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AN ALGAN/GAN BASED UV PHOTODETECTOR SIMULATION USING COMSOL TO OBTAIN THE FRESNEL COEFFICIENTS

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Outline

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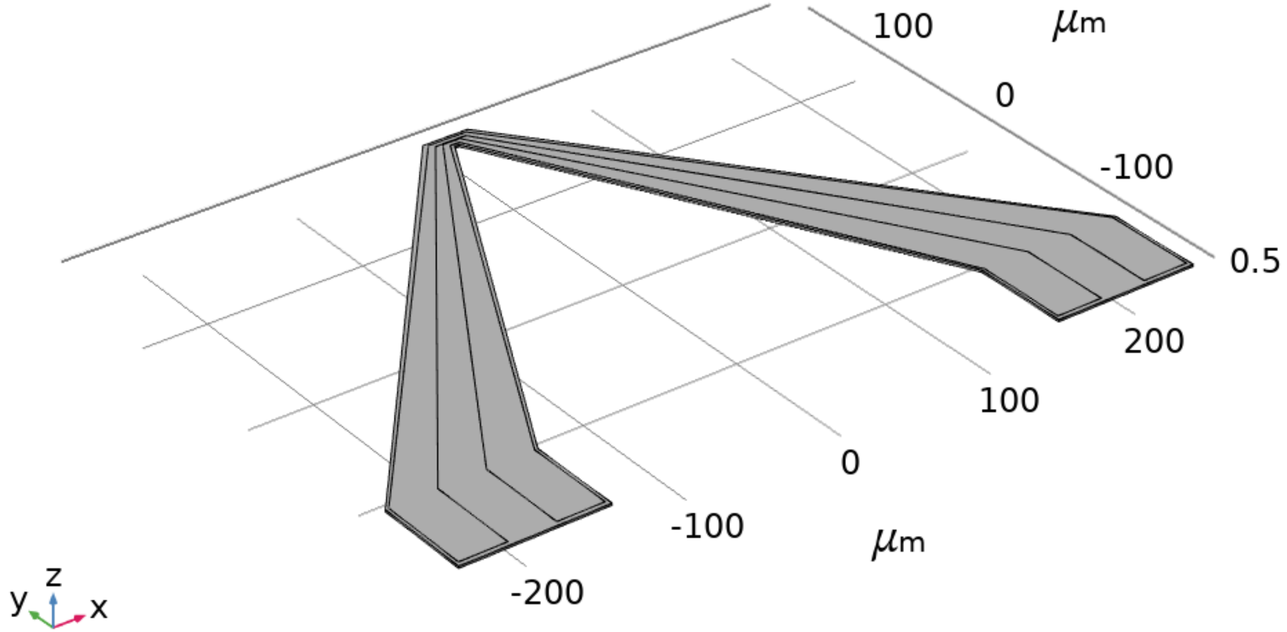
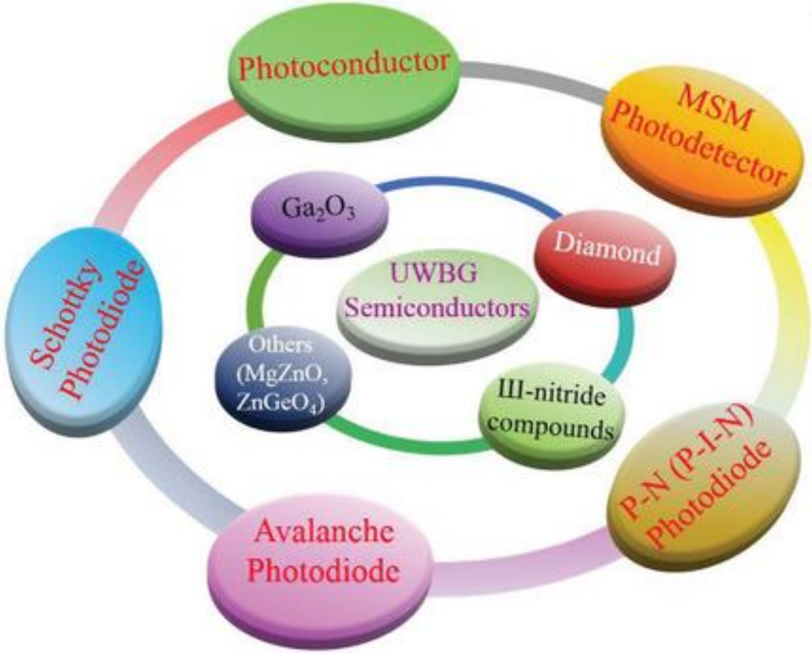


