Modeling On-Chip Nanoscale Waveguide based Trapping Device for Quantum Photonics using COMSOL Multiphysics®

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INTRODUCTION: Single photon source/ emitter (SPE) is a fundamental building block to the development of quantum communication technology. However, the realization of SPE is quite challenging as the separate placement of emitter (Q dot, nano diamond, etc.) after its fabrication to the associated enhancement device (nanoantenna, nanocavity, etc.) involves time-intensive manual manipulation of nanoparticles which is not a scalable approach [1]. In this effort, we seek to address this issue by incorporating the liquid surroundings to a waveguide-based hybrid metal-insulator-metal (MIM) structure and inducing ETP flow (temperature and AC bias induced fluidic motion) [2] to trap suspended emitters and enhance emissivity simultaneously.

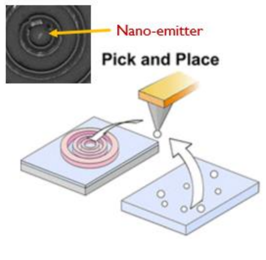

Figure 1. Manual method of emitter placement [1]

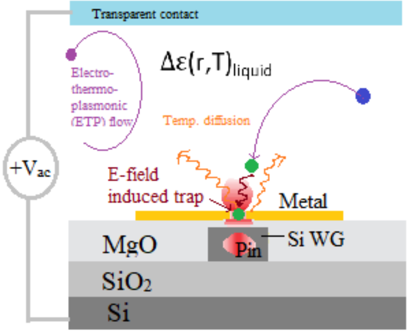

Figure 2. Schematic of the nanoscale trap and enhance device operation

COMPUTATIONAL METHODS: The primary focus of this work is to study the trapping ability and associated thermal feasibility of the proposed structure. The system's intended operating mechanism is shown in **Figure 2**. The optical force that acts on a suspended nano-particle is induced by field gradient [3] and can be calculated from Maxwell stress tensors. To exclude convectional perturbation, temperature rise is calculated assuming overall stationary medium.

$$\vec{F} = \int_V \vec{f}\, d\tau \;\rightarrow \vec{f} = \rho\, \vec{E} + \vec{J} \times \vec{B}$$

$$\vec{f} = \varepsilon_0 \vec{E}\, \vec{\nabla} \bullet \vec{E} + \frac{1}{\mu_0}\left(\vec{\nabla} \times \vec{B} - \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \right) \times \vec{B}$$

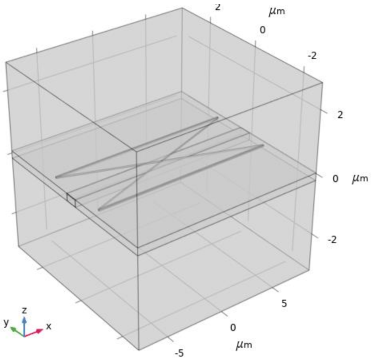

Figure 3. Schematic of the structure

RESULTS:

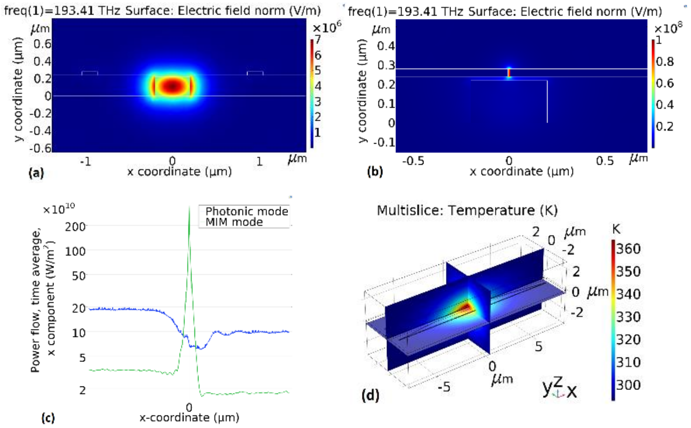

Figure 3. (a) Injected photonic mode (y pol.), (b) hybrid MIM mode, (c) Comparison of power flow between two modes, (d) Temperature profile (Bow tip gap= 10nm , P_{in}= 10mW).

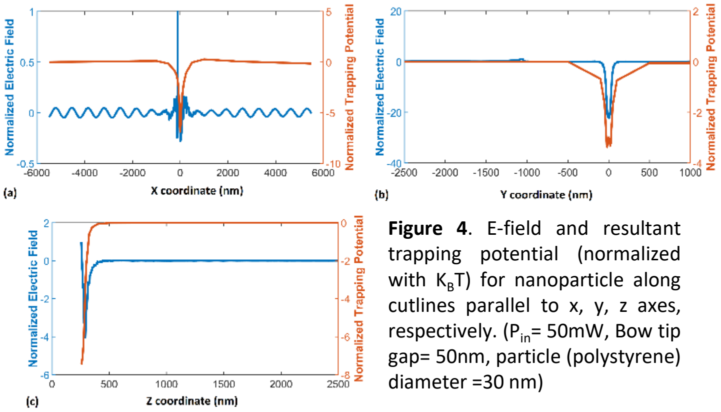

Figure 4. E-field and resultant trapping potential (normalized with K_BT) for nanoparticle along cutlines parallel to x, y, z axes, respectively. (P_{in}= 50mW, Bow tip gap= 50nm, particle (polystyrene) diameter =30 nm)

CONCLUSIONS:

- Effective adiabatic conversion of injected photonic mode to MIM mode is achieved with the geometry [see **Figure 1 (a-b)**].
- The confined enhancement of field creates sharp field gradient leading to stronger force (∝ E^2).
- Capability to trap nano particles with support of ETP flow verified [see **Figure 4**].
- Power flow transition between the distinguished modes indicative to effective emitter-waveguide coupling [see **Figure 1(c)**].

Future tasks:

- Efficient power coupling with lower input power
- Investigation of alternative heat compatible material
- Structural modification to accommodate additional heatsinks if required.

REFERENCES:

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Acknowledgement: