Enhancement in Terahertz Emission using AuGe Nanopatterns

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INTRODUCTION

Terahertz radiation (10^{12} Hz) lies in between the microwave frequencies and light frequencies. Terahertz (THz) technology finds itself just beyond the limits of electronics and just below the threshold of optical fiber, because of which it combines best of both the worlds. Increasing the emission power of the Terahertz antenna has been one of the most sought after issues in the world of terahertz technology. The field of Nanoplasmonics is of particular interest where there is light-matter interaction at nanometer scales. Exploiting the nature of light at nanometer scales, Surface Plasmon Polaritons (SPP) can be excited to cause localized electric field enhancement. We demonstrate an attempt to increase the THz antenna emission power by a factor of four by incorporating nano-patterns in the THz.

The Terahertz Photo-Conductive Antenna

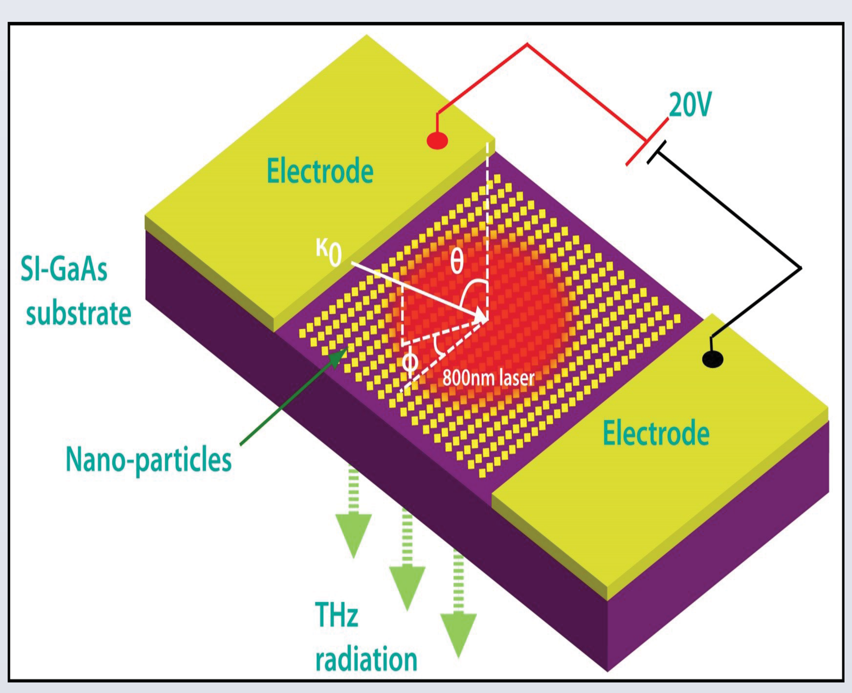

Figure 1: THz photoconductive antenna. A 800nm pulsed laser is focused in between the electrodes on the nano-patterns. A 20V dc bias is applied across the electrodes.

- The photo-carriers generated by the laser light get accelerated towards the biased electrodes and emit radiation in the terahertz frequency.

Surface Plasmon Polaritons

- Surface Plasmon Polaritons (SPPs) are electromagnetic excitations propagating at the metal-dielectric interface confined to a perpendicular direction.
- Dispersion relation to excite SPP :

$$\kappa_{SPP} = \kappa_0 \sqrt{\frac{\varepsilon_a \varepsilon_b}{\varepsilon_a + \varepsilon_b}}$$

- Since for normal incidence of light $\kappa_{parallel}$ is 0, the grating vector *G* alone must satisfy the SPP excitation momentum

$$\kappa_0 \sqrt{\frac{\varepsilon_a \varepsilon_b}{\varepsilon_a + \varepsilon_b}} = \frac{2\pi}{\Lambda}$$