Introduction

- ➢ Cantilever has been modeled to compute the Fresnel coefficients like absorptance, reflectance, and transmittance in the wavelength range of 300 nm to 500 nm
- ➢ Fresnel coefficients are calculated for different thickness of bottom GaN layer
- ➢ Fresnel coefficients are also calculated by varying Al alloy composition in $\mathrm{Al_xGa_{(1-x)}N}$

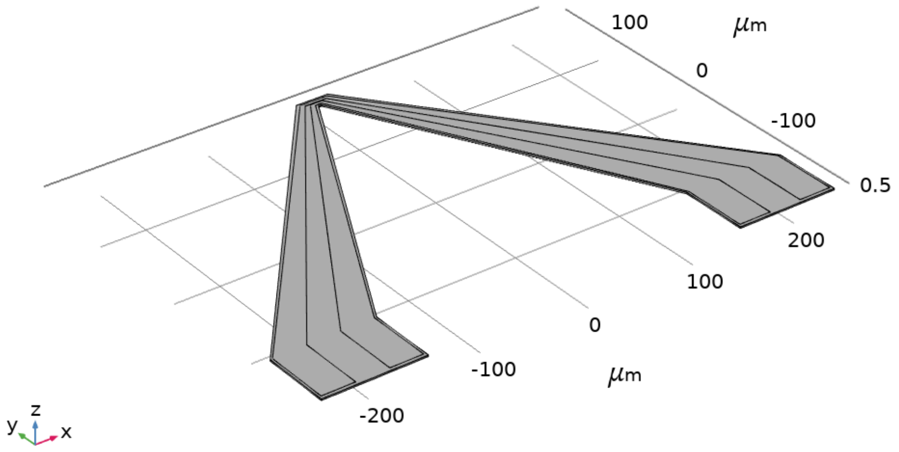


Source: C. Xie *et al.*, "Recent Progress in Solar-Blind Deep-Ultraviolet Photodetectors Based on Inorganic Ultrawide Bandgap Semiconductors," *Adv. Funct. Mater.*, **29**, 1806006 (2019).

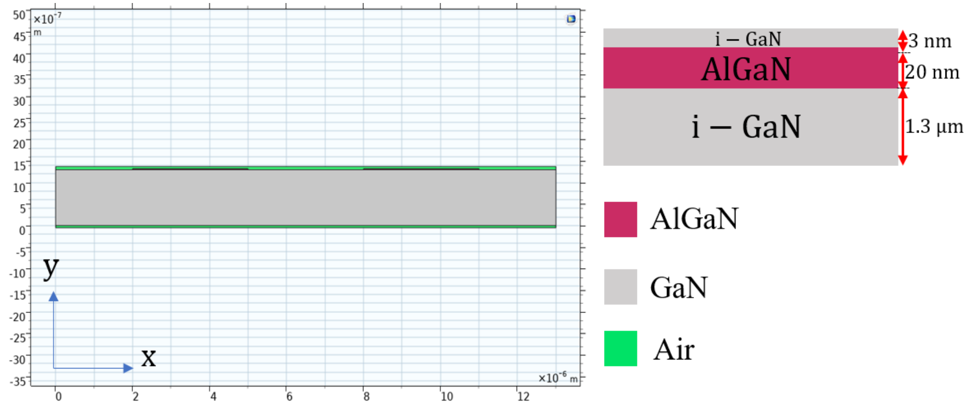
❑ Applications

- ➢ Detect UV irradiation on Earth which can increase due to depletion of ozone layer
- ➢ Short wavelength UV light used for flame detection
- ➢ Solar blind cameras for monitoring electrical power lines
- ➢ Detection of high-temperature flames from rocket motor of a missile observed in intense sun light

