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Studies on the Suitability of Indium Nitride for Terahertz Plasmonics

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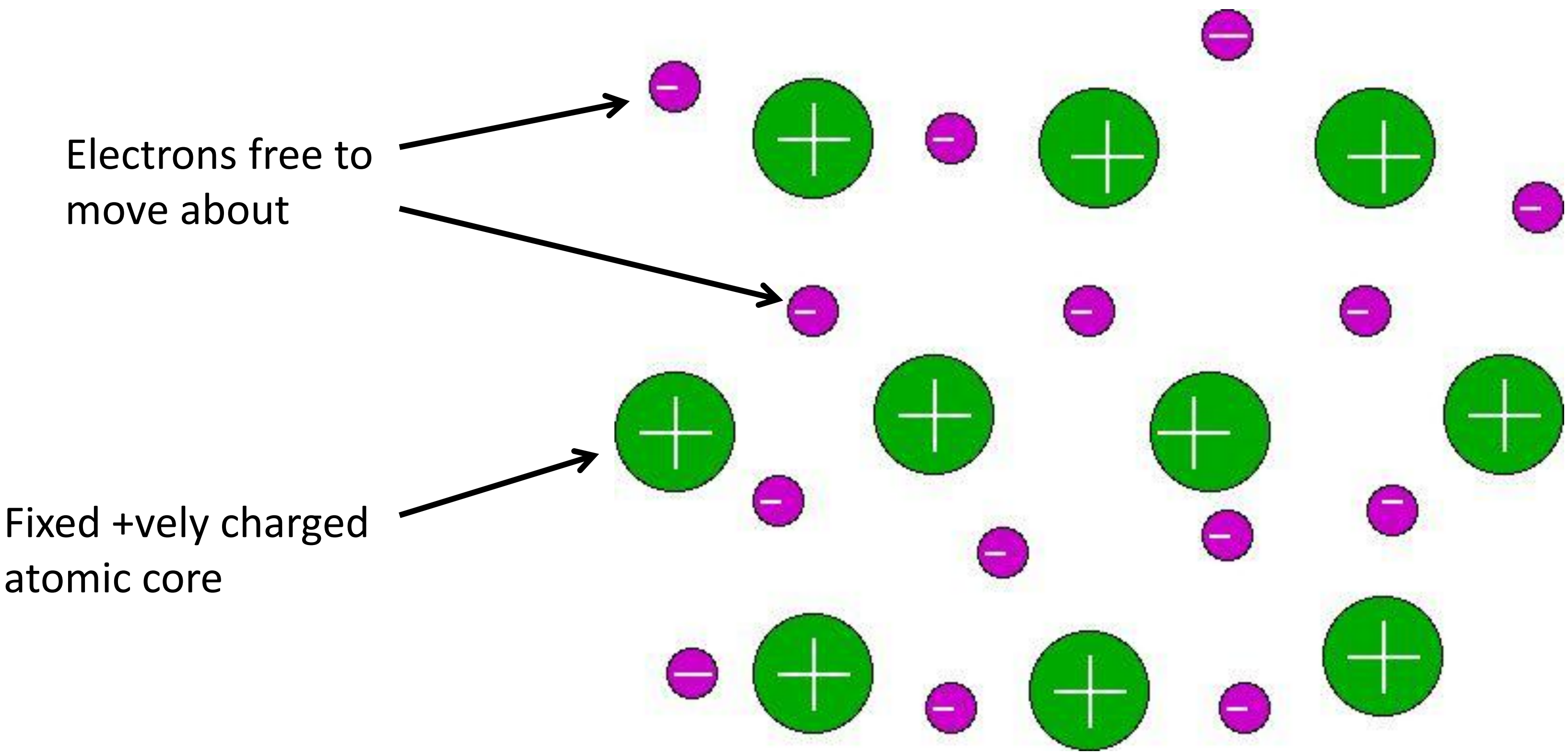
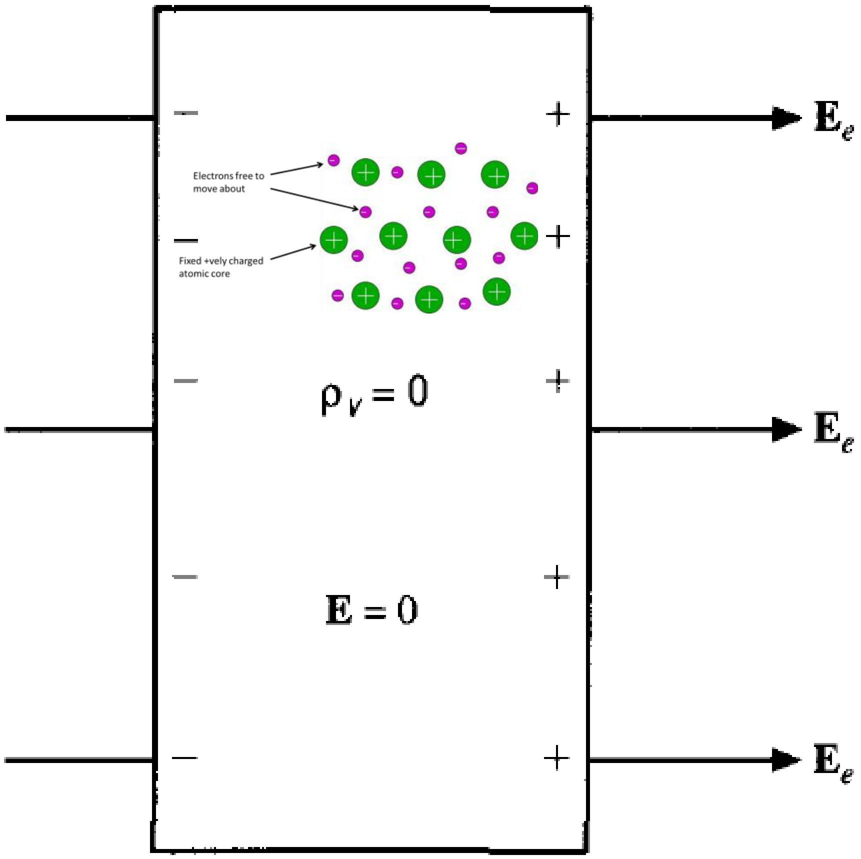
Outline