FABRICATION OF THz PCA

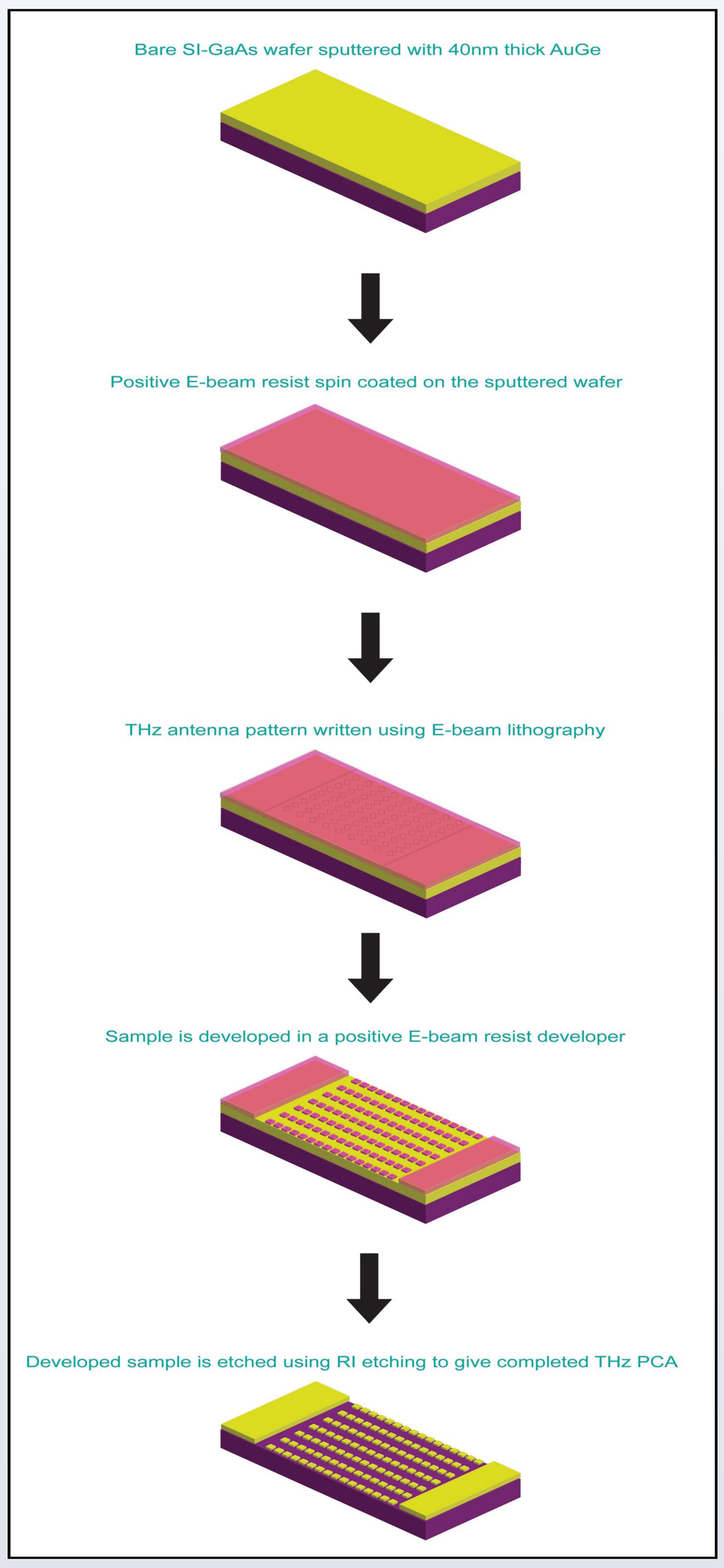

Figure 2: Fabrication process of THz PCA

- The fabrication of the THz PCA is not accomplished in one go, the process is optimized to obtain the feature size closest possible to the expected

