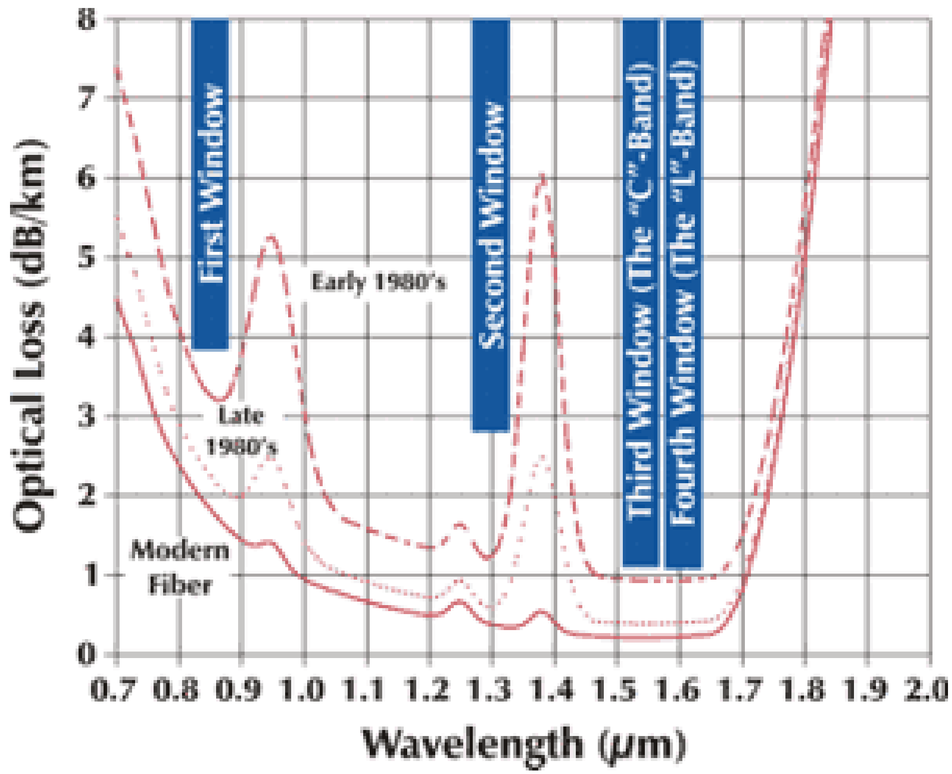
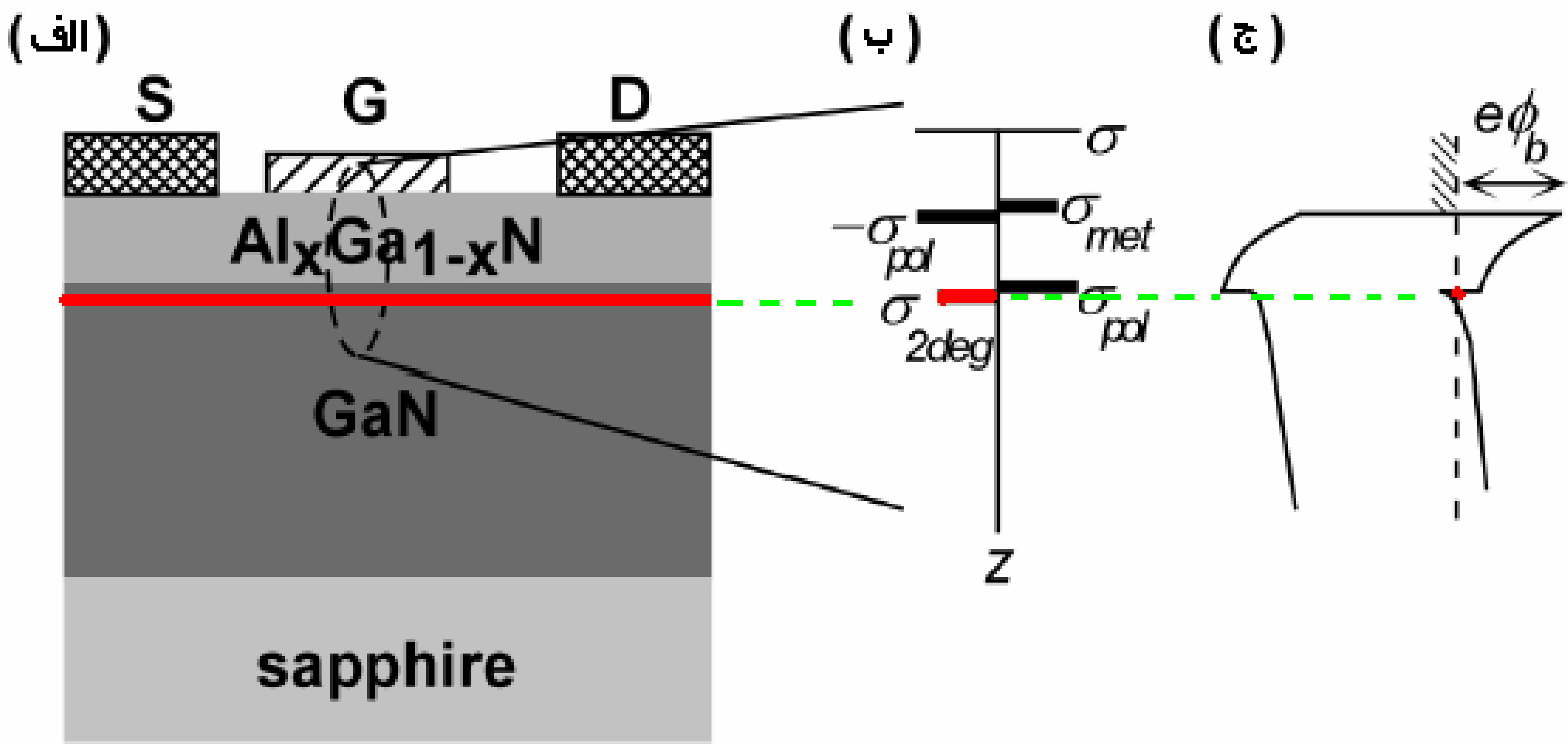


Figure 3 - Four Wavelength Regions of Optical Fiber

Why nitride intersubband devices?

