

Study of mechanism of phase transition of material using the light-scattering spectroscopy; detection of precursor phenomena of phase transition in solids

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Summary of Research

Using Light-Scattering Spectroscopy to Elucidate Phase Transitions in Materials

Our laboratory engages in research of laser light-scattering spectroscopy with the goal of elucidating the mechanisms underlying phase transition (changes in state) in a wide variety of materials. This research examines liquids and colloids as well as solids, including magnetic and dielectric materials.

Phase transition is the phenomenon whereby the structure or properties of a material change under certain temperature and pressure conditions. Phase transitions between solid, liquid, and gas phases occur in all materials at specific temperatures and pressures. Especially, we are interested in solid phase transitions—for example, phase transitions involving changes in atomic configuration or sudden changes in electric conductivity. A material that undergoes phase transition will often take on completely different properties.

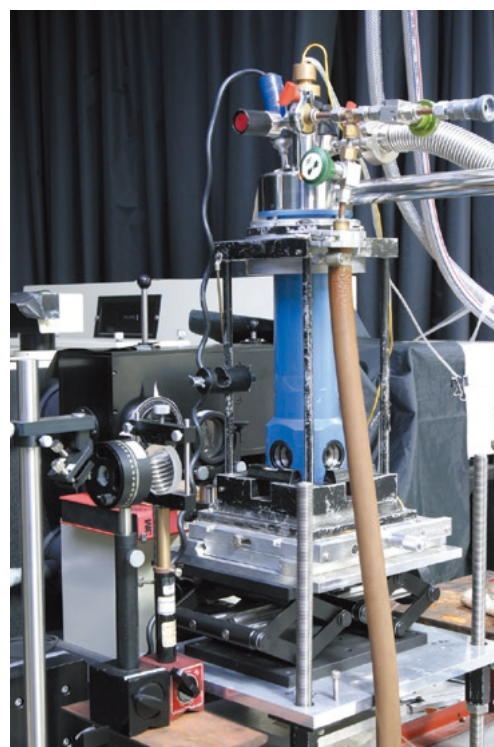
Shape-memory alloys are among the better-known materials whose mechanism is based on phase transition. The understanding of the phase transition mechanism enables us to control of the phase transition of materials and then it should open up a range of innovative new functional materials and a wide range of potential applications.

Our research theme—using light-scattering spectroscopy to investigate the mechanisms of phase transition in materials—involves exploring changes in structures and states of materials at the atomic and molecular levels and identifying the mechanisms that give rise to the physical properties one see in nature.

Wide-Ranging Experimental Studies That Generate Discoveries

It was once believed that we had achieved a complete understanding of the phase transition mechanism of silica (SiO_2), an essential material for substrate insulation in various devices and in piezoelectric elements. However, no explanation has been proposed for the emergence of strong scattering light near the phase transition point. To propose and validate a new phase transition model for silica, we performed numerous experimental studies based on optical measurements of Raman scattering, Brillouin scattering, birefringence, and other aspects, leading to the discovery that the temperature at which the integrated intensity of second-order Raman scattering begins to deviate from Landau theory of phase transitions is approximately 30 K (kelvin) above the phase transition temperature.

Research is also underway on mechanisms underlying the suppression effects of phase transition due to quantum effects in quantum paraelectric strontium



Helium flow optical cryostat (6–300 K)

Keywords

Phase transition, laser, light-scattering spectroscopy, Raman scattering, Brillouin scattering, fluorescence spectrum, birefringence, dielectric and magnetic properties.

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titanate (SrTiO_3). The goal here is to elucidate the mechanisms underlying the emergence of ferroelectricity in the quantum critical region that can be reached with external perturbations. One of our latest studies suggests that the ferroelectric phase transition of SrTiO_3 induced by substitution with isotope of oxygen is a crossover between displacive phase transition and order-disorder phase transition and that the order-disorder mechanism dominates in the critical region. We also discovered that the phase transition in $\text{SrTi}_{18}\text{O}_3$ is unlike that in typical ferroelectric materials. In $\text{SrTi}_{18}\text{O}_3$, the ferroelectric region does not manifest uniformly throughout the crystal. Instead, nanoscale granular ferroelectric regions begin to grow, and the alignment of the electric polarization of the polar region manifests as ferroelectric behavior. In this study, we examined the resultant direction of polarization, taking into consideration the interactions among nanoscale polarizations. This achievement was recognized with a Best of 2011 Award from *Europhysics Letters* (EPL).

These granular regions are believed to be the origin of the giant dielectric constant exhibited by certain materials, which are of great interest for their potential as dielectric materials. We are currently studying the temperature dependence of ferroelectric region size based on measurements of the wavelength dependence and scattering-angle dependence of Rayleigh-Mie scattering from the ferroelectric regions.

Advantages

Establishing Light-Scattering Spectroscopy Technologies for a Wide Temperature Range

Our laboratory specializes in light-scattering technologies across a wide temperature range (6–1,000 K) for use with solid samples, including dielectrics, molecular crystals, and liquid crystals. A microspectroscopy device is a recent laboratory addition to the instruments available at our laboratory. This device will allow us to apply spectroscopy to examine microparticles and opaque materials that could not be examined effectively by ordinary light-scattering techniques. The technologies we offer for measuring materials under various conditions will open up new avenues for research.