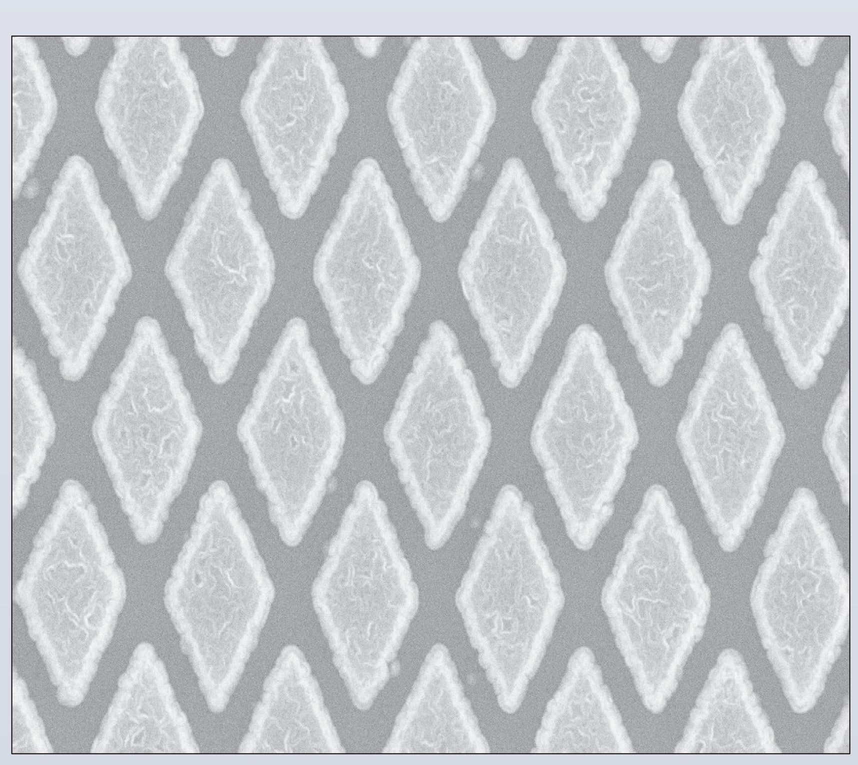

Figure 3: SEM image of the nanoparticles

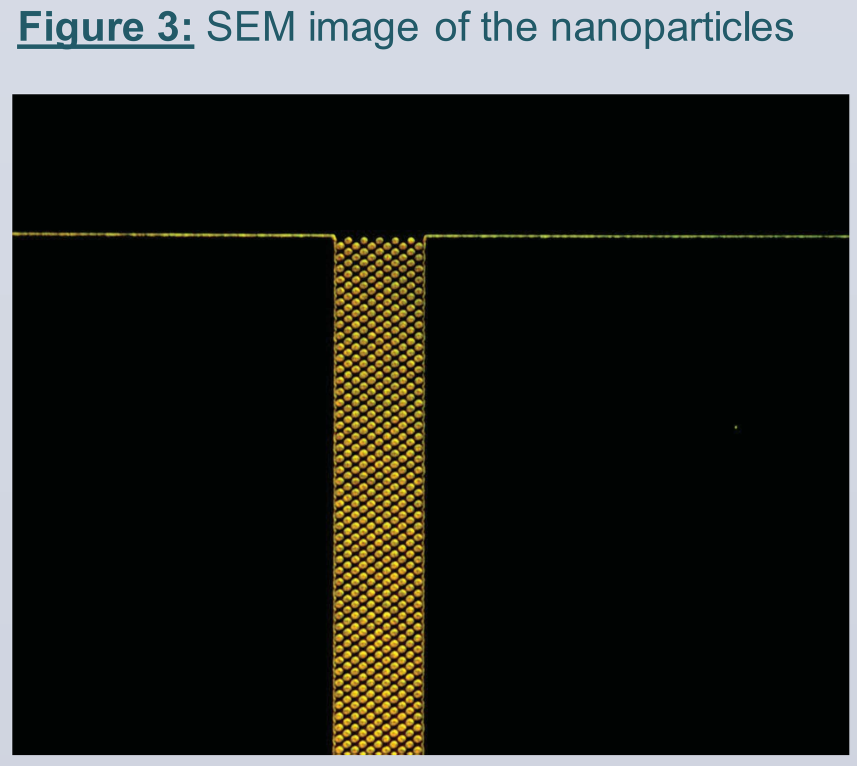

Figure 4: Dark field image of the THz PCA antenna under a microscope

COMSOL SIMULATION

- 'Electromagnetic Waves, Frequency Domain' interface in the Wave Optics module is used
- A plane wave incident at normal incidence on a single periodic AuGe nano-pattern and GaAs surface is simulated.
- The computation for the electric field in all the domains revolves around the wave equation :