- Wavelength tunability
- Speed:
- High power-handling:
- Excellent optical properties and material hardness
- Added functionalities and improved system performances

2D-Electron density & CB Profile 1



2D-Electron density & CB Profile 2

$$N_S(x) = \frac{+\sigma(x)}{e} - \left(\frac{\varepsilon_0 \varepsilon(x)}{d\, e^2}\right)\left[e\Phi_b(x) + E_F(x) - \Delta E_C(x)\right]$$

$$N_S = \sum_i ns_i = \sum_i \frac{m^* K_b T}{\pi \hbar^2} \ln\left(1 + \exp\left(\left(E_f - E_i\right)/K_b T\right)\right)$$

$$\varepsilon(x) = -0.5x + 9.5$$

$$e\Phi_b = (1.3x + 0.84)\ \ eV$$

$$\Delta E_C = 0.7\left[E_g(x) - E_g(0)\right]$$

$$E_g(x) = xE_g(AlN) + (1-x)E_g(GaN) - x(1-x)\ \times 1\, eV$$

$$= x \times 6.13eV + (1-x)\times 3.42eV - x(1-x)\ \ \times 1eV$$

Poisson Eq.

$$\frac{d}{dz}\left[\varepsilon(z)\frac{d\Phi(z)}{dz}\right]=-en(z)$$

$$n(z)=\left(N_d^*(z)-N_a^*(z)-n_{free}(z)+p_{free}(z)-\sum_i ns_i\Psi_i^*(z)\Psi_i(z)\right)$$

$$N_d^*=N_d\left(\frac{1}{1+2e^{(E_f-E_d)/K_bT}}\right)\quad,\quad N_a^*=N_a\left(\frac{1}{1+4e^{(E_a-E_f)/K_bT}}\right)$$

$$N_d=1\times10^{17}\,cm^{-3}$$
$$N_a=0$$

$$n_{free}=N_C F_{1/2}\left(\frac{E_f-\Phi(z)}{K_bT}\right)$$

$$\left.\frac{d\Phi}{dz}\right|_{z=neutral\ region\ insubstrat}=0\quad,\quad \Phi\big|_{z=Metal\_semiconductori\ interface}=\Phi_b,$$

Schrödinger Eq. 1

$$\left[\frac{-\hbar}{2}\frac{d}{dz}\left(\frac{1}{m^*(z)}\frac{d}{dz}\right)+V(z)\right]\Psi_i(z)=E_i\Psi_i(z)$$

$$V(z)=-e\Phi(z)+V_h(z)+V_{xc}(z)+V_{im}(z)$$

$$V_h(z)=\left[1-G(z)\right]\Delta E_C$$

$$G(z)=\begin{cases}(z+z_h)/z_t, & 0<z<z_h-a_t,\\ \dfrac{\{z+3z_h-a_t+(2a_t/\pi)\cos\left[\pi(z-z_h)/2a_t\right]\}}{2z_t}, & z_h-a_t<z<z_h+a_t,\\ 1, & z>z_h+a_t,\\ 1-G(-z), & z<0,\end{cases}$$

