PhD Thesis Defense JON DONNER 'Thermo-Plasmonics: Controlling and Probing Temperature on the Nanometer Scale'

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Plasmon Nano-optics

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In the last decades, optics has become central in many applications in modern society. Nano-optics, which studies the behavior of light at the nanoscale, holds promise to do the same. However, when using traditional optical elements such as mirrors and lenses to control light propagation, there is a fundamental limit on the localization of the field which could a priori impinge on the ability to use optics at the nanometer scale. One way to improve the confinement of electromagnetic waves is to couple light with materials that have high dielectric permittivity. In this context, a particular interest has been devoted to metallic nanostructures made of gold, silver or aluminum. In this case the interaction can lead to a coherent collective electron oscillation and is known as a Surface Plasmon (SP). Such enhanced interaction results in both strong absorption and scattering of light.

An inherent effect in such systems is the unavoidable damping of the SP. This causes internal Joule dissipation, which results in heat generation. Although this phenomenon is considered to be a drawback in many plasmonic applications, recent studies have shown the promise of nanoscale heat generation for both physical and biological application. This strategy is at the basis of a rapidly growing field called Thermo-Plasmonics. Controlling, exploiting and monitoring plasmonic heating is the topic of my PhD.

In the first chapter of the thesis, the Joule effect induced in plasmonic nanoparticles is described.
Thereafter, this concept is used to develop both physical and biological applications which rely on the ability to control nanoscale temperature in order to perturb the surrounding environment.
A physical application consisting of a fast tunable Photothermal Lens based on plasmonic heating is described in the third chapter. To this end, we develop a model to predict the lens behavior. Next, experimental characterization of a fabricated thermal lens is performed. Finally, we show that such a system could be used for fast and accurate focal plane tunability as well as for adaptive optics applications.

In the fourth chapter I describe another thermo-plasmonic based application which relies on the use of nanoscale heat generation to modify and even control the fluid flow in a micro-fluidic system. To do so, we numerically calculate the fluid convection that is induced by plasmonic heating at the micro and nanoscale. Next, an experimental implementation of a microfluidic pump based on plasmonic heating is presented.

The applications mentioned above rely on the efficient opto-thermal conversion in gold nano particles to generate local heat sources. One advantage of gold is that it is nontoxic, allowing the application of thermo-plasmonics to bio systems. This is a pertinent line of investigation, because temperature is a basic parameter which influences many cellular biological processes. Nanotechnology is not only providing new ways to generate point like heat sources but also to accurately monitor the resulting temperature maps.

Within this context, we developed a tool that permits the measurement of temperature at the nanoscale in biological systems. This is done by monitoring the fluorescence polarization anisotropy (FPA) of a fluorescent molecule. Specifically, in the fifth chapter I present the use of Green Fluorescent Protein (GFP) as a thermal nanoprobe suited for in vitro cellular temperature mapping. This is performed by monitoring the FPA of the GFP. We apply this method to measure the temperature generated by photothermal heating of gold nanorods inside and outside cells. Consequently, we extend this technique and perform the first in vivo intracellular thermal imaging. In the sixth chapter we demonstrate this method with GFP expressing neurons of a worm. In both cases we show that the method enables diffraction limited spatial resolution, good temperature accuracy and fast readout together with high bio-compatibility.

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