$$\nabla \times \mu_r^{-1}(\nabla \times E) - \kappa_0^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)E = 0$$

Where *E* is the electric field, ω is the angular frequency, ε_r is the relative permittivity, μ_r is the relative permeability and σ is the electrical conductivity.

- The polarized electric field vector at the plane of incidence is

$$E_0 = E_0 \exp(-i(\kappa_x x + \kappa_y y))$$

Also,

$$\kappa_p = (\kappa_x, \kappa_y, \kappa_{pz})$$
$$= \kappa_p(\cos\phi_p \sin\theta_p, \sin\phi_p \sin\theta_p, -\cos\theta_p)$$

Where *p* = *a* (air), *b* (substrate); θ and ϕ are polar and azimuthal angles of incidence and κ is the wave vector in that medium

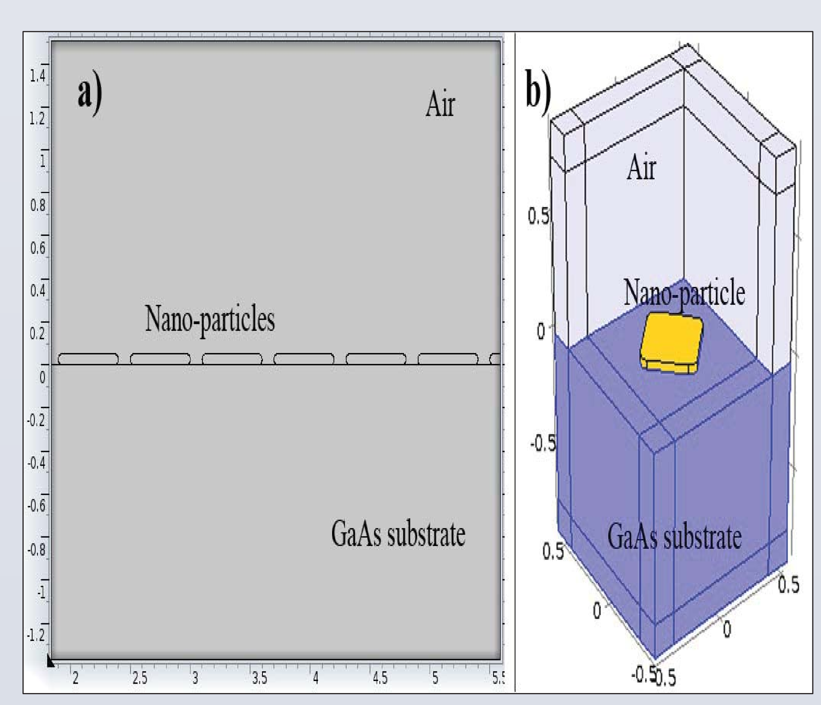

Figure 5: **(a)** 2D Simulation CAD **(b)** cut-out of 3D simulation CAD. A single nano-pattern is 500nm diagonally and is separated by 100nm from adjacent nano-patterns