Schrödinger Eq. 2

$$V_{xc}(z) \equiv V_{xc}\{n(z)\} \equiv \mu_{xc}[n_0 = n(z)]$$

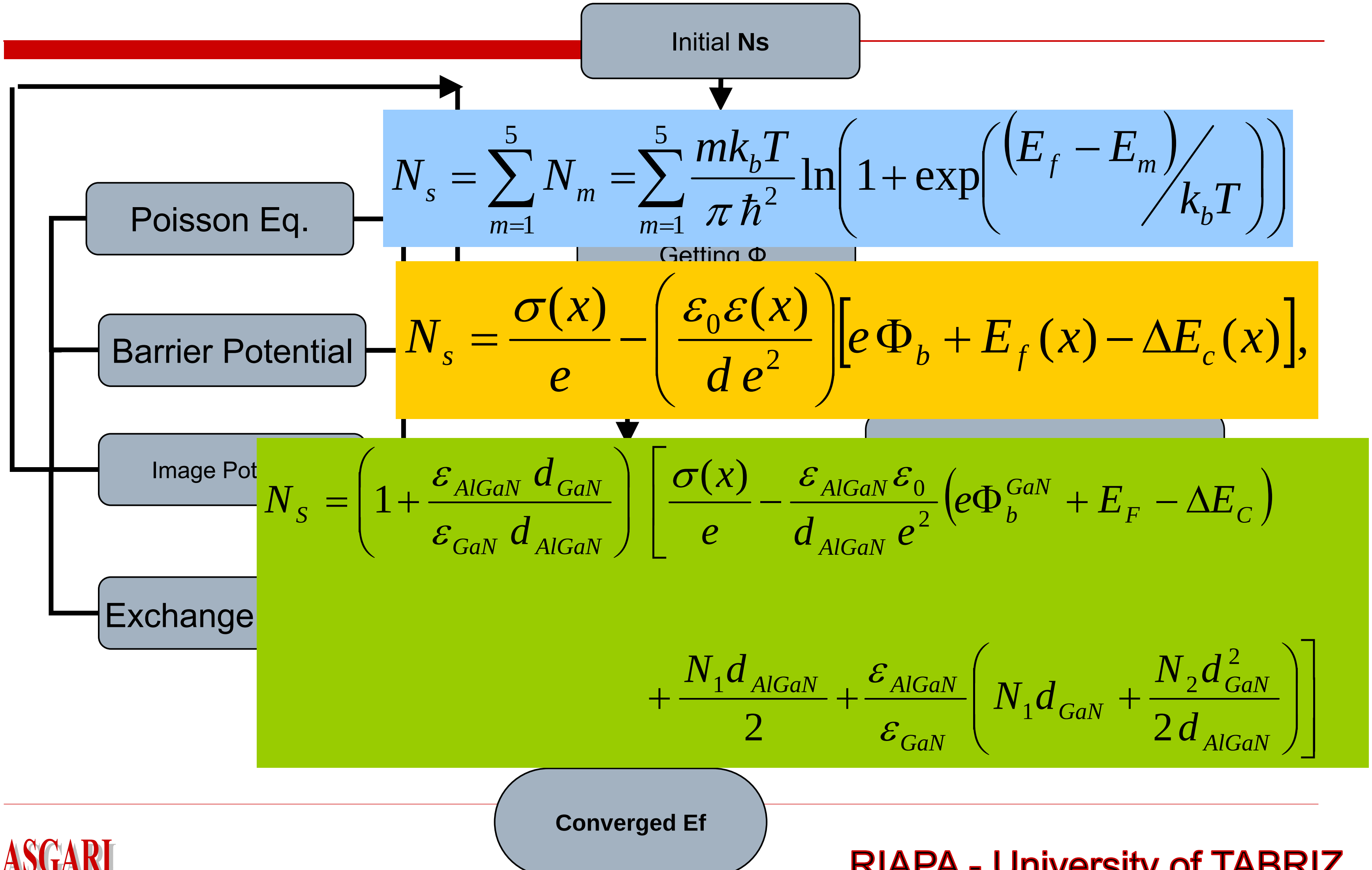
$$V_{xc}(z) = -\left[1 + 0.773x \times \ln(1 + x^{-1})\right] \times \left(2 \big/ \pi \alpha r_S \right) R_y^*$$

$$\alpha = (4/9\pi)^{1/3} \;,\; x \equiv x(z) = r_S \big/ 21 \;,\; r_S \equiv r_S(z) = \left[\frac{4}{3}\pi a^{*3} n(z)\right]^{-\frac{1}{3}}$$

$$a^* = \frac{4\pi\varepsilon_0\varepsilon(z)\hbar^2}{m(z)e^2} \;.$$

$$V_{im}(z) = \begin{cases} \left[(\varepsilon_{GaN} - \varepsilon_{AlGaN})e^2\right] \big/ \left[16\pi\varepsilon_0\,\varepsilon_{GaN}\,(\varepsilon_{GaN} + \varepsilon_{AlGaN})z\right], & z > \text{interface} \\ \left[(\varepsilon_{GaN} - \varepsilon_{AlGaN})e^2\right] \big/ \left[16\pi\varepsilon_0\,\varepsilon_{AlGaN}\,(\varepsilon_{GaN} + \varepsilon_{AlGaN})z\right], & z < \text{interface} \end{cases}$$