Geometry Setup



3D Geometry of $GaN-Al_xGa_{1-x}N-GaN$ ultraviolet photodetector



Longitudinal cross section at the tip region of the cantilever

- Simplified 2D geometry has been used in the finite element model
- Thicknesses of the top GaN, intermediate $Al_xGa_{1-x}N$, and bottom GaN layers are 3 nm, 20 nm, and 1 µm respectively
- The gap between the two adjacent $Al_xGa_{1-x}N$ layers is 3 µm
- An air medium of 50 nm thickness is added throughout the width of the cantilever to consider the surrounding environment of the cantilever

Simulation procedure

- To get the electric filed distribution on the 2D geometry, the governing equation to be solved can be written as

$$\nabla \times (\nabla \times E) - k_0^2 \epsilon_r E = 0, \qquad (1)$$

where $k_0 = \frac{2\pi}{\lambda}$ is the free space propagation constant and ϵ_r is the relative permittivity of the material.

- For the given 2D geometry, the complex electric field E which is distributed along x and z axis can be written as

$$E(x, z) = \tilde{E}(x) e^{-jk_z z}, \qquad (2)$$

where $\tilde{E}(x)$ represents the complex amplitude of the electric field distributed along the x axis and k_z is the out-of-plane wave vector component which is along the z direction.

- The relative permittivity of the material can be written as

$$\epsilon_r = (n - jk)^2, \qquad (3)$$

where n and k are the respective real and imaginary parts of the refractive index of the material.

- In this simulation, the electrical conductivity (σ) and relative permeability $(\mu_r)$of the material are assumed to be 0 and 1 respectively.

Simulation procedure cont.…

- For the given 2D geometry the reflection (R) and transmission (T) coefficients are obtained by calculating the s-parameters.
- The reflection coefficient (R) is calculated as

$$R = |s_{11}|^2. \tag{4}$$

- The transmission coefficient (T) is calculated as

$$T = |s_{21}|^2. \tag{5}$$

- The equation to calculate s_{11} can be written as

$$s_{11} = \frac{\iint\left((E_c - E_1)\cdot E_1^*\right)\, dA_1}{\iint E_1\cdot E_1^*\ dA_1}, \tag{6}$$

  where E_c is the computed electric field and E_1 is the electric field pattern on port 1.
- The computed electric field can be written as

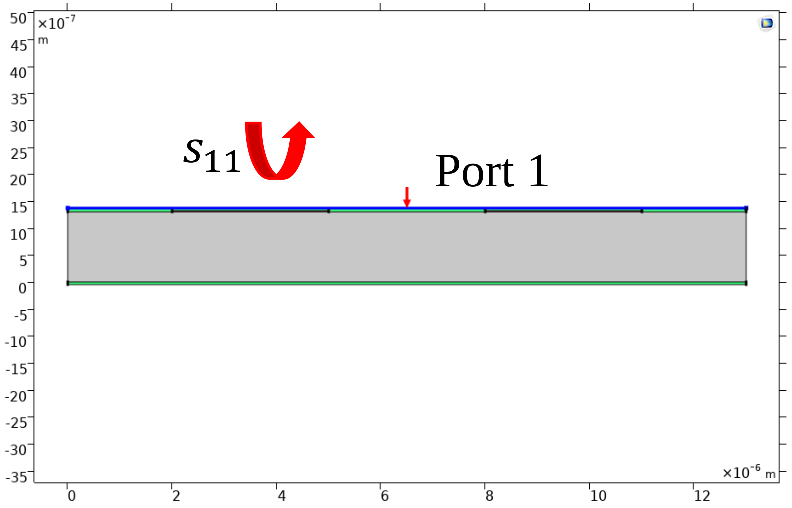
$$E_c = \sum_{i=1} s_{i1} E_i. \tag{7}$$

