Nanoscale optical high-temperature sensor

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Abstract **All-dielectric nanoparticle possesses strong inherent Raman response due to allowed optical phonon modes. We show that such (crystalline silicon) nanoparticle with a magnetic quadrupolar Mie resonance converts light to heat with simultaneous Raman thermometry up to 900 K. The advantage of using crystalline silicon is the simplicity of local temperature control by means of Raman spectroscopy working in a broad range of temperatures, that is, up to the melting point of silicon (1690 K) with submicrometer spatial resolution. Our platform paves the way to novel nonplasmonic applications, extending the temperature range and simplifying the thermoimaging procedure.**

Index Terms **— Nanoparticles, silicon, Raman scattering, light-induced heating.**

I. Introduction

High refractive index dielectrics like silicon and germanium have become basic materials for fabrication of advanced optical devices [1]. Apart from intriguing nonlinear optical properties [2], these materials have intrinsic Raman vibration as well as high thermal stability up to 1600 K and higher. These opportunities can expand the application of such dielectrics. For instance, it could be a device like all-in-one nanometer scale optical thermometer and heater [3].

Here, we report on optical field localization inside the silicon nanoparticle at a magnetic quadrupolar resonance providing efficient optical heating up to 900 K, and the Raman thermometry with submicrometer spatial resolution (Fig. 1).

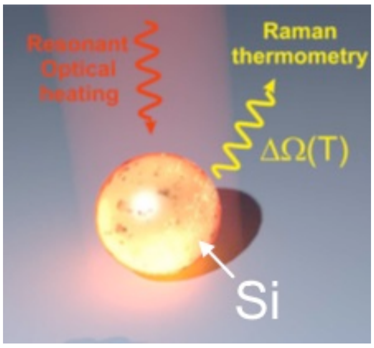

Fig. 1. Schematic illustration of strong optical heating and Raman thermometry of silicon nanoparticle.

II. Results

Unlike metals, crystalline silicon possess inherent Raman signal making it possible to provide direct Raman thermometry at the nanometer scale during optical heating as shown in Fig. 1.

Indeed, the spectral position of a Raman line is known to be thermosensitive due to anharmonic effects in lattice vibrations [3]. Such direct connection of the Raman signal with temperature allows providing the Raman thermometry. In Fig. 2, experimentally observed thermal-induced shift of the silicon Raman peak is presented. According to mathematics in Ref. [3], the shift down to 508 cm^{-1} corresponds to the heating up to 900 K. It should be noted that we do not observe any irreversible changes in composition or optical properties of the silicon nanoparticle after its heating up to such high temperatures.

Regarding optical heating, the Mie-type resonances also support an enhanced interaction of light with silicon nanoparticle to heat it up to melting temperature, while the excitation intensity is extremely small [3]. In comparison of absorption and heating properties of silicon and gold nanoparticles in air calculated basing on the Mie theory [3], the silicon nanoparticles are effectively heated at resonant conditions. Indeed, the silicon nanoparticles demonstrate resonant heating behavior for certain wavelengths and sizes and even exceed maximum temperature values for gold in the IR range. The similar behavior is observed for nanoparticles in surrounding water, which makes silicon nanoparticles to be prospective for biological applications, where the nanoparticles are immersed in liquids.

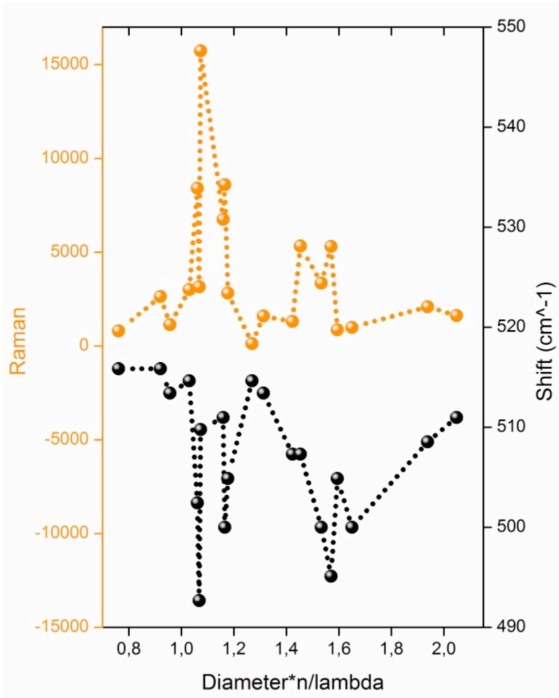

Fig. 2. Dependence of maximum light-induced heating of silicon nanoparticles on their diameter (*n* is a refractive index of silicon, *lambda* is a wavelength of a He-Ne laser). Temperature is reflected in the Raman shift [3]; while the intensity of the Raman signal

provides the information about resonant state of the silicon nanoparticle [4].

III. Conclusion

Here, we have shown that a resonant silicon nanoparticle represents "all-in-one" platform integrating effective photoinduced heating and broad-range temperature sensing. Using Raman thermometry we have revealed experimentally that at a magnetic quadrupolar optical resonance photoinduced heating of the silicon nanoparticle can be four times more effective as compared to plasmonic nanospheres. We have found that the silicon nanoparticles can be effectively heated inside different environment like water or air. The nanoparticles can be used for plenty of applications where strong and controllable optical heating around a single nanoparticle is crucial: nanosurgery, photochemistry, as well as photothermal signal modulation.

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