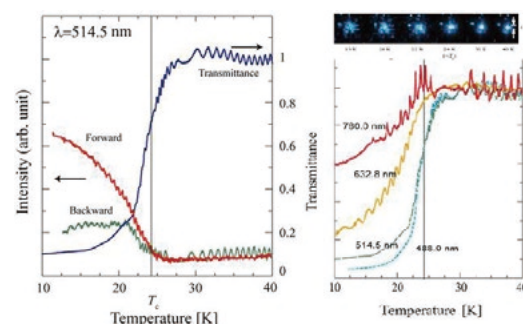
With respect to spectroscopic technologies, our studies are unique in that we focus both on the properties observed in scattering light by light-scattering spectroscopy (Raman scattering, Brillouin scattering, and Rayleigh-Mie scattering) and on the electronic structures of atoms and molecules as observed in fluorescence and absorption spectra.

Future Prospects

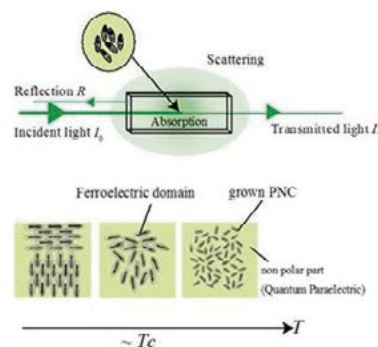
Developing Spectroscopic Technologies for Nanoscale Thin Films, Particles and Ceramics

The large dielectric constants exhibited by relaxor ferroelectrics are believed to be traceable to nanoscale regions within the material. These materials may allow the development of new dielectric materials and are of great interest for potential industrial applications. Besides, the mechanisms associated with a phase transition occurring in a non-uniform medium and the growth and polarization alignment of nanoscale PNR are also of great interest from the perspective of basic research. The PNR observed in such non-uniform ferroelectric materials may represent the precursor phenomenon of ferroelectric phase transition. Our laboratory uses a combination of Raman microspectroscopy and the Rayleigh-Mie scattering method, which provides information on the size and shape of nanoscale particles, to elucidate phase transition mechanisms in non-uniform media.

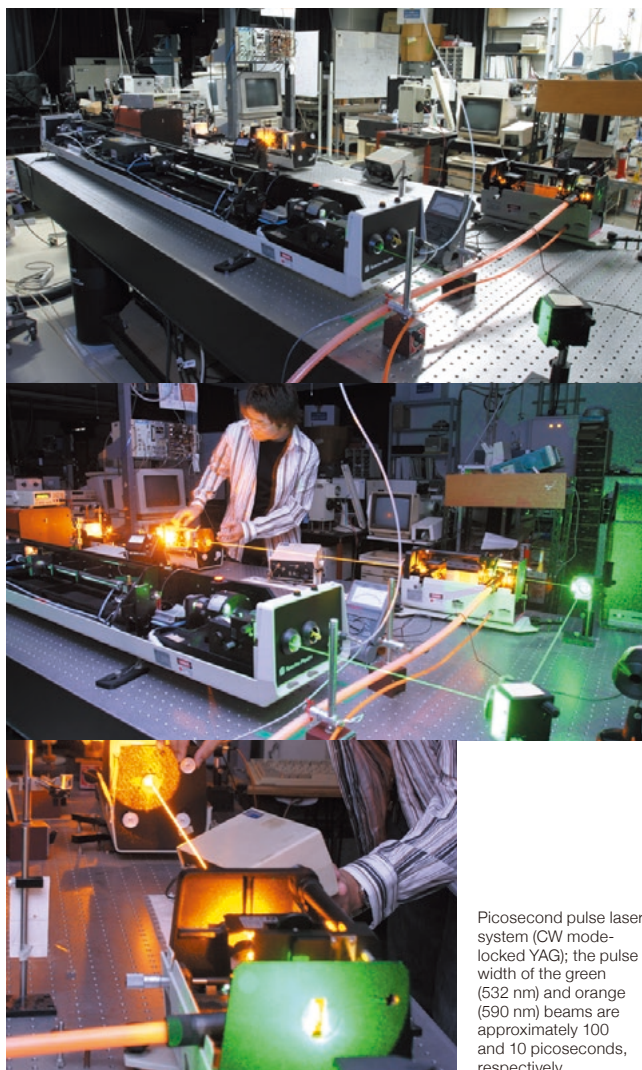
Industry has shown significant interest in dielectric materials that exhibit large dielectric constants, due to their potential for use in capacitors. In this area of research, to develop a Pb-free dielectric material, we plan to develop methods for controlling the mechanism operating in non-uniform media at nanoscale orders and their phase transition temperatures.



(Right) wavelength dependence of transmissivity; (left) temperature changes in transmittance, forward scattering, and backward scattering



Phase transition model for SrTiO_3



Picosecond pulse laser system (CW mode-locked YAG); the pulse width of the green (532 nm) and orange (590 nm) beams are approximately 100 and 10 picoseconds, respectively.