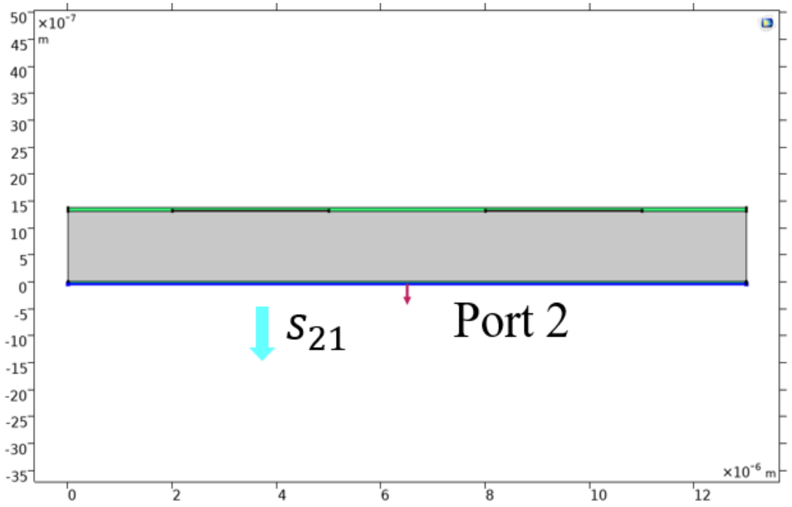
- The equation to calculate s_{21} can be written as

$$s_{21} = \frac{\iint(E_c\cdot E_2^*)\, dA_2}{\iint E_2\cdot E_2^*\ dA_2}, \tag{8}$$

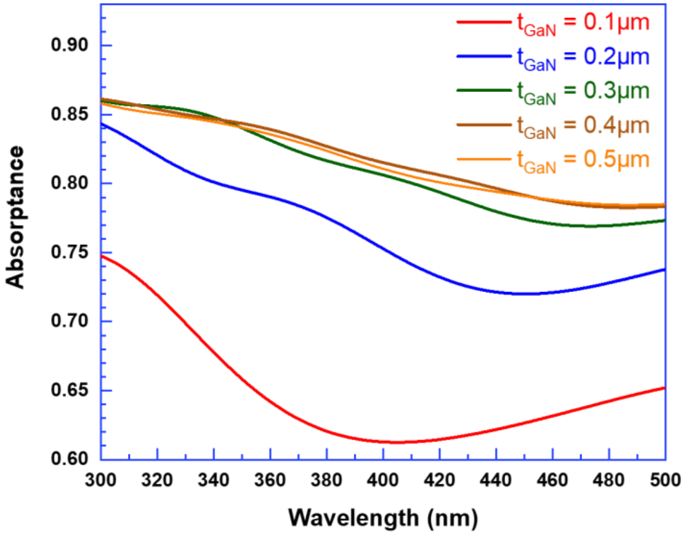
  where E_2 is the electric field pattern on port 2.
- The absorption coefficient (A) is calculated as

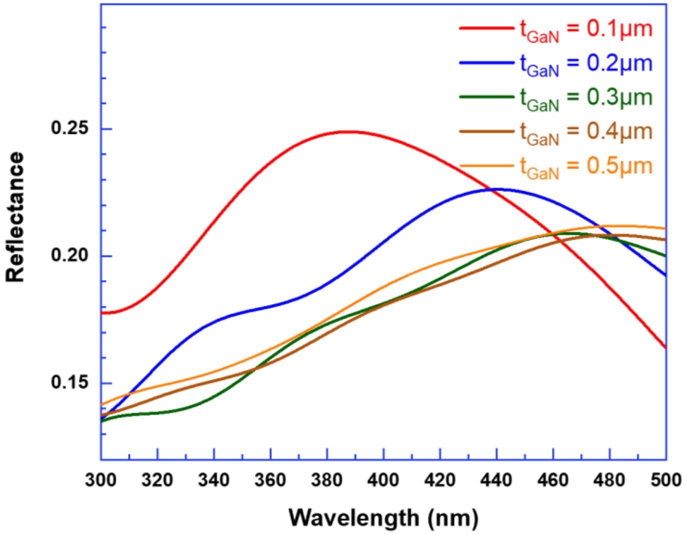
$$A = 1 - R - T \tag{9}$$

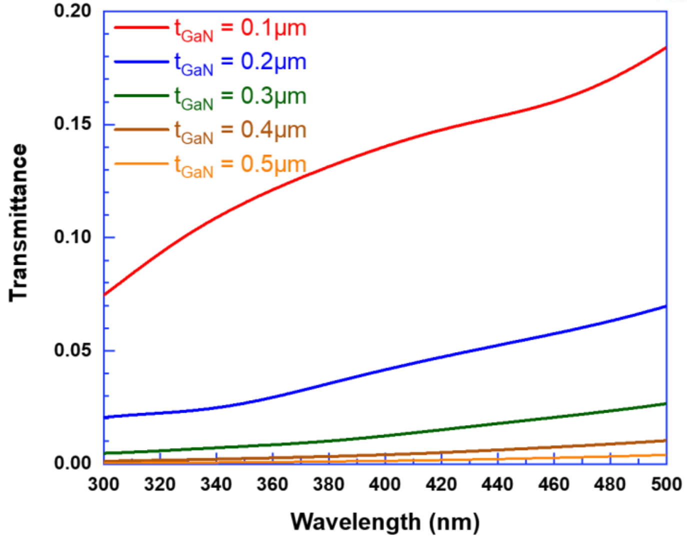


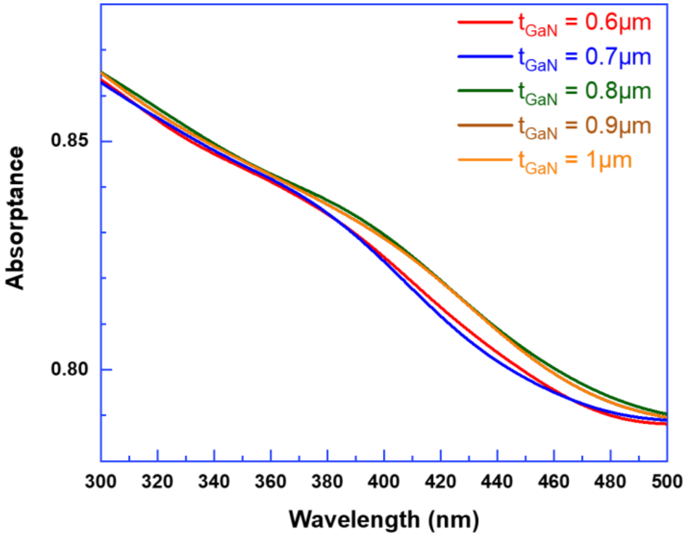


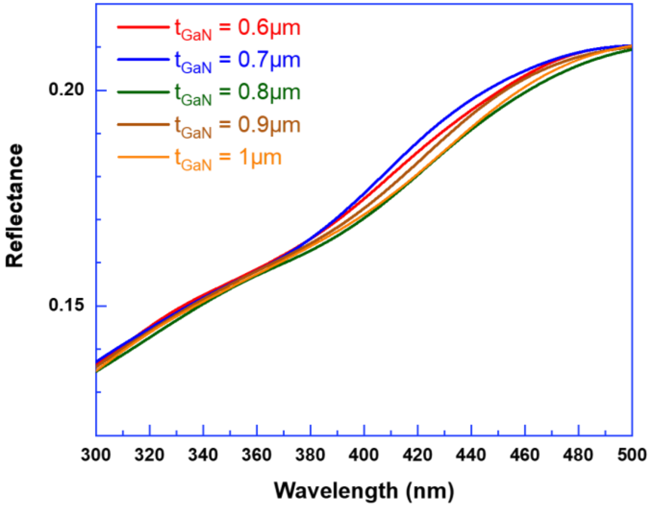
Fresnel coefficients for different thickness of GaN