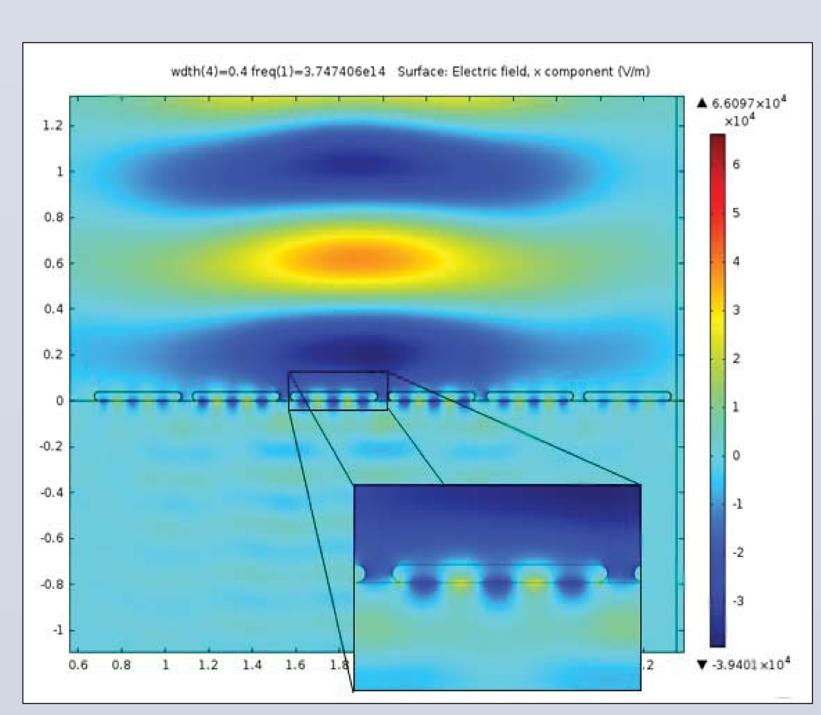

Figure 6: 2D simulation results. Enhancement in the electric field beneath the nano-pattern is observed as an indication of excitation of SPP for a height of 40nm of the nano-patterns

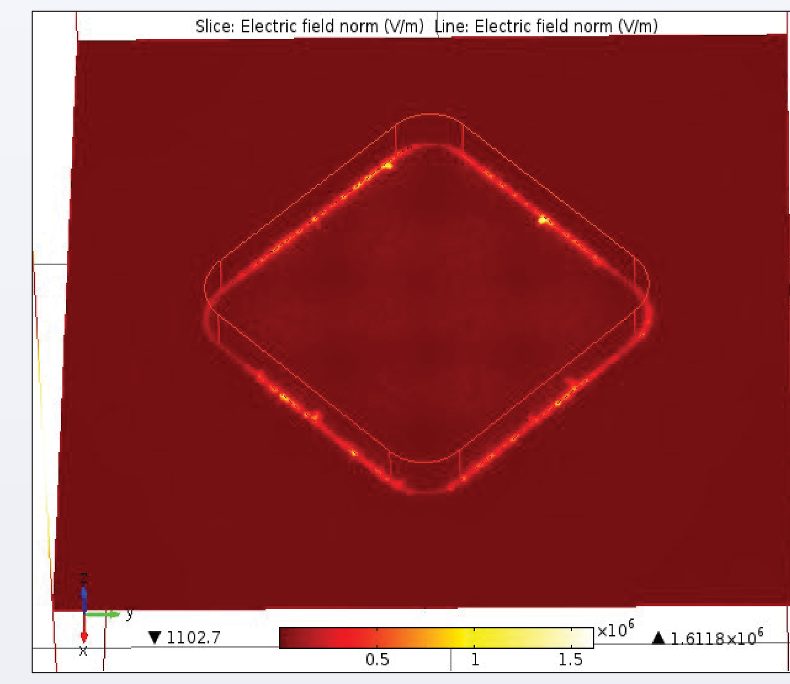

Figure 7: 3D simulation results show the field enhancement at the nano-pattern-GaAs interface on the edges of the nano-pattern

EXPERIMENTAL RESULTS

- Approximately four-fold increase in the THz emission power was observed without a significant change in the spectrum.

