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Local heating with titanium nitride nanoparticles

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Abstract: We investigate the feasibility of titanium nitride (TiN) nanoparticles as local heat sources in the near infrared region, focusing on biological window. Experiments and simulations provide promising results for TiN, which is known to be bio-compatible.

OCIS codes: (250.5403) Plasmonics; (190.4870) Photothermal effects; (160.1435) Biomaterials

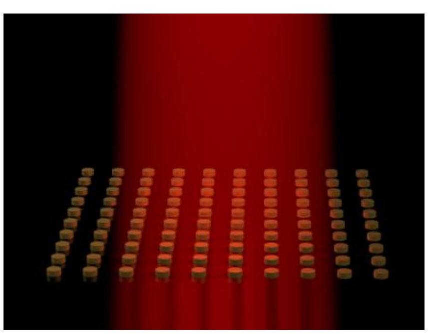
Introduction

Local heating with sub-wavelength particles has been intensely studied in the frame of various applications such as photothermal therapy and solar energy harvesting [1, 2]. Not surprisingly, gold (Au) and silver (Ag) drew attention due to their plasmonic resonances in the visible region of electromagnetic spectrum [3]. However, for a variety of applications that require resonances in the near infrared (NIR) window, such as in vivo bio-imaging, serious efforts are needed in order to engineer particle geometry of noble metals and bring the resonance wavelengths into the region of interest [4].

Recently, we have shown that TiN nanoparticles provide high field enhancement in near field and strong absorption within the particle [5,6]. Local heating performance of a nanoparticle is directly related to absorption efficiency at the wavelength of interest. Hence, promising results obtained for absorption efficiency of TiN nanoparticles in NIR region lead us to investigate the local heating capabilities of TiN nanostructures. In this study, we examine the heat generation from TiN particles numerically and experimentally. Finite element method (FEM) based software (Comsol, Multiphysics) is employed so as to couple electromagnetic and heat transfer simulations. While illuminating with pulsed laser at various wavelengths, nanoparticle arrays fabricated by electron beam lithography (EBL) are examined with FLIR A320 infrared camera. When illuminated at resonance wavelength, particles absorb electromagnetic energy and act as nanometer-scale heat sources. Change in the temperature of the substrate and nanoparticle arrays are observed by the use of a thermal camera with spatial resolution of 25 µm.

Figure 1 (a) shows an illustration of nanodisk arrays used in this work. TiN and Au nanoparticles with identical geometric parameters are fabricated with EBL and examined both numerically and experimentally. Transmittance data simulated for these nanoparticles are given in Figure 1 (b), in which a strong but very narrow localized surface plasmon resonance (LSPR) dip can be observed for Au particles. Although the amplitude of plasmonic resonance is very strong for Au particles, spectral position and narrow width of resonance are drawbacks for biological applications. On the other hand, TiN LSPR resonance position is very well suited for bio-imaging. In addition, LSPR resonance in TiN nanoparticle is very broad, which is an advantage for bio-applications.

a



b

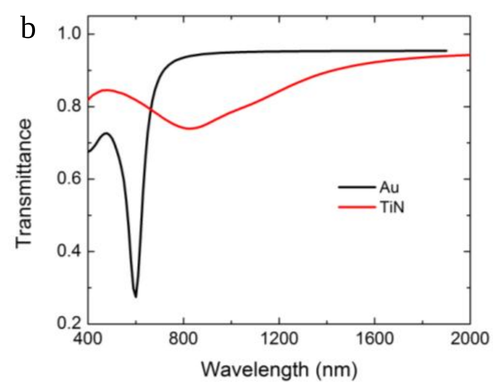


Fig. 1. (a) Illustration of nanodisk arrays. (b) Simulated transmittance of Au and TiN arrays located over glass substrate.

Once the spectral positions of LSPR peaks are defined for both materials, nanoparticle arrays can be illuminated with laser pulses at several different wavelengths. Figure 2 (a) shows the thermal image of a TiN nanodisk array before illumination, at room temperature. Five different observation points are marked on the image. One of the observation points is in the middle of nanoparticle array while the others are distributed evenly away from the particles. Thermal image of the same area under laser illumination, after reaching steady state, is shown in Figure 2 (b). Position of the nanoparticle array can be easily determined from the contrast in thermal image after illumination.

Figure 2 (c) shows the temperature variation of each observation point in time. TiN particles are illuminated with laser light at 780 nm, near LSPR wavelength, around five minutes and, then, left for cooling for another five minutes. Temperature increase up to 5 ^{o}C is measured at the nanoparticle array. Although the size of TiN particles and wavelength of illumination were not optimized, significant amount of temperature change is observed. Note the rapid drop in temperature when laser light is turned off at around 300 sec, which implies strong heat dissipation to environment.

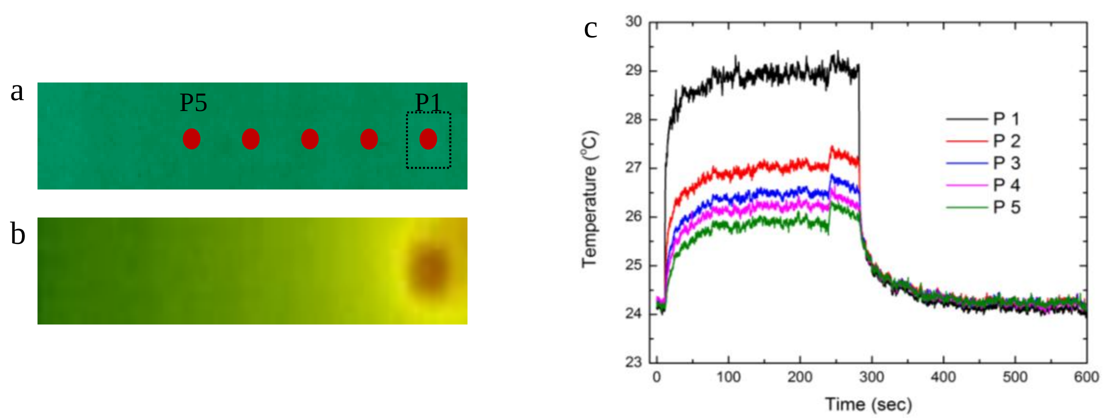


Fig. 2. (a) Thermal image of TiN nanoparticle array located over glass substrate at room temperature. Marks on the image show the observation points used in time dependent temperature plot, and dashed rectangle shows the position of nanoparticle array (b) Thermal image of the same area when the array is illuminated with pulsed laser light at 780 nm wavelength. (c) Time dependent temperature data for the five observation points located on the nanoparticle array and on the substrate.

In this contribution, both experimental and numerical results of local heat generation with TiN nanoparticles will be discussed. Obtained results will be compared with the Au nanoparticle arrays with identical geometric parameters. Results for a wide range of visible and NIR regions of the electromagnetic spectrum will be presented. It will be shown that TiN, being bio-compatible and CMOS compatible, is a promising material for local heating applications in the biological transparency window.

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