2D-Electron density & CB Profile 3

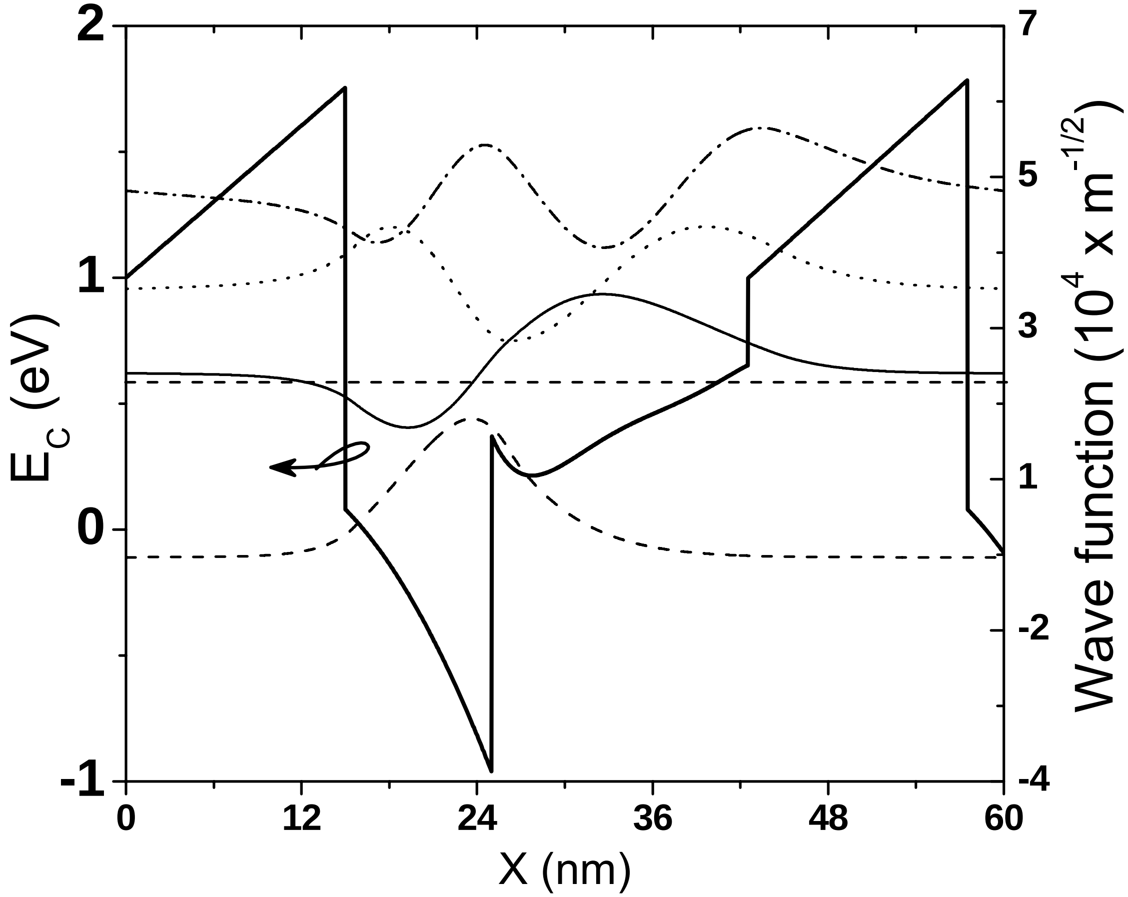


$$N_s = \sum_{m=1}^{5} N_m = \sum_{m=1}^{5} \frac{m k_b T}{\pi \hbar^2} \ln\left(1 + \exp\left(\left(E_f - E_m\right) \Big/ k_b T\right)\right)$$

$$N_s = \frac{\sigma(x)}{e} - \left(\frac{\varepsilon_0 \varepsilon(x)}{d\, e^2}\right)\left[e\Phi_b + E_f(x) - \Delta E_c(x)\right],$$

$$N_S = \left(1 + \frac{\varepsilon_{AlGaN}\, d_{GaN}}{\varepsilon_{GaN}\, d_{AlGaN}}\right)\left[\frac{\sigma(x)}{e} - \frac{\varepsilon_{AlGaN}\,\varepsilon_0}{d_{AlGaN}\, e^2}\left(e\Phi_b^{GaN} + E_F - \Delta E_C\right) + \frac{N_1 d_{AlGaN}}{2} + \frac{\varepsilon_{AlGaN}}{\varepsilon_{GaN}}\left(N_1 d_{GaN} + \frac{N_2 d_{GaN}^2}{2\, d_{AlGaN}}\right)\right]$$

2D-Electron density & CB Profile 3



Absorption Coefficient

$$\alpha(\omega) = c_{\text{int}} \cos^2(\theta) \left| \left\langle F_n \left| \frac{\partial}{\partial z} \right| F_m \right\rangle \right|^2 \left(\frac{\pi\hbar^2}{m_e k_B T} \right) (N_{sm} - N_{sn}) \times \left(\frac{\Gamma}{2\pi} \right) \left[\left(\frac{\Gamma}{2} \right)^2 + (\hbar\omega - \hbar\omega_\circ)^2 \right]^{-1}$$

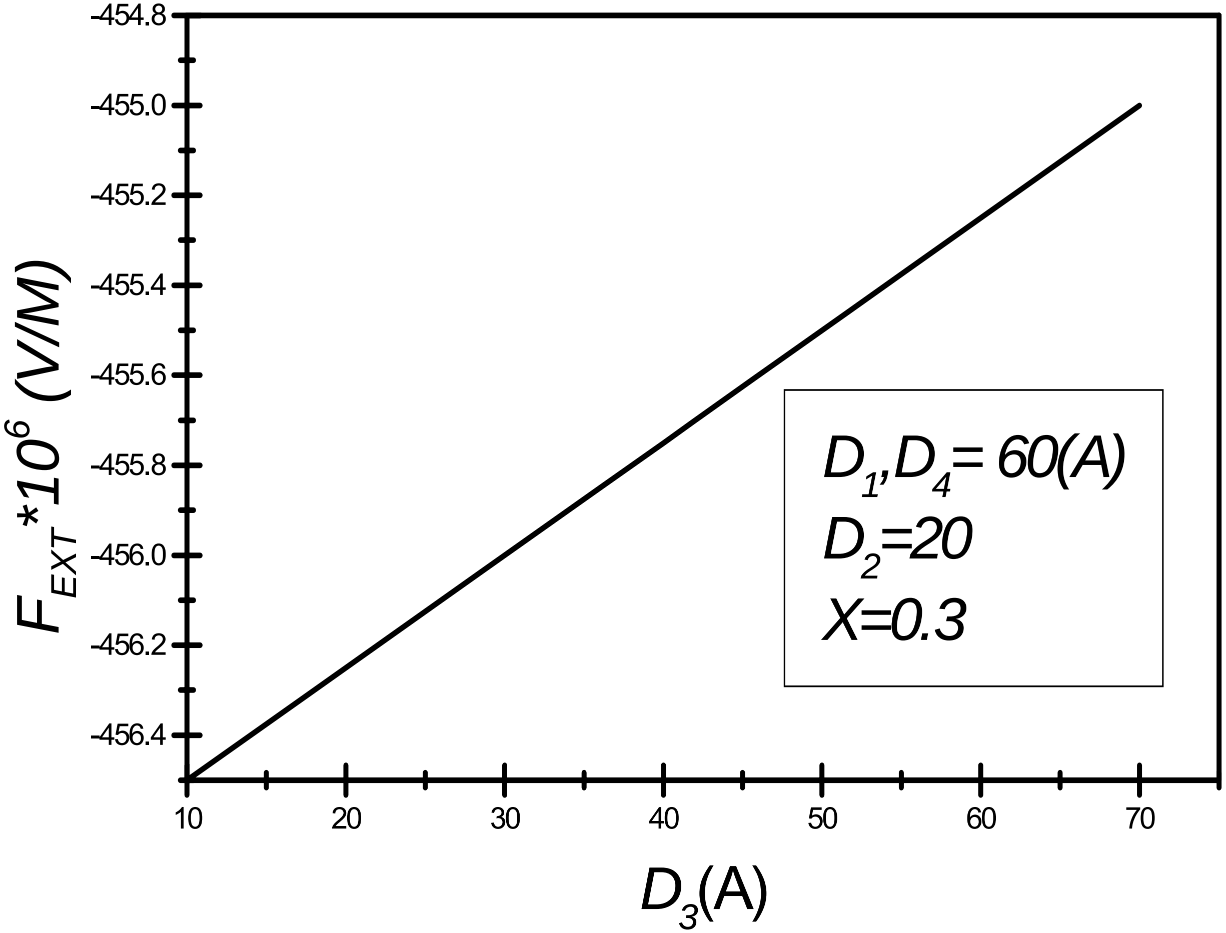
$$c_{\text{int}} = \frac{e^2}{k_B T L C \omega \varepsilon_\circ n_r m_e}$$

