Development of Scanning Photothermal Microscope for Nanoscale Sub-surface Structural Defect Characterization

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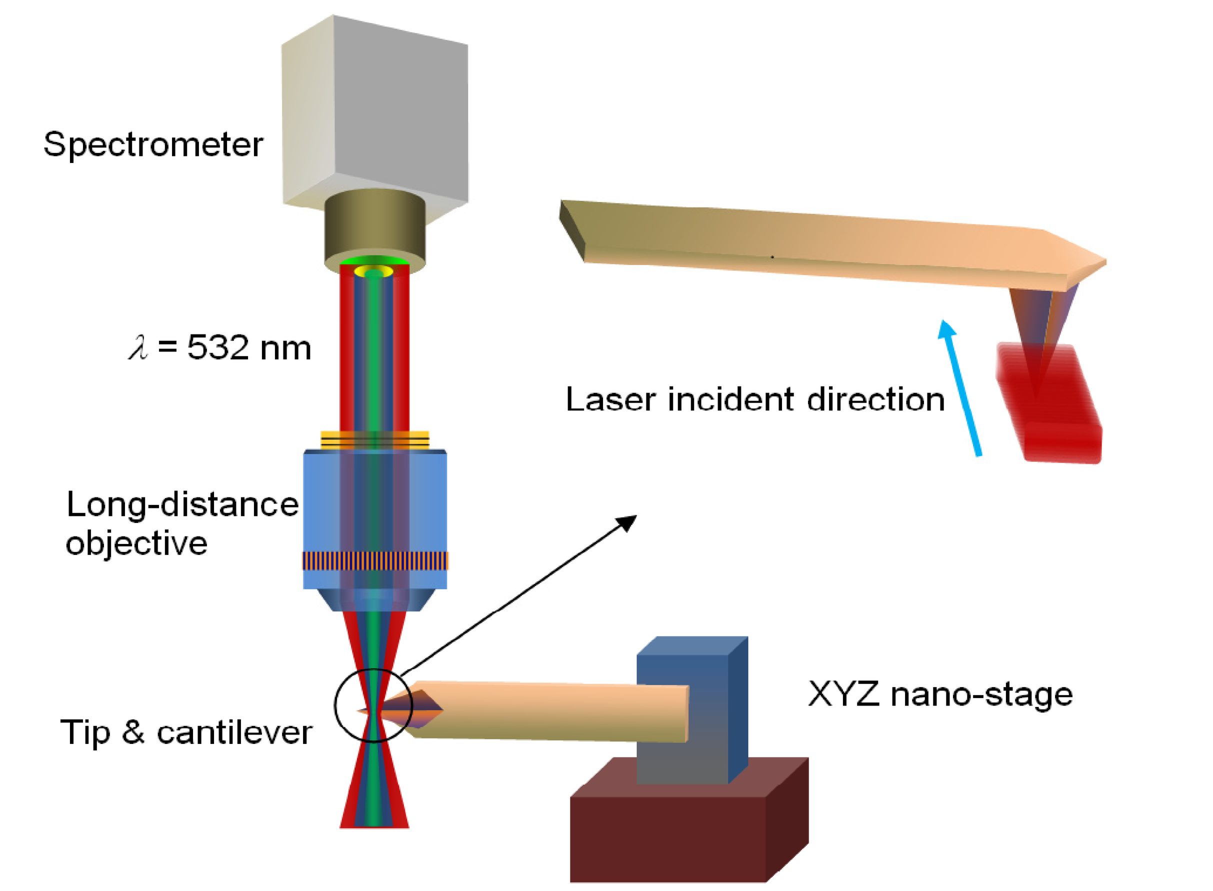
MOTIVATION

- The existing scanning probe technologies focus on characterizing surface properties.
- Under laser irradiation, the atomic force microscope (AFM) tip can give rise to strong near-field scattering and focusing, leading to strong nanoscale heating.

