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Nanoparticle SERS

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The Next Generation of Advanced Spectroscopy: Surface Enhanced Raman Scattering from Metal Nanoparticles

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Surface enhanced Raman scattering (SERS) has enjoyed an ever growing research base since its discovery with the number of papers published using the technique and investigating the basis behind it growing exponentially year by year.[1] SERS is an advancement of Raman scattering which overcomes some of the limitations of normal Raman scattering. Raman spectroscopy is a vibrational spectroscopy which gives specific information about molecules. The disadvantage of Raman scattering is that it is an inherently weak process, however it can be used in aqueous solutions, due to water being a weak Raman scatterer, lending itself to analysis and study of molecules in aqueous solution including the study of biomolecules. Another major disadvantage is the fluorescence which often accompanies Raman scattering and can sometimes overwhelm the bands in the spectrum rendering the experiment useless. To overcome this, the phenomenon of surface enhanced Raman scattering can be used.

SERS requires a metal surface, normally of gold or silver, to enhance the Raman scattering through two different mechanisms—chemical enhancement and electromagnetic enhancement.[2] The chemical enhancement is viewed differently by physicists and chemists, however it involves the interaction of the molecule with the surface of the enhancing metal to form a new charge-transfer state, which increases the Raman scattering intensity. The second mechanism, electromagnetic enhancement, involves the interaction of the plasmon band of the metal nanoparticle with the molecule to enhance the Raman scattering. Enhancement factors of up to 10^{14} have been reported[3] and single molecules can be reliably detected with excellent molecular specificity.[4] The two major advantages of using SERS as a technique for either studying molecules vibrationally or as an analytical technique is its exquisite sensitivity coupled with its molecular specificity. Mixtures of components can be identified without separation making the surface enhanced Raman spectroscopy more amenable to more complex analysis than the equally sensitive fluorescence spectroscopy.[5] Essentially to achieve SERS, the molecule of interest must be adsorbed onto a suitable roughened metal surface. The format of the metal surface has traditionally been either electrodes, vapour deposited films or more commonly nanoparticles.[6] All of these types of surfaces have issues in terms of specific surface adsorption of the analyte and the ability to be ubiquitous surfaces to provide enhancement of difficult to adsorb species which means that one surface tends not to work for all SERS experiments.

Recently there has been a large increase in the investigation and use of metal nanoparticles shelled with a protective coating which can be used in a number of ingenious methods.[7] Many coatings have been examined, however for the purposes of this Highlight only a silicon coating will be focused on. In a very elegant approach Tian and co-workers have developed a "shell isolated nanoparticle enhanced Raman spectroscopy" based system known as SHINERS.[8] In this approach, gold nanoparticles are shelled in a very thin silica or alumina shell which is typically less than 2 nm thick (Figure 1). These particles can then be deposited onto either a surface to provide a monolayer of nanoparticles to act as an enhancing surface or deposited onto a target of interest such as a cell. The silica or alumina coat acts as a protective coating to prevent unwanted non-specific interaction of the gold with other species, however it also allows adsorption of the target analyte to be close enough to the gold to experience electromagnetic enhancement and hence an increase in the Raman scattering.

The authors demonstrate the applicability of this approach through the detection of the adsorption of hydrogen onto single-crystal platinum surfaces which cannot be measured by conventional vibrational spectroscopy. In a further example of the power of SHINERS, a single yeast cell was exposed to the gold–silica nanoparticles and Raman spectra accumulated across the cells. In comparison to normal Raman spectra of these yeast cells, there were enhancements of bands corresponding to protein backbones and amino acids. This demonstrates the potential for the examination of living cells at a biomolecular level in an information-rich manner. In a