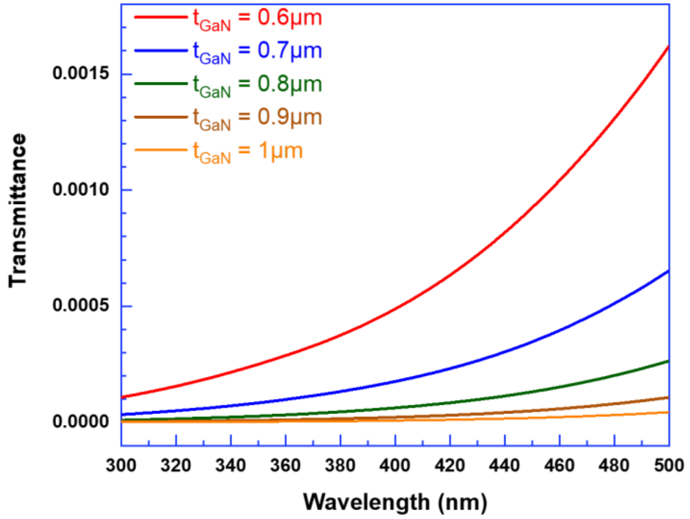




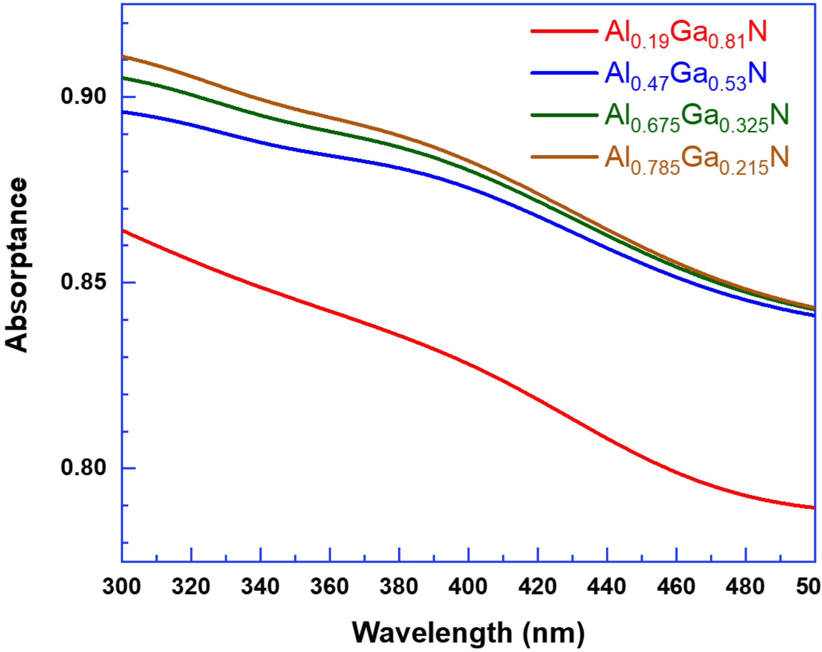


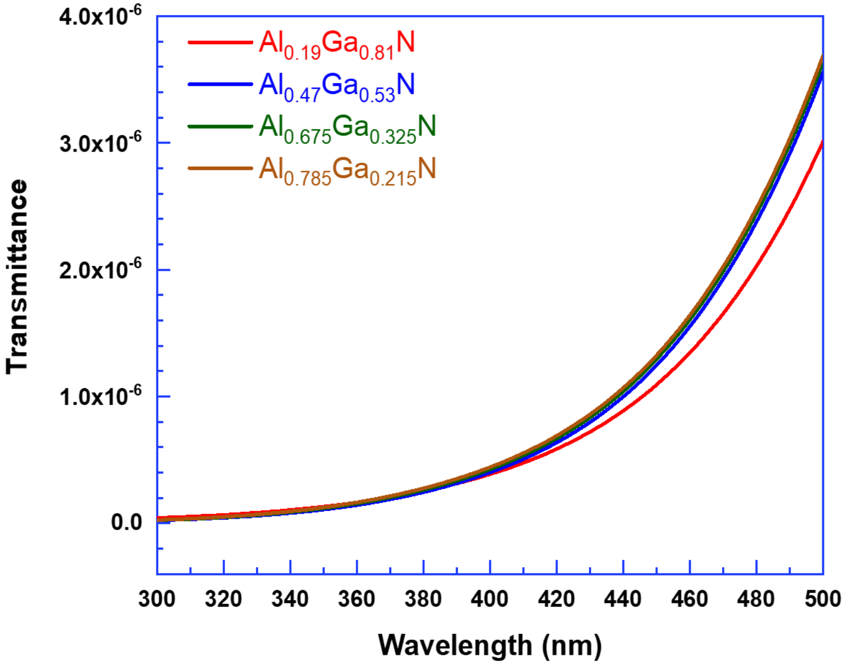


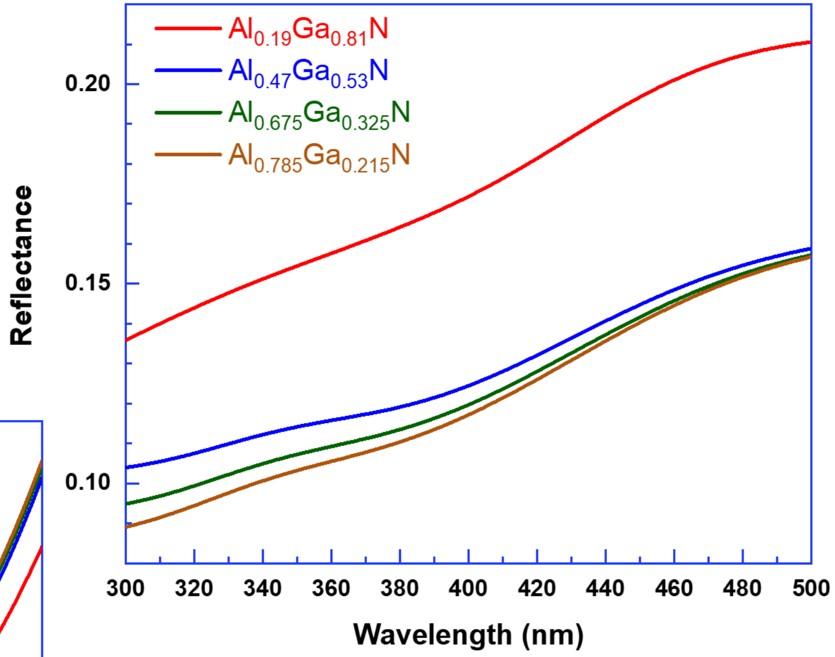




Fresnel coefficients for different Al alloy composition in $Al_xGa_{(1-x)}N$







Conclusion

- For bottom layer GaN thicknesses > 0.5 μm, the absorptance and reflectance profiles remains basically unchanged

- For thicknesses <0.5 μm, the absorptance increases monotonically with the thickness of the bottom GaN layer

- From the simulations it has been observed that for thicknesses ≥1 μm, the transmittance of UV light through the cantilever is zero

- With the thickness of the bottom GaN layer being fixed at 1.3 μm, the effect of Al alloy composition in $Al_xGa_{(1-x)}N$ on the Fresnel coefficients has also been studied

- From the simulation results, it can be concluded that at any given wavelength as the Al% increases, the absorptance and reflectance of the cantilever monotonically increases and decreases, respectively

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