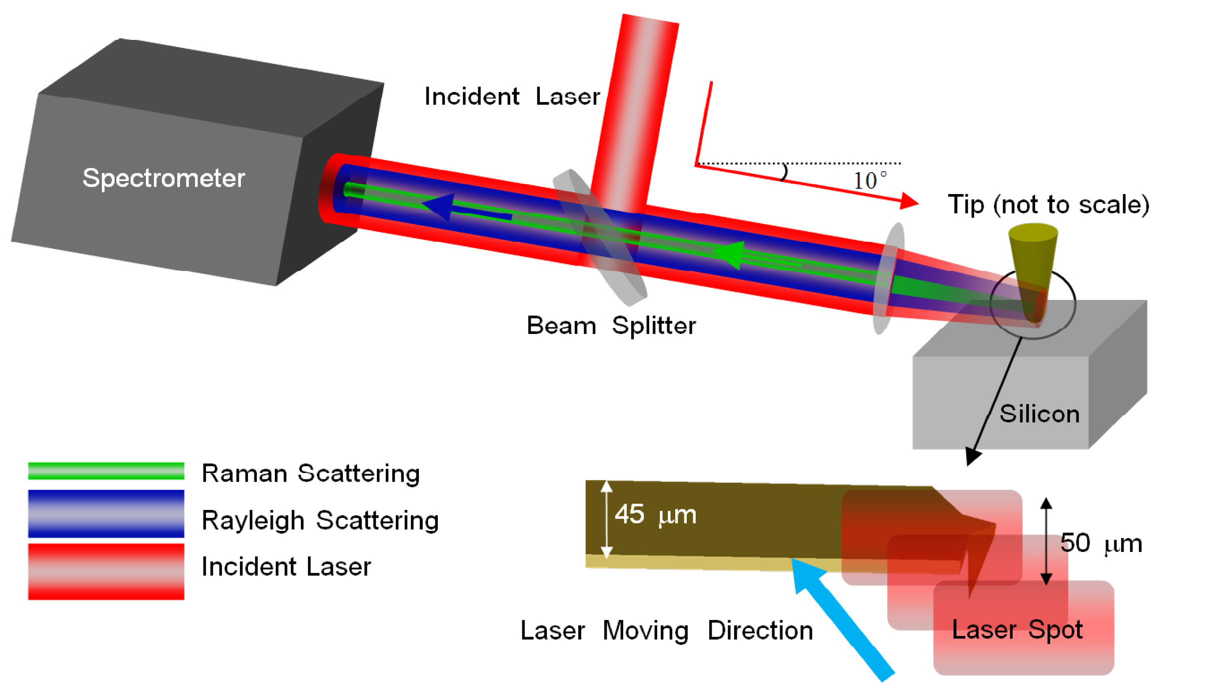
OBJECTIVES

- Investigate the thermal probing inside an AFM silicon tip and a silicon substrate under laser irradiation.
- Explore how the thermal response changes when a laser beam illuminates the different spot of an AFM tip with different laser powers.
- Simulate the enhanced optical field and its induced thermal transport in tungsten and silicon tips under laser irradiation.
- Study the effects on electric field distributions caused by curvature radius, tip aspect ratio, and polarization angle of the incident laser.

EXPERIMENTAL SETUP



- Thermal response of silicon nanotip to laser irradiation.