- Fundamentals
  - Plasmonics: Origin
  - Electromagnetics of metals
  - Negative permittivity
  - Surface plasmon coupling
- Why THz?
  - Applications
- Why InN?
  - Permittivities of Au and InN at THz
- Simulation results
  - Structure and Boundary Conditions
  - Electric field plots

Free electron model of metals

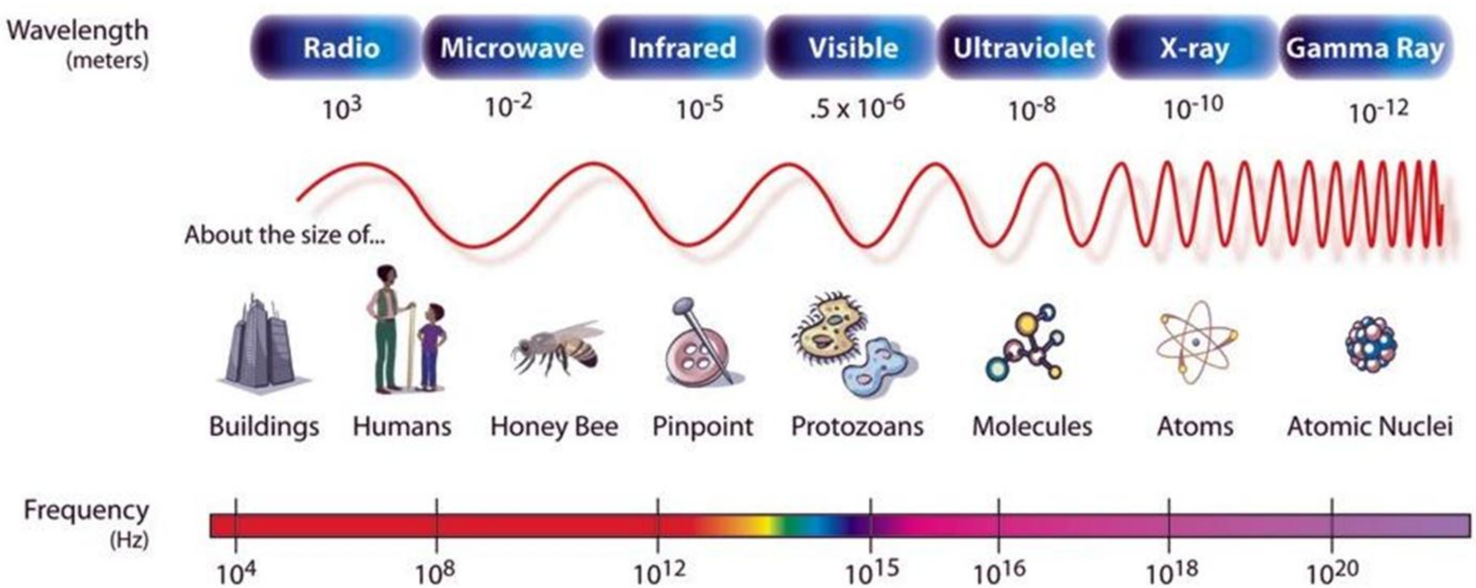


Behaviour under applied electric field



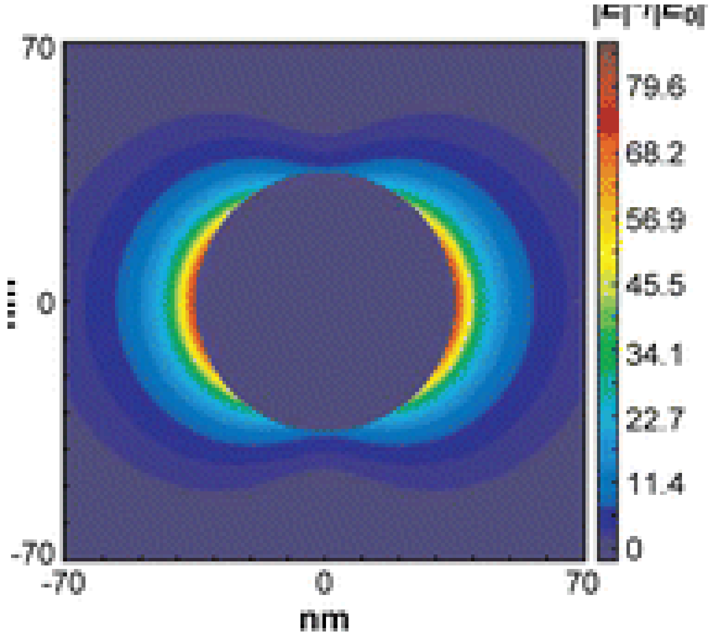
Plasma Frequency

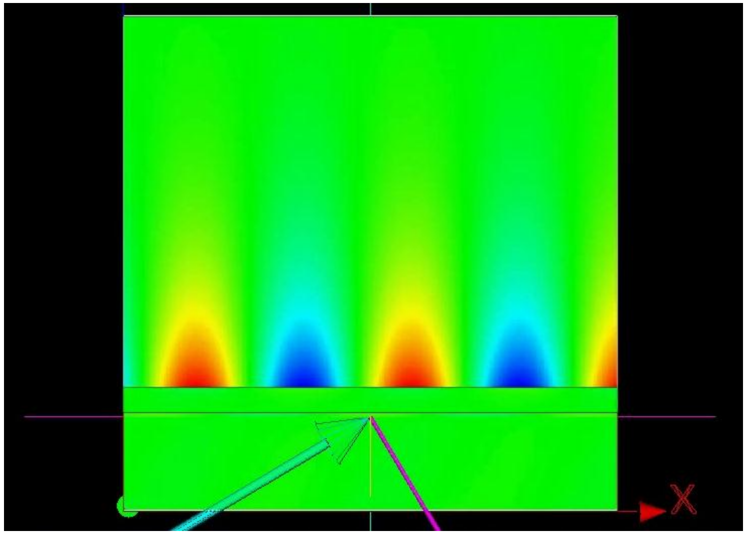
Material	Plasma Frequency	Wavelength
Gold (Au)	2.18×10^{15}Hz	200nm
Silver (Ag)	2.28×10^{15}Hz	180nm
Aluminium (Al)	3.57×10^{15}Hz	80nm