$$\varpi_\circ = \frac{E_{cn} - E_{cm}}{\hbar}$$

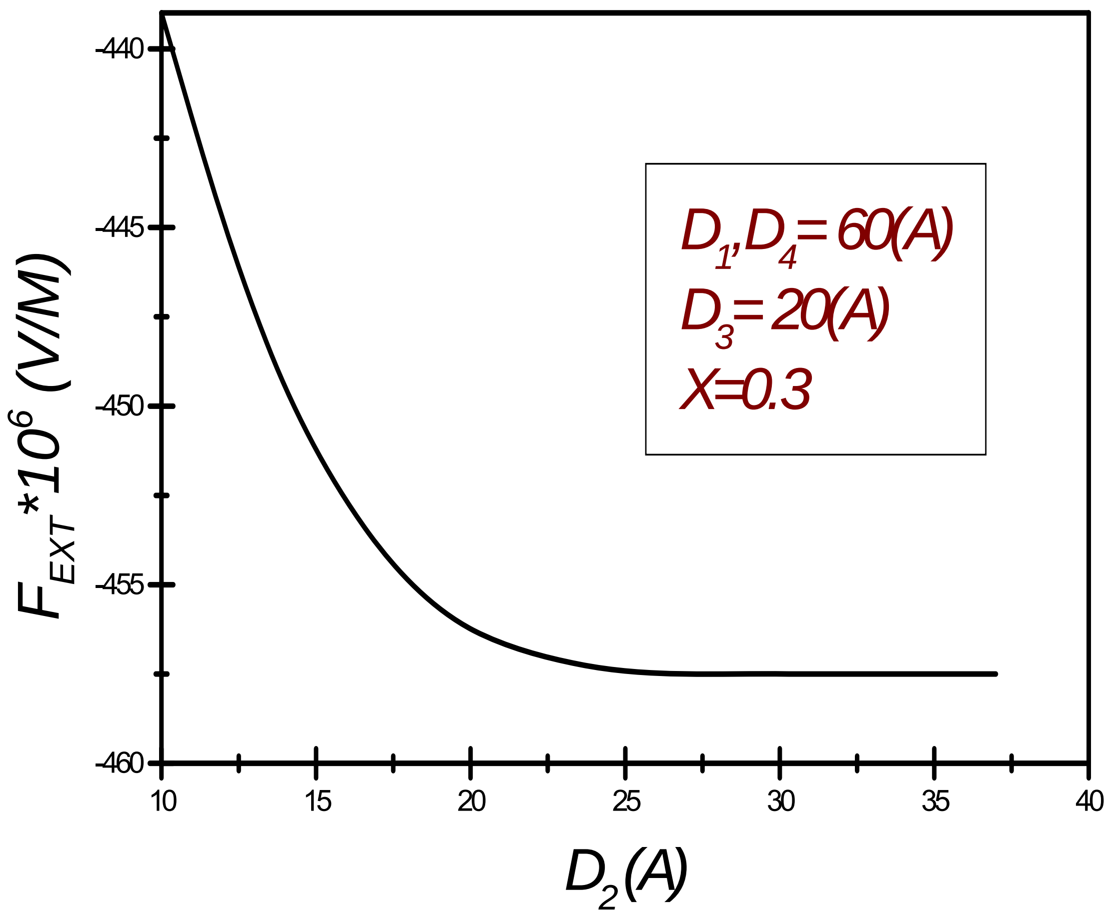
2D-Electron density & CB Profile 3

D_1	D_2	D_3	D_4
AlN	GaN	AlGaN	AlN

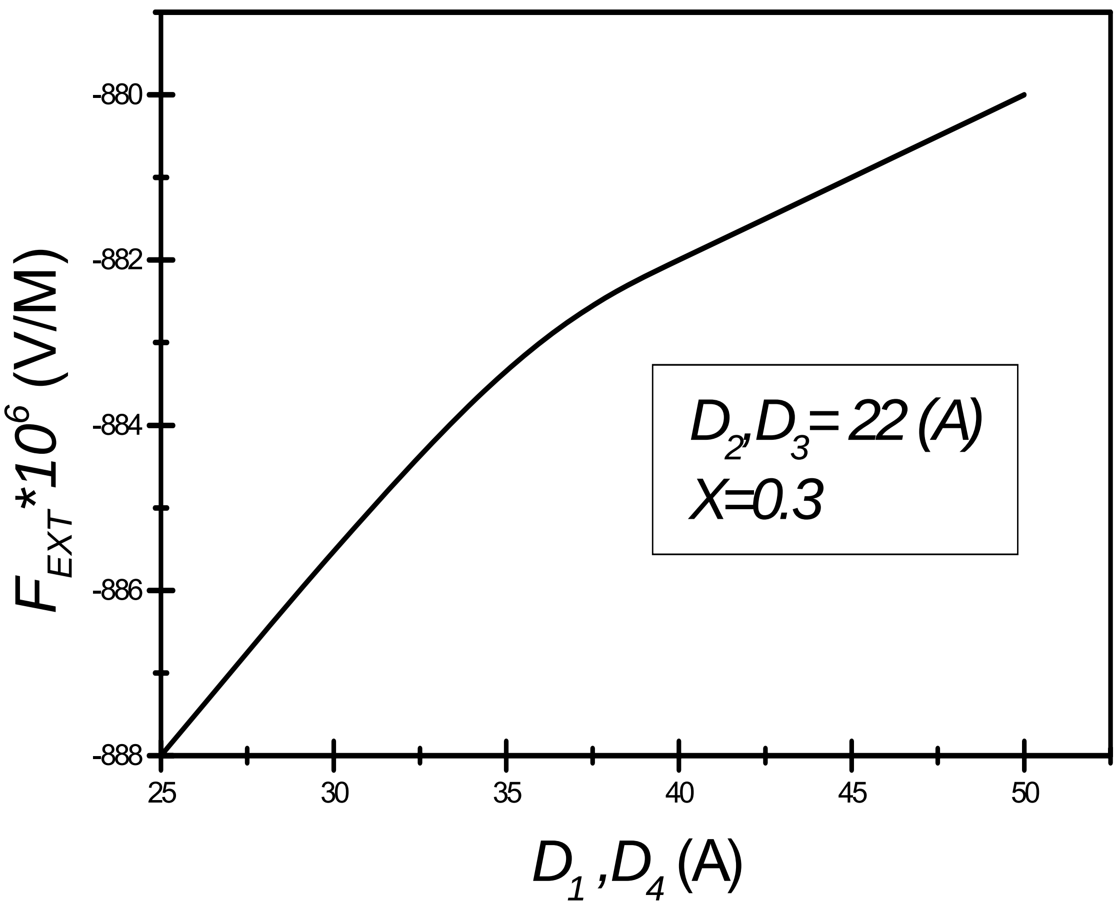