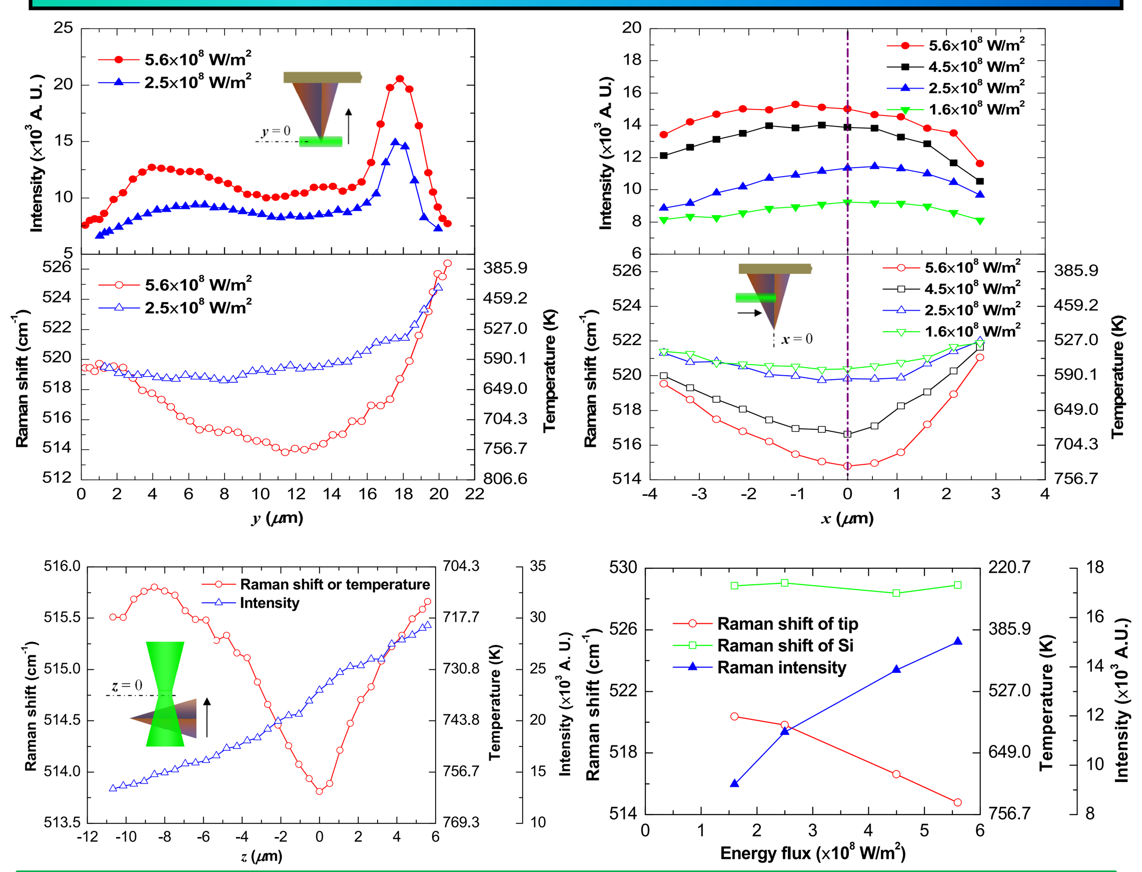


- Thermal probing of silicon under nanotip focused laser heating.

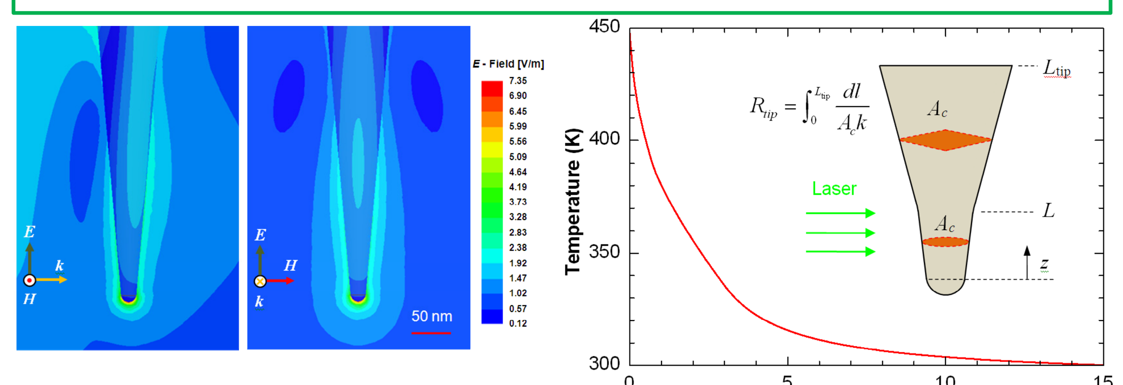
ABSTRACT

The overarching goal of this project is to conduct research on break-through sub-surface structural defect characterization based on laser-coupled scanning probe photothermal concept to achieve depth profiling with nanoscale spatial resolution. The sub-surface characterization features nanoscale spatial resolution using frequency-modulated near-field laser focusing and thermal expansion sensing. Research are carried out to study the physical phenomena in sub-surface characterization, including near-field laser focusing, nanoscale heating, thermal transport, and elastic surface displacement. A physical model is developed for dynamic surface displacement under periodical nanoscale laser heating.

