

Nanoimaging through plasmonics and beyond plasmonics

Satoshi Kawata

Department of Applied Physics, Osaka University, Osaka, Japan
RIKEN, Wako, Saitama, Japan

Optical microscopy has always been a convenient tool for analyzing and imaging various materials. However, this technique in its conventional form is not suitable for analyzing and imaging nanomaterials due to two major reasons. One is the poor spatial resolution in conventional microscopy, which is restricted by the diffraction limits of the probing light, making it impossible to analyze materials smaller than about half of the wavelength. Second reason is the weak optical signal, such as Raman intensity, associated with the extremely small volume of nanomaterials. However, when conventional Raman microscopy is combined with the near-field techniques, it achieves new and exciting features as it goes beyond the conventional limits of optical microscopy, in terms of both the spatial resolution and scattering intensity. This is done by so called tip-enhanced Raman scattering (TERS) technique [1-3], which utilizes a metallic nanotip for characterizing and imaging samples at nano scale. When a metallic nanotip is illuminated with light, the local surface plasmon polaritons are resonantly generated at the tip apex, resulting in strong evanescent field that is localized near the tip apex within a volume comparable to the size of the tip apex. The size of the tip apex is typically about 25 nm, which determines the spatial resolution in TERS experiments. If a sample is brought near the tip, the tip interacts with the sample molecules via this evanescent field and generates strong Raman scattering from only those sample molecules that are adsorbed in the evanescent field. As a result, huge enhancement of Raman scattering is observed along with extremely high spatial resolution, which makes this technique an ideal tool for experimental analysis of nanomaterials. We have utilized this technique to study several samples, and were able to optically image them with a resolution better than 25 nm in linear [1,2] and 15 nm in nonlinear [3] TERS experiments, far beyond the diffraction limits of the probing light. Also, an enhancement of Raman scattering by a factor as high as one million was observed.

In another nanoimaging technique based on plasmonics, we proposed a nanolens made of multilayered array of silver nanorods [4]. This nanolens, unlike other plasmonic lenses, such as the superlens, is capable of colored and magnified imaging with extremely low loss of plasmon energy, which makes it possible to have a long distance image transfer. The magnification makes it possible to observe the image in the far field using usual recording techniques, such as through a CCD camera, even though the resolution at object remains of the order of nanometers.

In addition to the contributions from plasmonic confinement of light, mechanisms beyond plasmonics can further improve the imaging quality tremendously. One of such examples is the inclusion of tip-applied pressure in TERS, which distorts the sample locally. Owing to the sharp curvature of the tip apex, the contact area between the tip and the sample can be extremely small, ideally of molecular level. By optically sensing this localized distortion, one can obtain super high resolution. In recent studies [5,6], resolution better than 4 nm was demonstrated through this imaging technique that goes beyond the plasmonics.

- [1] N. Hayazawa, et al., *Chem. Phys. Lett.* **335**, 369 (2001).
- [2] N. Hayazawa et. al., *J. Chem. Phys.* **117**, 1296 (2002).
- [3] T. Ichimura, et al., *Phys. Rev. Lett.* **92**, 220801 (2004).
- [4] S. Kawata, et al., *Nature Photon.* **2**, 438 (2008).
- [5] T. Yano, et al., *Nature Photon.* **3**, in press (2009).
- [6] T. Ichimura, et al., *Phys. Rev. Lett.* **102**, 187101 (2009).