Localizing Light and Temperature in Deep Sub-Wavelength Volumes – Generating and Controlling Nanoscale Temperature Gradients by Leveraging on Plasmonic Nanocones

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1. Introduction

Localized and efficient heating can arise in plasmonic nanostructures illuminated by light [1,2]. In particular, for nanostructures under continuous wave (CW) illumination, even though the photoinduced generated heat can be strongly localized, the whole nanostructure typically acquires a uniform temperature [1]. This is because the thermal conductivity of plasmonic materials is in general much larger than the surrounding dielectric environment facilitating the diffusive spread of heat along the nanostructure and making it extremely challenging to realize local temperature spots and strong nanoscale temperature gradients. The ability to produce strong and sustained temperature gradients at nanoscale dimensions can be of technological interest for example in optofluidics and plasmonic optical tweezers [3].

In this work, we tackled this challenge by envisioning a way to realize localized temperature spots and thus strong temperature gradients within a single plasmonic metallic nanostructure with sub-wavelength dimensions even under CW illumination [4]. To this end, we leverage on the well-known capability of nanocone geometries on concentrating light and electromagnetic (EM) energy at their apex. By choosing resonant illumination conditions, which lead to EM hotspots, we fully exploit strong localized heating aiming at producing large apex-base temperature gradients.

2. Results and Discussion

To achieve our aim, we have developed a three-dimensional (3D) Finite Element Method model that was employed to investigate the photothermal response of a free-standing sub-wavelength gold nanocone under linearly polarized plane wave illumination [4]. The model was validated with respect to an illuminated gold nanosphere [1].

Our numerical results show that the 3D temperature distribution is characterized by a temperature maximum localized at the apex, establishing a strong temperature gradient along the nanocone [4]. The temperature distribution is shown to depend on the cone dimensions, shape, different surrounding environments, incoming wavelength and light polarization. The possibility of tuning the temperature gradient by tilting the angle of incidence of the incident plane wave is also explored.

3. Conclusions

This work demonstrated the possibility to produce a localized temperature spot at the apex of a plasmonic nanocone under CW illumination inducing a strong temperature gradient between the apex and base. We highlight that this effect might seem counterintuitive as it arises at sub-wavelength dimensions and under CW illumination which would induce the expectation of a uniform temperature. We demonstrated strong nanoscale temperature gradients and the influence of several geometrical and material parameters on the temperature distribution with a possibility for remotely tuning the generated temperature gradients.

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