RESULT I

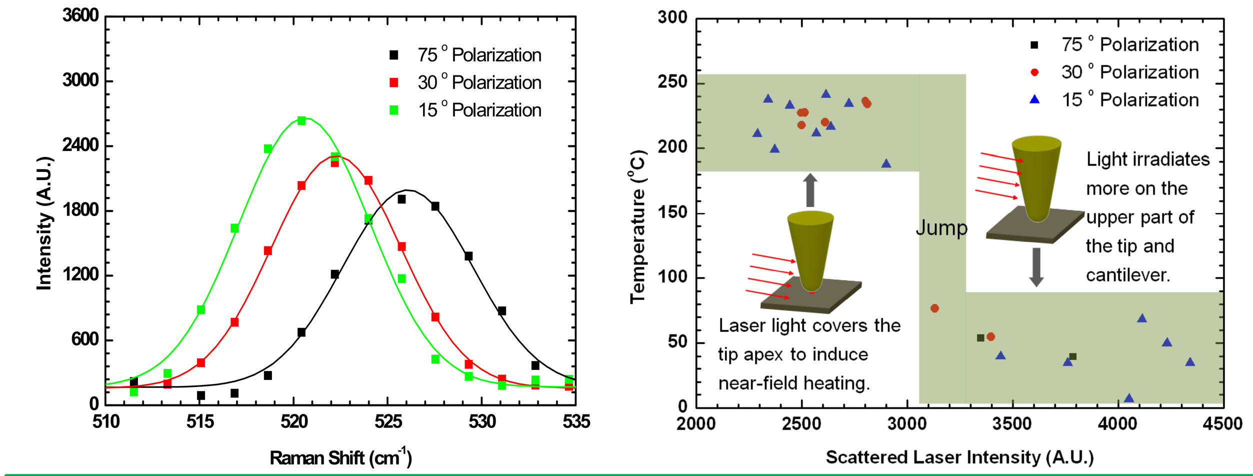


- Raman intensity, Raman shift, and Temperature in silicon tip along the x-, y-, and z-directions under four different energy fluxes.

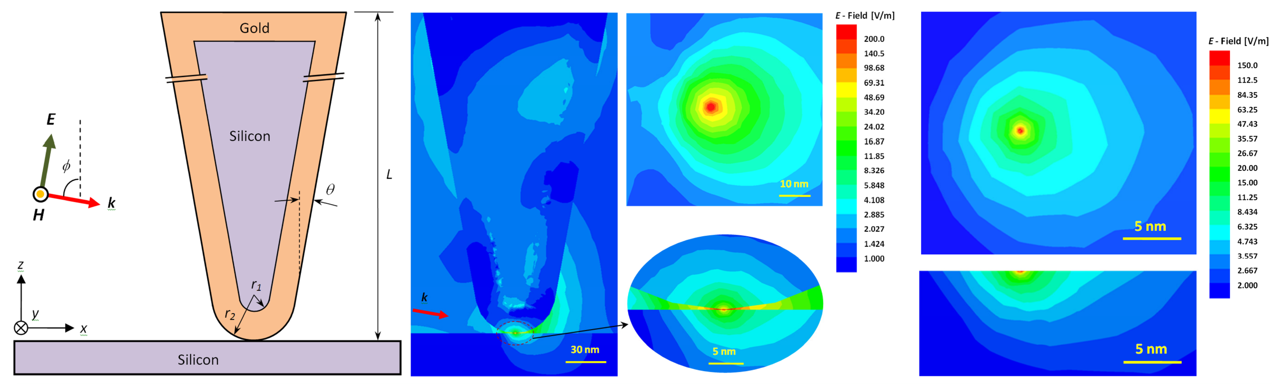


- Electric field and temperature profile around the tip. The maximum electric field intensity is 2.14 V/m for the incident electric field of 1 V/m. The laser energy flux is 5.6×10^8 W/m^2.