Indium Antimonide (InSb)	6.37×10^{12}Hz	47µm
Indium Nitride (InN)	52×10^{12}Hz	6µm



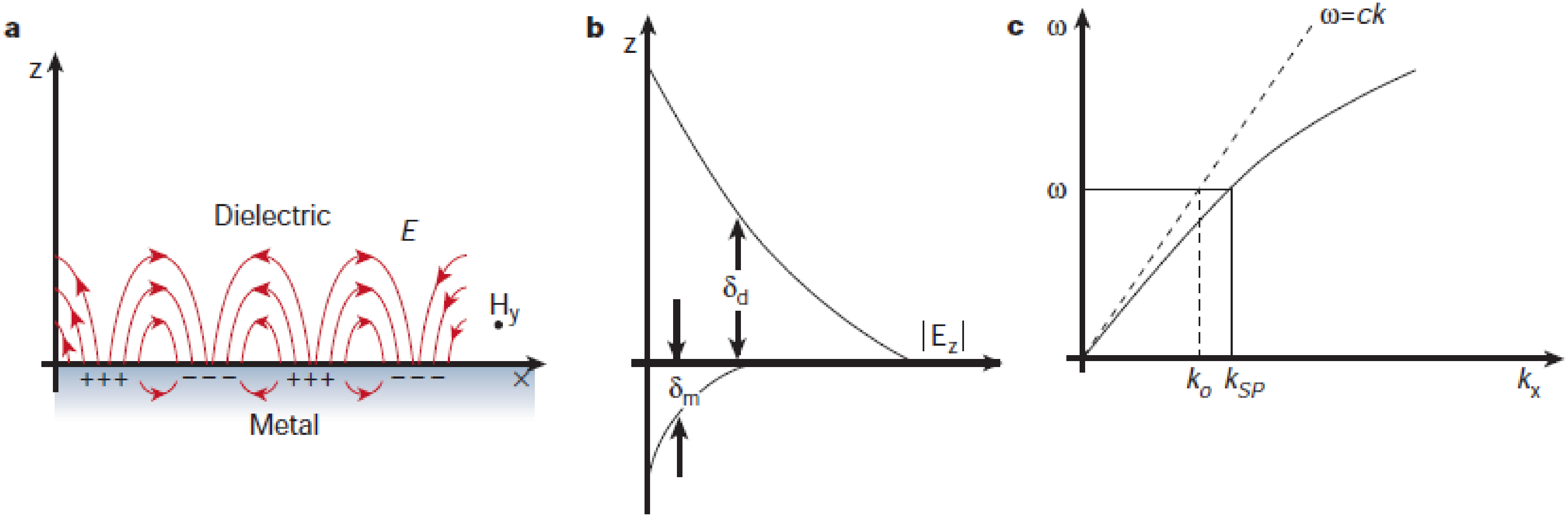
Ref: H. Ahn ; C.-L. Pan ; S. Gwo; "**Terahertz emission and spectroscopy on InN epilayer and nanostructure**", Proc. SPIE 7216, Gallium Nitride Materials and Devices IV, 72160T (February 16, 2009)

Local and Surface Plasmons





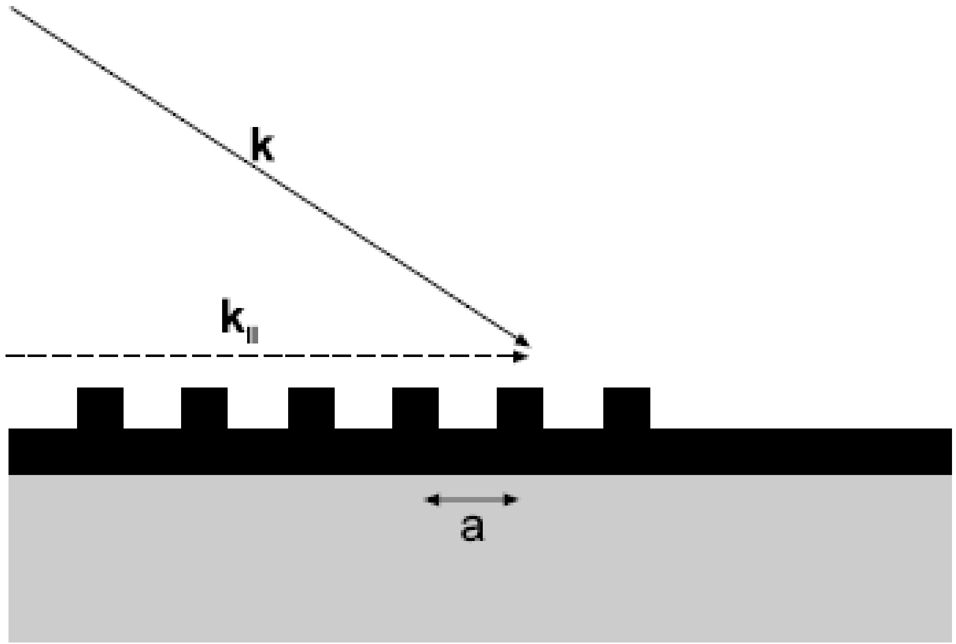
Plasmonics



- Performance enhancement
  - ✓enhanced E-field at metal dielectric interface due to surface plasmon wave

Ref: Barnes, W. L., Dereux, A. & Ebbesen, T. W. "**Surface plasmon subwavelength optics**" Nature 424, 824–-830 (2003).