The electric field vs. D3



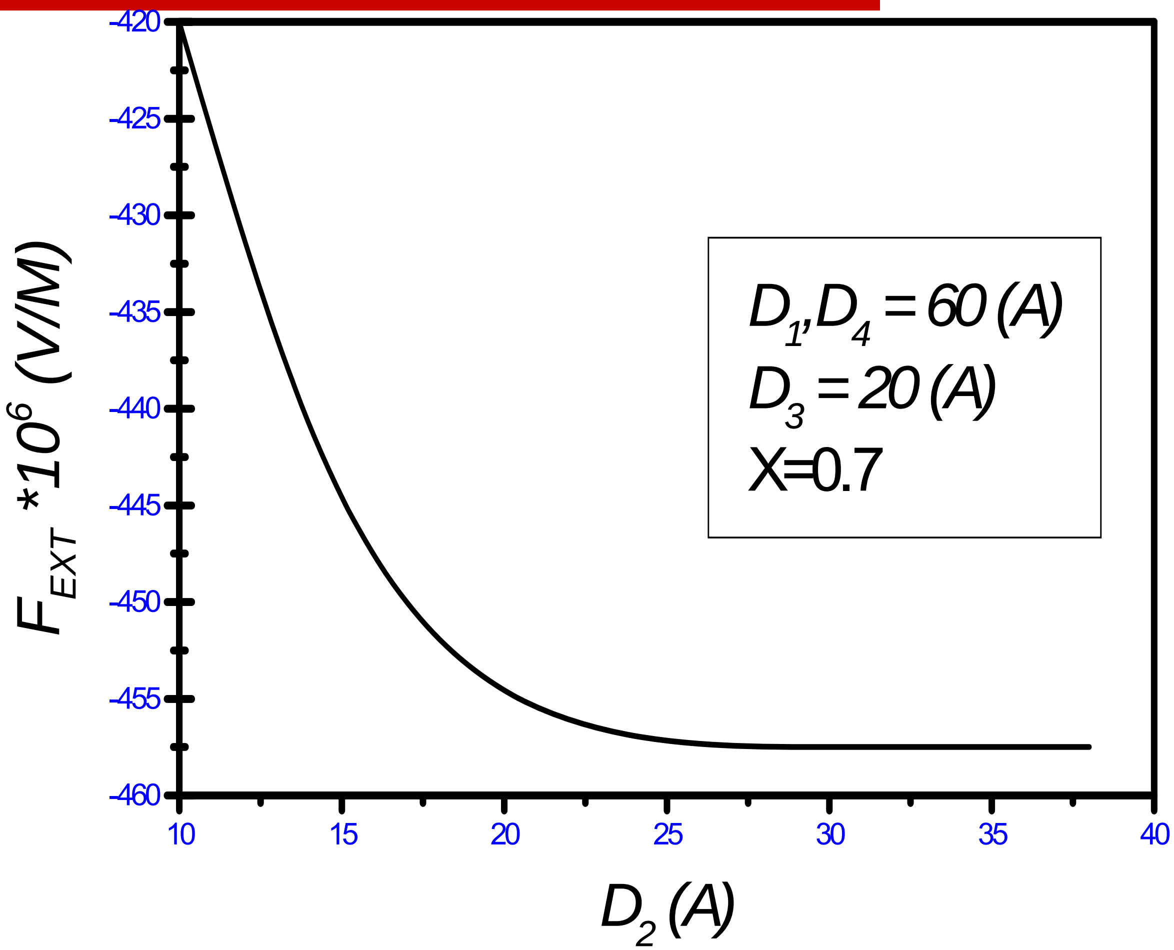
The electric field vs. D2



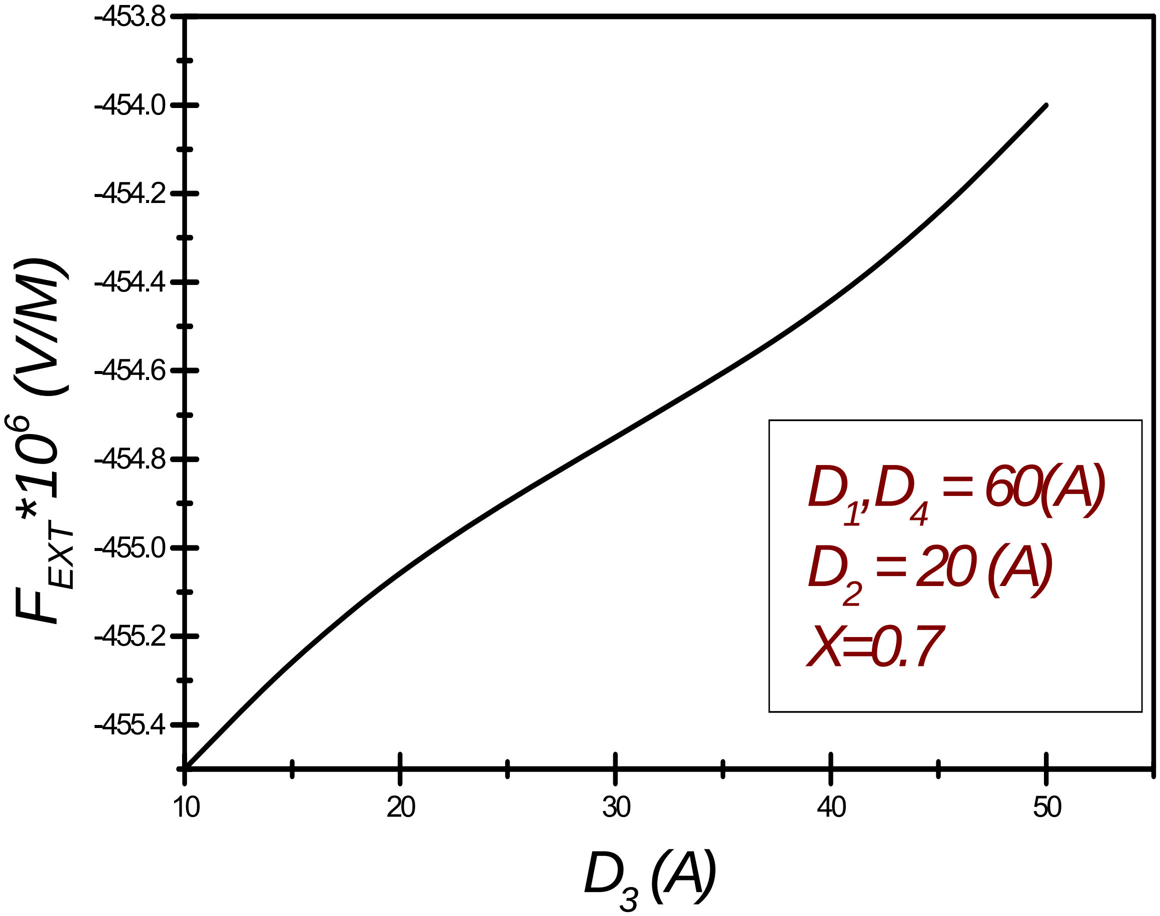
The electric field vs. D1&D4



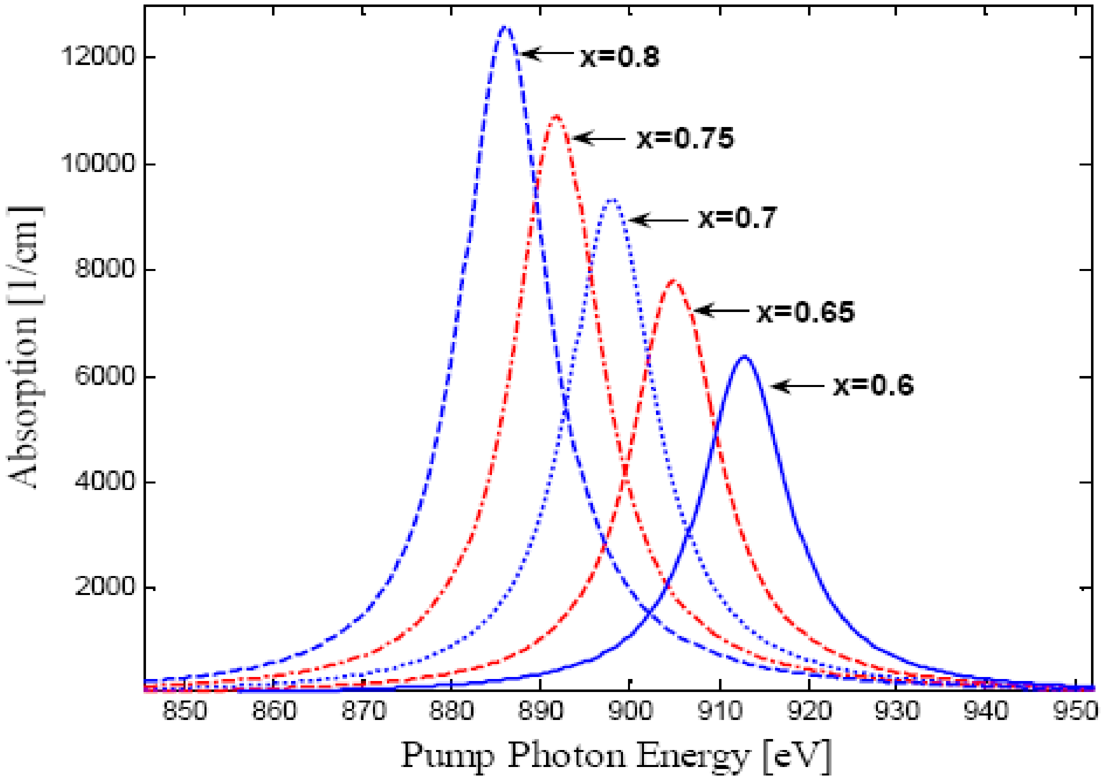