RESULT II

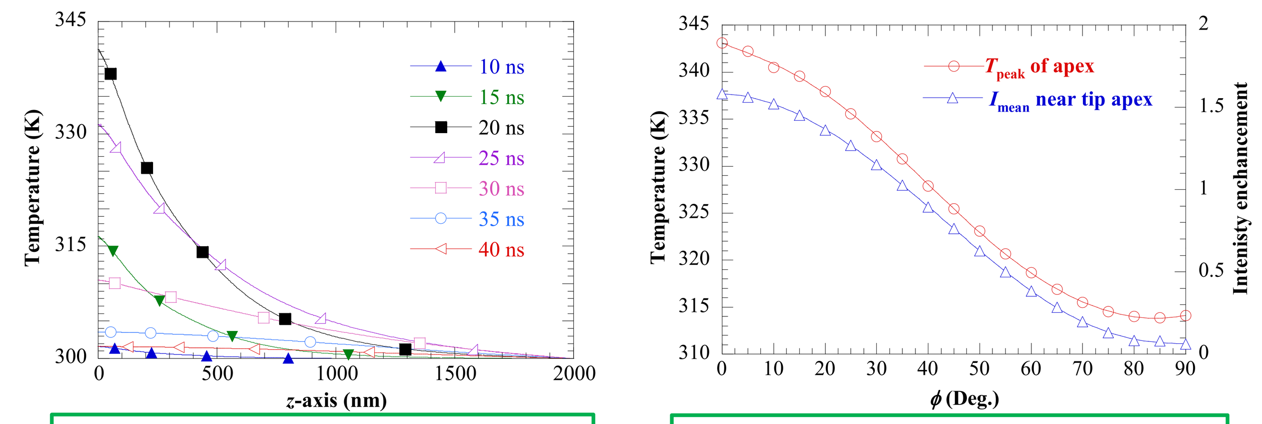


- Raman spectra and temperature in the silicon substrate. There is a jump for the temperature variation against the scattered laser intensity. High temperature is observed when the laser covers the apex of the tip where enhancement of electric field beneath the tip happens.



- Electric field distribution around the tip and inside the silicon substrate. Quantitative analysis gave temperature rises as 235 °C and 105 °C for 15° and 30° cases, agreeing with the experimental results (~250 °C).

RESULT III



θ = 10°, r = 30 nm, d = 5 nm, ϕ = 0°, q'' = 2.5 mJ cm^{-2}.

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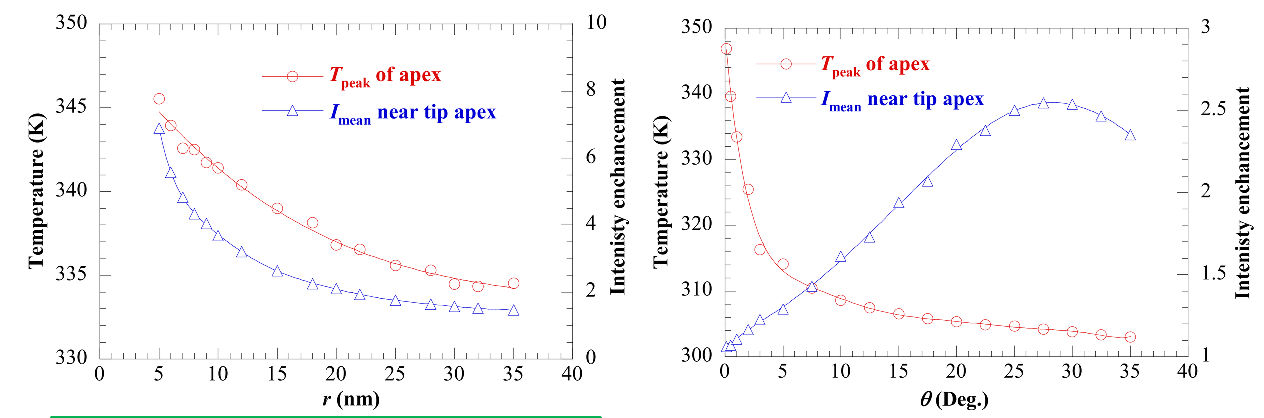

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- Peak temperature of apex and mean laser intensity near apex inside the tip.

FUTURE WORK

- Determine near-field thermal response of silicon substrate under particle-focused laser irradiation.
- Provide far-field thermal, stress and structure imaging of particles, silk, and glass fiber at nanoscale.

DOCTORAL STUDENTS INVOLVED

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