Grating Coupling



$$\beta = k \sin\theta \pm \nu g$$

$$\beta = k_0 \sqrt{\frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2}}.$$

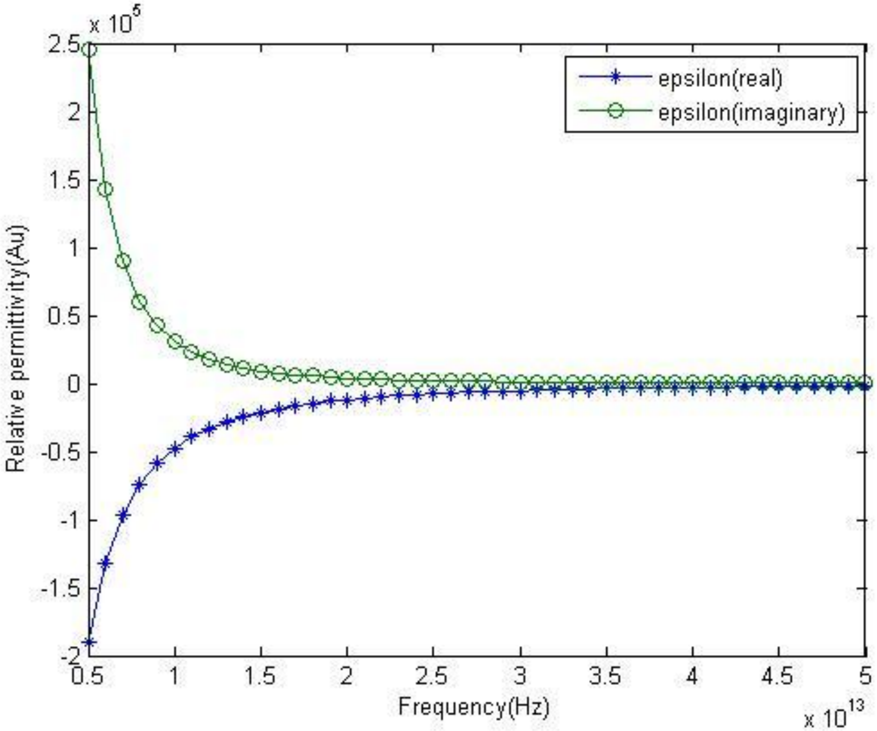
$$g = \frac{2\pi}{a}$$

Why THz? - Applications

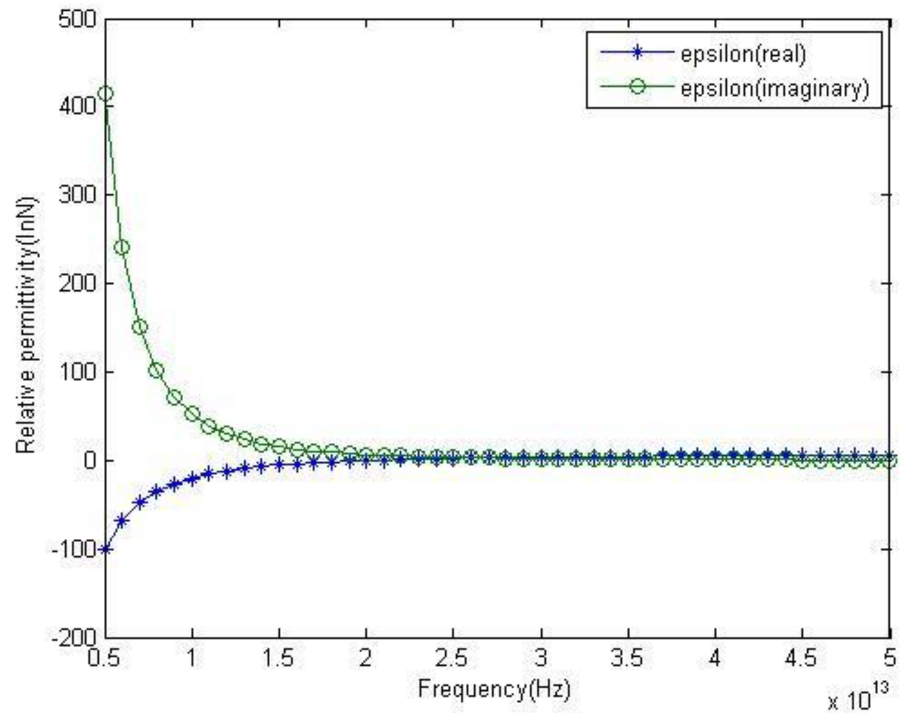
- Imaging
  - Medical diagnostics, skin cancer, dental imaging (non-ionising alternative to x-rays)
- Sensing
  - Molecules have signature spectra in THz. Eg, Explosives, drugs
- Biomedical
  - Biological molecules have signature spectra in THz. Label free detection.
- Semiconductor
  - Materials evaluation, studying semiconductor wafers and ICs for defects. THz technology will receive a boost if it can be developed for use in semiconductor industry

* **Ref:** F. Sizov, A. Rogalski, **THz detectors**, Progress in Quantum Electronics, Volume 34, Issue 5, September 2010, Pages 278-347 (2010)

Why InN?



Au



InN

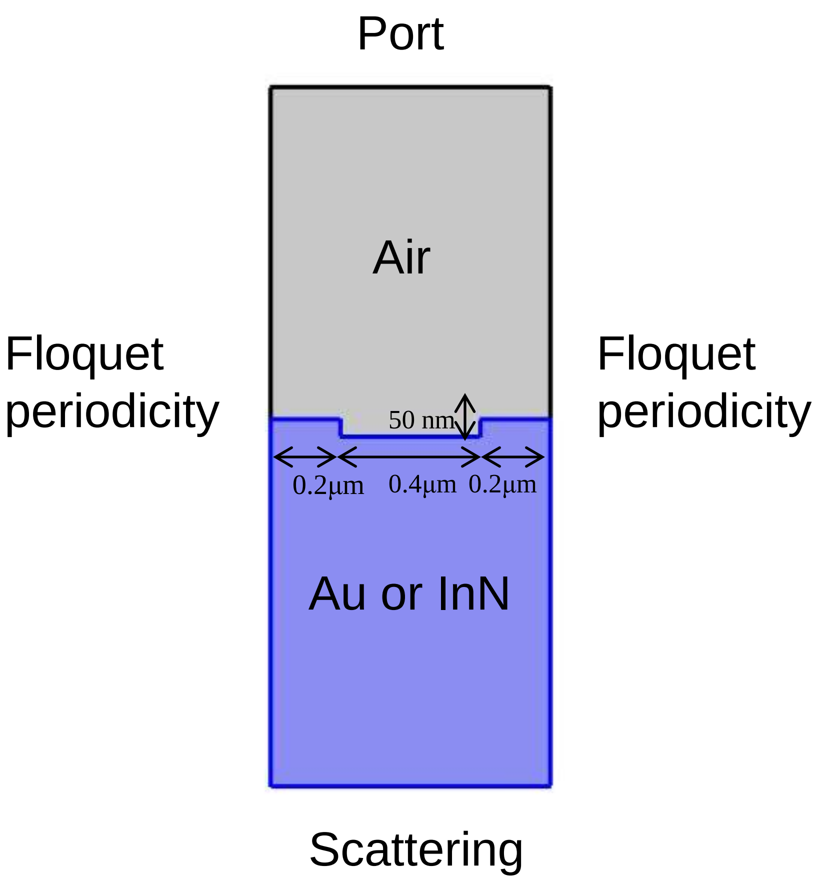
$$\varepsilon(\omega) = \varepsilon(\infty) - \frac{\omega_p^2}{\omega^2 + i\omega\gamma},$$

$$\omega_p^2 = e^2 N / (\varepsilon_0 m^*),$$

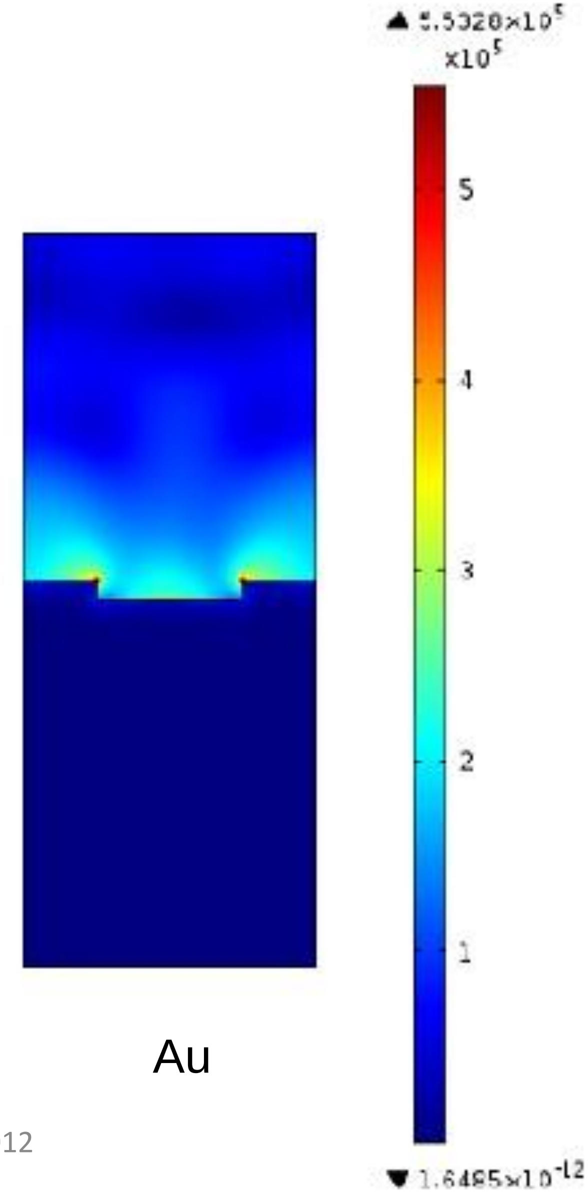
$$\epsilon_r = \epsilon_\infty - \frac{\omega_p^2}{\omega^2} \qquad \epsilon_i = j * \frac{\gamma\omega_p^2}{\omega^3}$$

Material	Plasma Frequency	ε(∞)
Gold (Au)	2.18 x 10^{15}Hz	9.5
Indium Nitride (InN)	52 x 10^{12}Hz	6.7

