1. Introduction

The Applied Plasmonics and Nanosensing Laboratory is associated with the Graduate School of Pure and Applied Sciences at the University of Tsukuba, and is led by Professor Edwin Carlen. Professor Carlen joined the University of Tsukuba in April 2013 from the University of Twente/MESA+ Institute for Nanotechnology in the Netherlands where he was an Associate Professor. Professor Carlen received his primary education in Physics and Electrical Engineering and received his Ph.D. degree from the University of Michigan, Ann Arbor, in the United States in 2001. Research at the Applied Plasmonics and Nanosensing Laboratory is directed at developing new types of sensors and devices with nanometer dimensions that are based on nanoscale physical, electronic, optical and chemical phenomena. We use a variety of analytical measurement techniques including low-power electrical, atomic force microscopy, laser confocal optical microscopy, dark field scattering microscopy, and conventional optical microscopy.

2. Plasmonics

The emerging field of plasmonics, the science and engineering of surface plasmon polariton excitation on conductor-dielectric interfaces, has grown significantly over the last half century since the discovery of bulk plasmons, and surface plasmon polaritons on noble metal foils more than fifty years ago. Surface plasmons excited on metal surfaces are electromagnetic waves of collective electron oscillations that are confined to the interface between a dielectric material and a conducting surface, such as a metal. Surface plasmons can take the form of propagating electromagnetic waves on flat surfaces that are confined in one dimension normal to the interface, for an air-metal interface, or localized electron oscillations on curved metal interfaces where the surface fields are confined to the surface of nanostructures and in nanogap regions between adjacent nanostructures (Fig. 1), which results in coupled-mode surface plasmon resonances and energies that are dependent on the nanogap dimensions and extremely enhanced electromagnetic fields. The confined fields in the nanogap spaces can be used for a variety of applications, such as surface-enhanced Raman spectroscopy, dark-field scattering spectroscopy and enhanced light absorption for photovoltaics.

![Figure 1. Electromagnetic field generated in the nanogap region between adjacent nanostructures.](image)

Our research activities in plasmonics has four primary branches: 1) nanofabrication of metal nanoparticles and nanostructured surfaces, 2) theoretical modeling of local surface plasmon resonances and nanogap plasmon resonances, 3) far-field optical characterization of local surface plasmon resonance, and 3) applications of metal nanoparticle local surface plasmon resonances, such as surface-enhanced Raman spectroscopy and dark-field scattering spectroscopy.

2.1 Nanofabrication

Many different techniques have been reported to
fabricate functional metallic plasmonic substrates for chemical and biological sensor applications. Colloidal suspensions of metal nanoparticles of various shapes and sizes are most commonly used due to their preparation simplicity and reports of Raman scattering spectra from single molecules; the large scattering enhancements were later attributed to single molecules located in nanogaps between nanoparticle dimers. However, nanoparticle assemblies typically have poor enhancement reproducibility, which is attributed to their random composition and lack of precise dimensional control, dimer separation distance, and excitation polarization alignment.

Figure 2. Scanning electron microscopy image of the cross-section of a nanostructured gold surface developed for plasmonics applications.

We are developing new top-down fabrication techniques composed of nanostructured templates that are manufactured using a combination of conventional microfabrication and nanofabrication techniques. The nanostructured templates are subsequently coated with plasmonically active materials, such as silver or gold; hence we do not pattern and etch the metal layer. Figure 2 shows a scanning electron microscopy image of the cross-section view of gold nanowire array.\(^1\,^2\)

2.2 Surface-enhanced Raman spectroscopy
Raman spectroscopy is a powerful technique for chemical and biological analysis because it can provide a chemical fingerprint of probed molecules and an aqueous environment does not affect the measurement, which is a limitation for infrared spectroscopy. The chemical fingerprint represents the vibrational structure of the probed molecules, which is measured from inelastically scattered photons from the polarizable bonds of the molecules in the probe region of the collection optics. However, inelastic light scattering is a weak process, e.g. a typical inelastic scattering process generates several orders of magnitude fewer photon fluxes than optical absorption processes used in infrared and fluorescence spectroscopies. The scattering cross-section of molecules adsorbed in close proximity to nanogaps located between metal nanostructures (Fig. 2) is strongly enhanced due primarily to the confined and enhanced electromagnetic field, which is called surface-enhanced Raman scattering (SERS). An enhancement factor of ten million drastically increases photon emission compared to a conventional Raman scattering process. Surface-enhanced Raman spectroscopy is emerging as a powerful and important analytical technique that can provide a chemical fingerprint of small quantities of surface adsorbed species.\(^3\) Our research group is currently developing new analytical techniques for spectroelectrochemistry for monitoring surface reactions and their intermediate species.

References

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