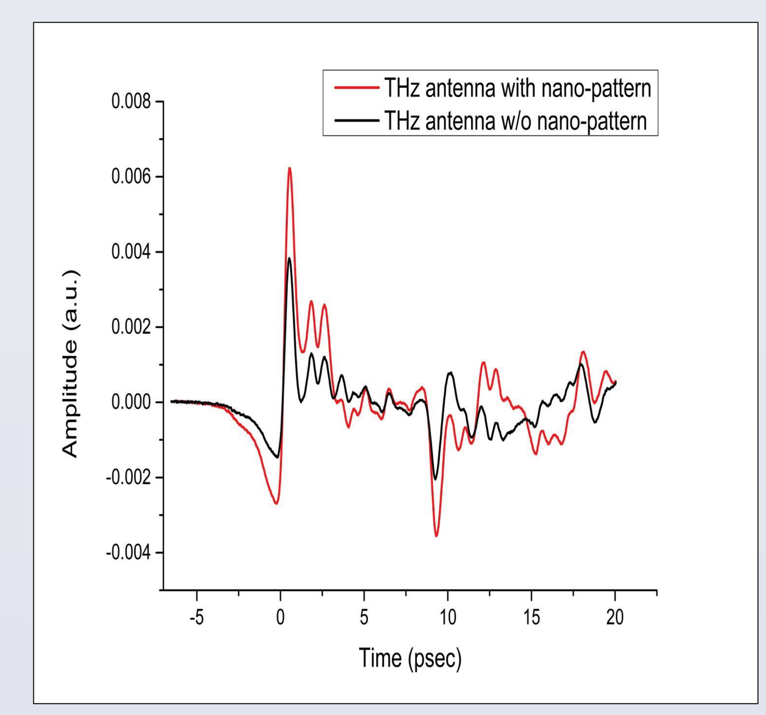

Figure 8: Time domain signals of the THz antenna with and without the nano-patterns. Approximately a two-fold increase in the amplitude is seen.

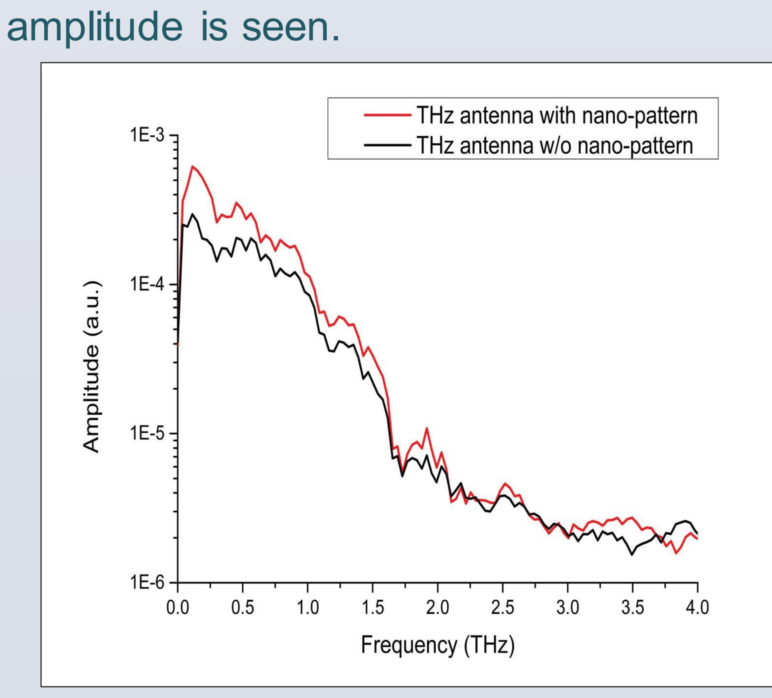

Figure 9: Frequency domain signals of the THz antenna with and without the nano-patterns.

CONCLUSION

A four-fold increase in the THz emission power was achieved by incorporating AuGe nano-patterns suitable for excitation of surface plasmon polaritons. Using COMSOL's Wave Optics module, an optimized height of 40nm was found to give the strongest excitation of SPPs.

REFERENCES

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