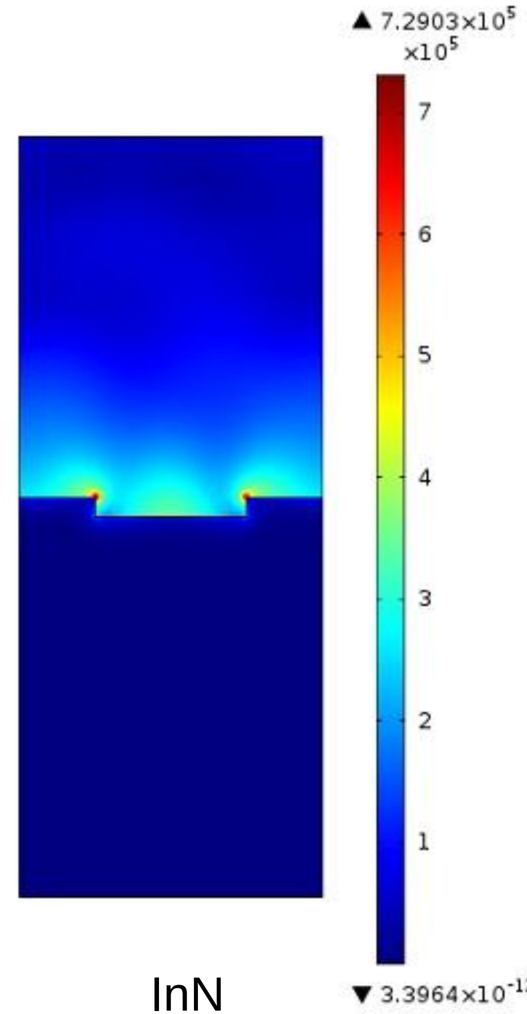
Simulation Results - Structure



Simulation Results – Electric Field

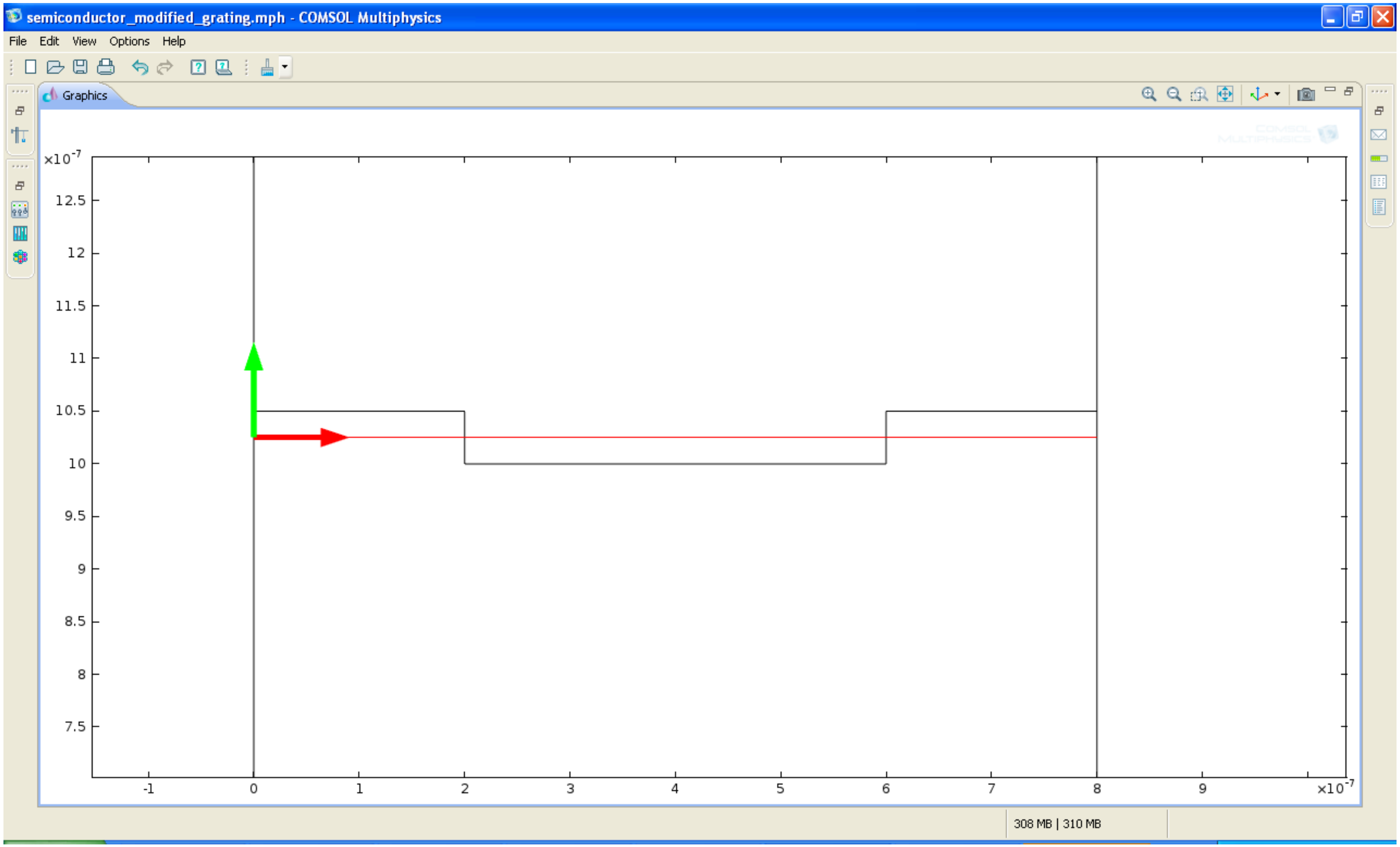


Au

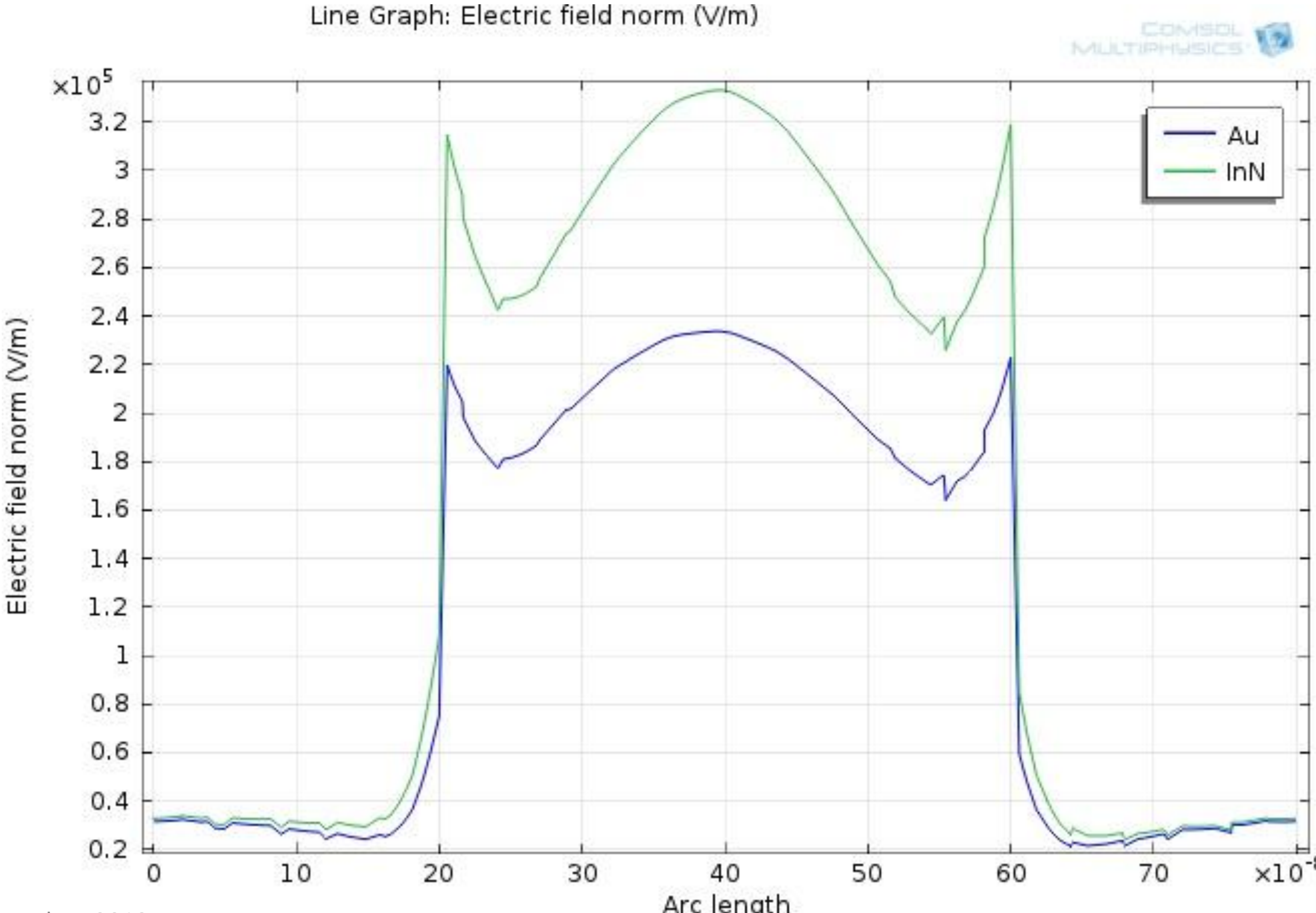


InN

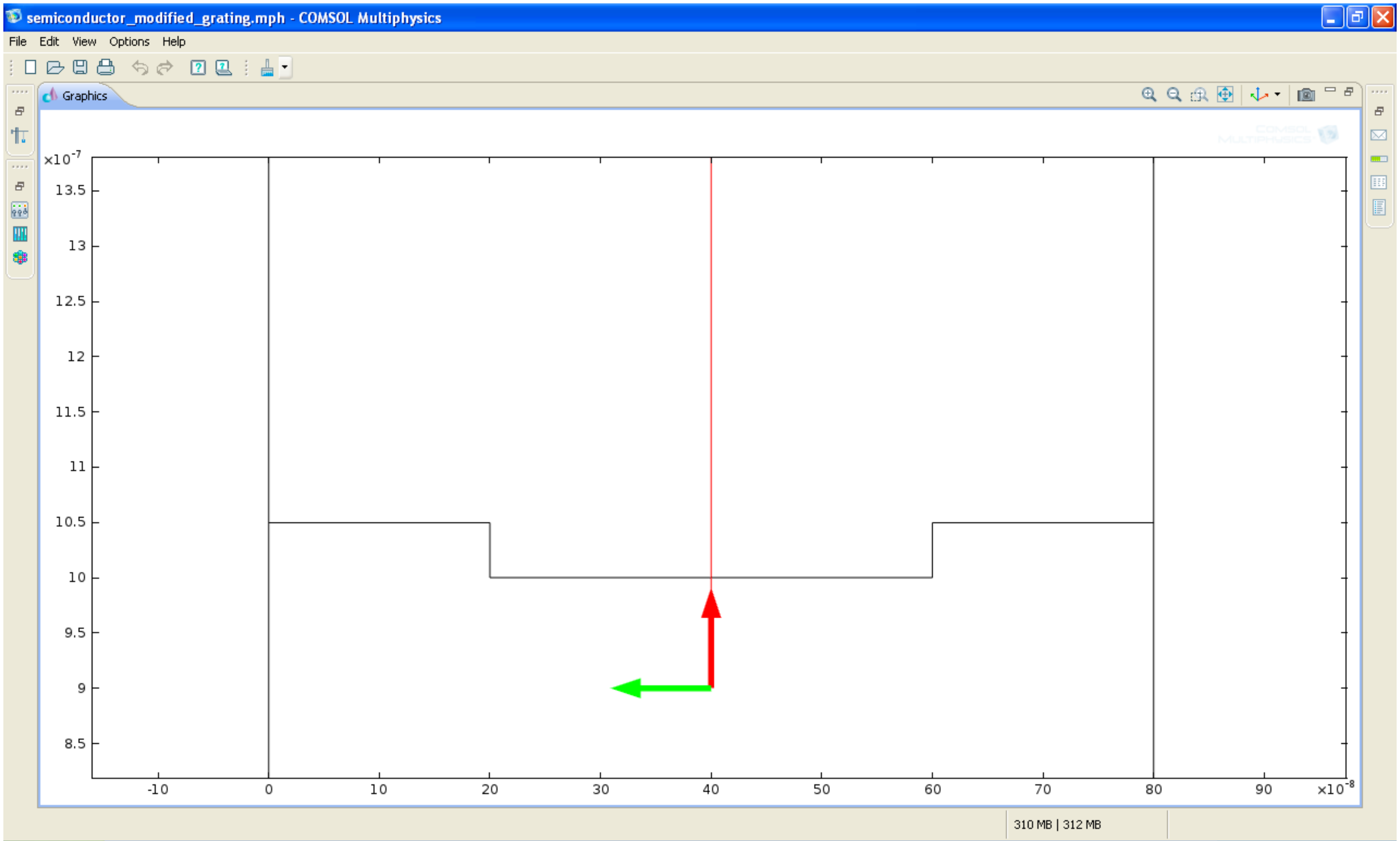
