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PROBING OF TEMPERATURE RISE IN NEAR-FIELD LASER HEATING BY PARTICLES

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1. Introduction

Micro/nanoscale particles can act as spherical lenses and heat the substrates under laser irradiation [1]. Li *et al.* simulated the optical field distribution of a particle-substrate model under normally irradiated laser beam [2]. Simulation of laser interaction with materials (SLIM) was used to calculate the temperature of a substrate beneath particles with laser irradiation [3]. To our knowledge, nearly no experiment about temperature measurement inside a substrate under particles has been reported. Such measurement is very challenging since the near-field heating area in the substrate is very small, usually around 200 nm or smaller. In this work, the thermal response of a silicon substrate beneath silica particles under laser irradiation is measured by using the Raman thermometry for the first time, and the electric field distribution and temperature distribution inside the system are simulated.

2. Experimental Results

Figure 1 shows the schematic of the experimental setup. A sample that is set on a 3-D piezo-actuated nano-stage is located under the focused laser beam from a Raman spectrometer. The sample is a monolayer of silica particles formed on a silicon substrate. The incident laser, which is used as both temperature probing and heating source, is focused on the substrate by the particles. The excited Raman scattering signal and Rayleigh scattering signal are collected by using a 50× objective lens. The substrate is heated by the laser in a sub-wavelength region (r ~ 200 nm) right beneath the particles. The amount of temperature rise inside the silicon substrate is affected by the diameter of particle and energy flux of laser. In our experiment, three particles of 400, 800 and 1210 nm diameter, and four laser energy fluxes of 2.5×10^8, 3.8×10^8, 6.9×10^8 and 8.6×10^8 W/m^2 are used.

Figure 2(a) shows a typical Raman spectrum for silicon.

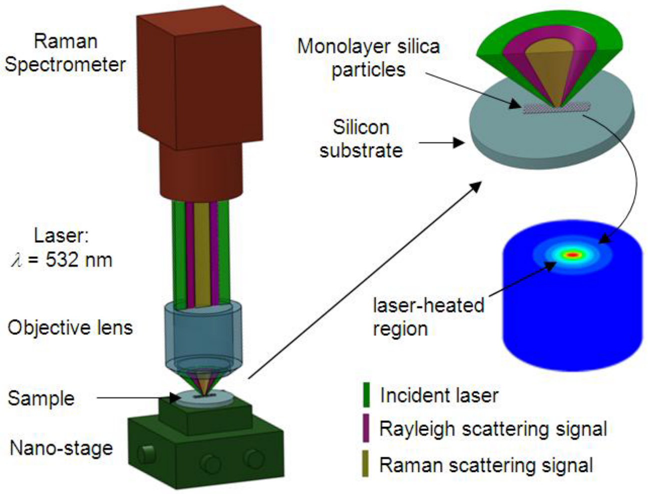

Fig. 1 Schematic of experimental setup for near-field heating and temperature probing (not to scale).

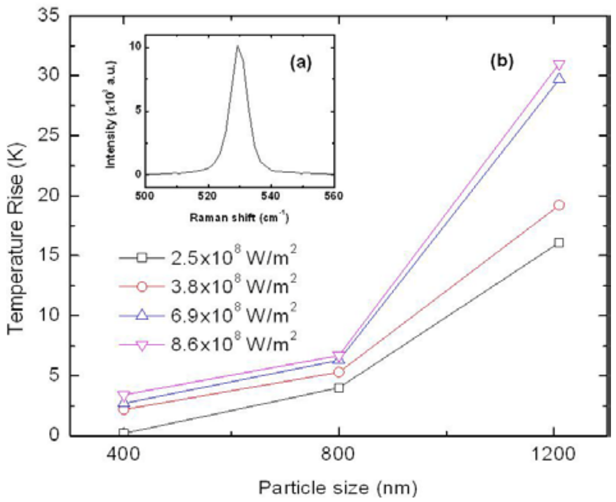

Fig. 2 The relationship between temperature rise in silicon and diameter of silica particle under different laser energy fluxes.