The electric field vs. D2



The electric field vs. D3



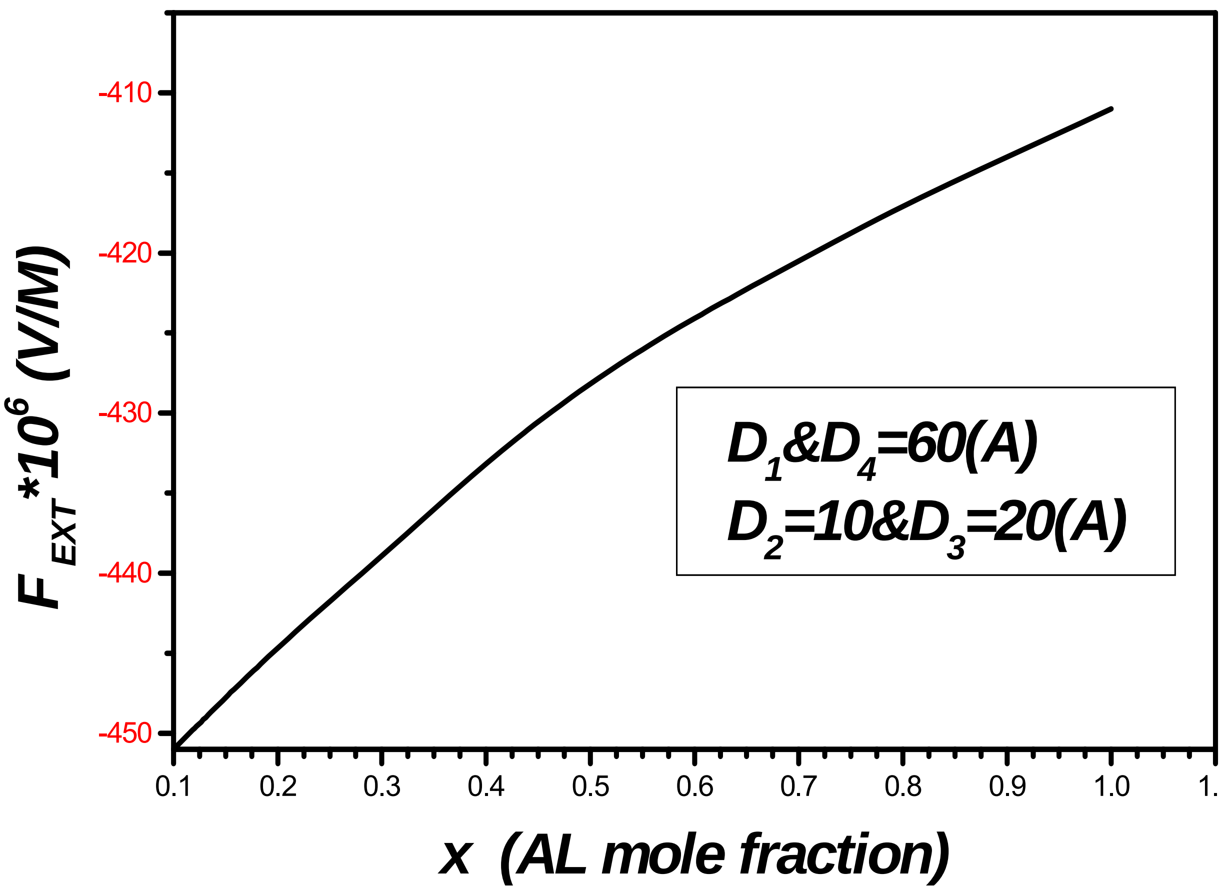
Absorption Coefficient



The electric field vs. Al molar

X	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.8	0..9
F× 10^6	-644	-630	-621	-615	-610	-595	-583	-577	-569

The electric field vs. x



Summary

- Fext ↓ D3 ↑
- Fext ↑ D2 ↑
- Fext ↓ D1 & D4 ↑
- Fext ↓ x ↑

Thanks for Your Attention

Any Question?