Simulation Results – Horizontal Cutline



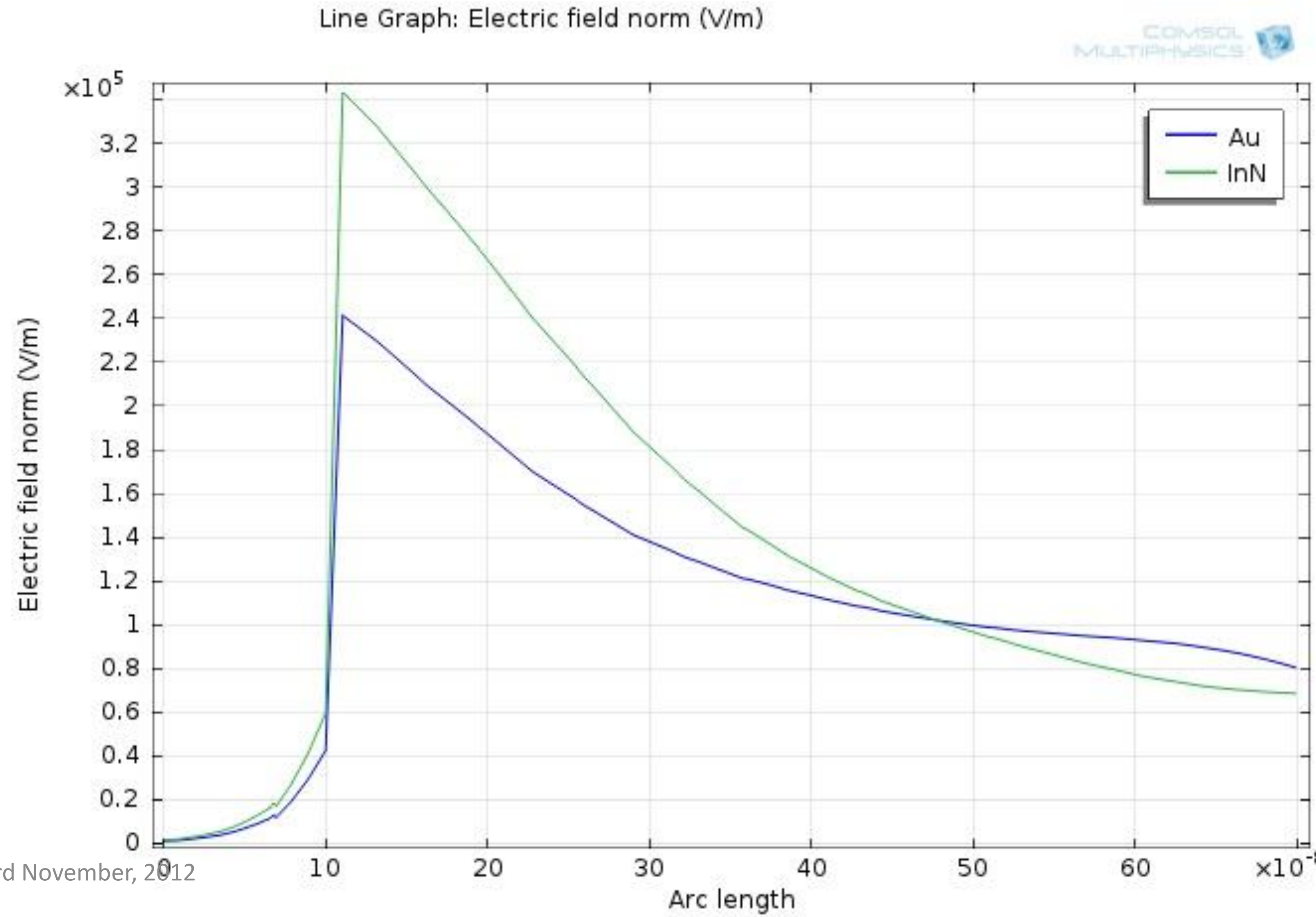
Simulation Results – Horizontal Cutline



Simulation Results – Vertical Cutline



Simulation Results – Vertical Cutline



Conclusions

- InN has values of permittivity that are better suited for plasmonics in the THz regime
- Greater field enhancement (upto 1.4 times) in case of InN as compared to Au
- Tighter confinement of field to interface
- Greater flexibility of ω_p in case of semiconductors