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How temperature rise of silicon vary with particle size of silica under different laser energy fluxes is shown in Fig. 2(b). With the increase of the particle size, the incident laser is more focused on the silicon substrate, and the temperature raises more. Under energy flux of 8.6×10^8 W/m^2, the temperature rises are 3.4, 6.7 and 31.0 K for silica of 400, 800 and 1210 nm diameter, respectively. As the particle size increases from 400 to 800 nm, the temperature rise doubled; while it increases to 1210 nm, the temperature rise goes up to 9 times of that of 400 nm. When the energy flux of the incident laser increases, more energy will be focused on the silicon and absorbed. As a result, the temperature inside the silicon increases.

3. Theoretical Analysis

The electric field modeling is performed by using High Frequency Structure Simulator (HFSS V13, Ansys, Inc.). Figure 3 shows the electric field distributions inside the substrate-particle systems. Symmetric electric field distributions are observed. The enhancement inside the substrate occurs mostly right beneath the particle. The temperature distributions inside the silicon substrates, shown in Fig. 4, are obtained by using ANSYS FLUENT (V12.0.1 Ansys, Inc). The highest temperature rise is located at the center top of substrate under the particle positions. The calculated maximum temperature rises inside the silicon are 2.8, 4.0 and 9.0 K for 400, 800 and 1210 nm cases, respectively. Modeling results agree well with experimental results. The difference between them could be due to the pre-focused laser in the experiment. The incident laser employed in the electric field calculation is a uniform plane wave, while in the experiment, the laser is focused by a 50× microscope objective in advance before it irradiates onto the sample.

4. Conclusions

In summary, the thermal response of a silicon substrate beneath silica particles under laser irradiation was probed based on Raman thermometry. The laser energy was focused within sub-wavelength areas inside the substrate by particles. Silica particles of three diameters (400, 800 and 1210 nm) under incident laser of four energy fluxes (2.5 × 10^8, 3.8 × 10^8, 6.9 × 10^8 and 8.6 × 10^8 W/m^2) were used in the experiment. The temperature rise increases as the particle size of silica increases, and stronger laser irradiation results in higher temperature rise in the substrate. Simulations were conducted on the enhanced electric and temperature fields. The modeling results agree with the measurement results. The difference could be due to the pre-focused laser beam by the objective lens in the experiment.

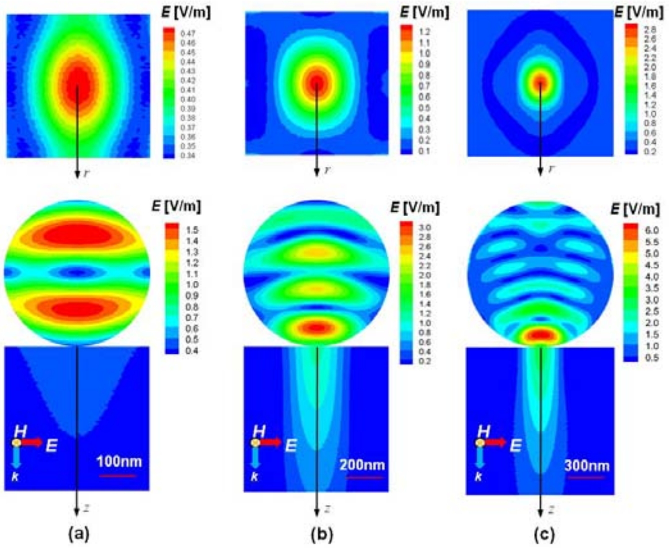

Fig. 3 Electric field distributions inside substrates and particles of (a) 400, (b) 800 and (c) 1210 nm diameter.

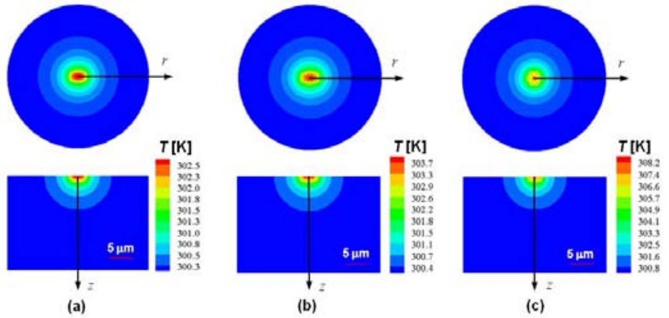

Fig. 4 Temperature distributions inside substrates under particles of (a) 400, (b) 800 and (c) 1210 nm diameter.

5. Acknowledgements

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References

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