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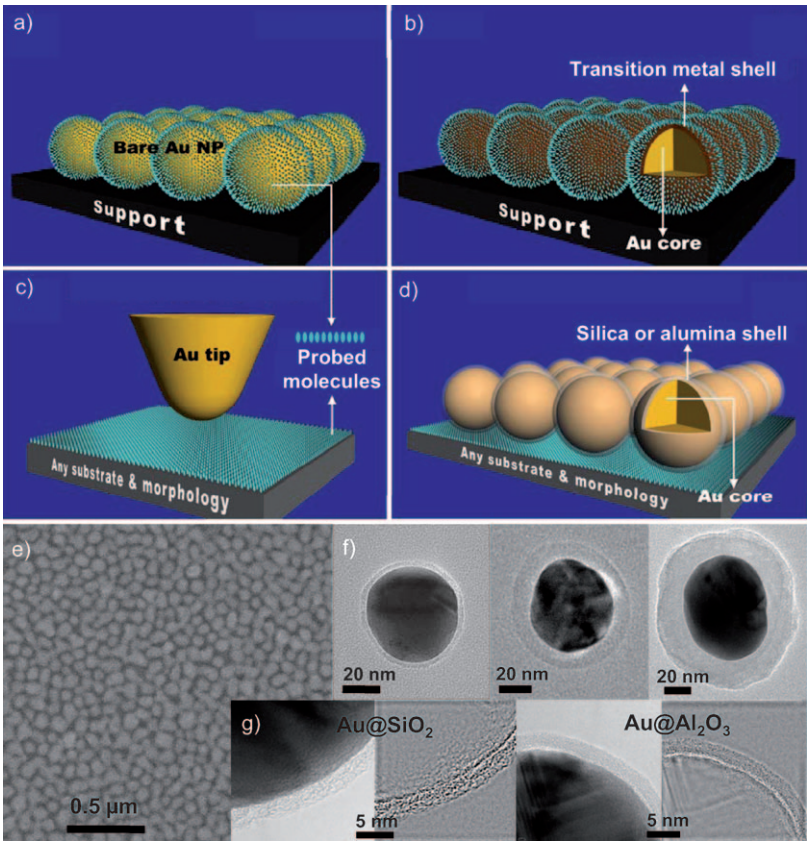

Figure 1. The working principles of SHINERS compared to other modes. Schematic of the contact mode. a) Bare Au nanoparticles: contact mode. b) Au core–transition metal shell nanoparticles adsorbed by probed molecules: contact mode. c) Tip-enhanced Raman spectroscopy: noncontact mode. d) SHINERS: shell-isolated mode. e) Scanning electron microscope image of a monolayer of Au/SiO_2 nanoparticles on a smooth Au surface. f) HRTEM images of Au/SiO_2 core–shell nanoparticles with different shell thicknesses. g) HRTEM images of Au/SiO_2 nanoparticle and Au/Al_2O_3 nanoparticle with a continuous and completely packed shell about 2 nm thick.[8]

final advancement of the application of SERS in difficult situations, SHINERS particles were applied to the surface analysis of citrus fruits. The question was whether surface deposition of pesticide residues, such as parathion, could be detected on the citrus fruits. When SHINERS particles were applied to a fresh orange and examined using a portable Raman spectrometer, spectra which were clearly identified as coming from the parathion were identified, whereas control experiments using normal Raman scattering failed to produce confirmation of the presence of the pesticide. Taken together, these three examples indicate the versatility and applicability of these new self-contained Raman enhancing surfaces and also their ease of application in a range of situations which cannot be examined by conventional Raman spectroscopy.

An alternative to using the metal nanoparticles as a purely enhancing surface for target species is to use a metal nanoparticle as a SERS label. In this case, nanoparticles are functionalized with a Raman reporter molecule which gives a strong characteristic Raman spectrum from the species adsorbed onto the surface of the metal nanoparticle. This can then be encapsulated in a silica shell locking the SERS signal on permanently and protecting the nanoparticle from the interrogation environment.[7b] A number of groups have been working on this approach to provide SERS-active nanoparticles capable of being used for bioanalysis, and Schlücker and co-workers have recently reported the synthesis of SERS labels for NIR laser excitation.[9] In this approach the authors used a self-assembled monolayer on a single colloidal gold–silver nano shell which has a tuneable plasmon resonance moving towards the near-infrared region of the electromagnetic spectrum. The shell can then be functionalized with a biomolecular probe (Figure 2). This is important for biological analysis as it minimizes cellular or tissue autofluorescence which can dramatically affect the signal-to-background ratio and allows analysis in the spectroscopic biological window.

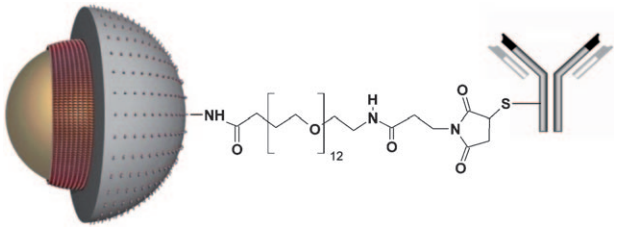

Figure 2. Structure of silica-encapsulated and biofunctionalized SERS labels. Left: Gold–silver nanoparticle with a self-assembled monolayer of Raman label molecules (red) and a protective silica shell with amino groups (gray). Middle: heterobifunctional polyethylene glycol spacer. Right: monoclonal antibody for antigen recognition.[9]

A gold nanoparticle was shelled with silver and a self-assembled monolayer of the Raman label (mercaptonitrobenzoic acid) was then coated by layer-by-layer deposition with polyelectrolytes followed by silica shelling by a modified Stöber method. The surface of the silica was then functionalized with an antibody that recognizes prostate specific antigen (PSA) and the SERS-active nanotags were used to image PSA in a tissue sample. In a more recent advance of this approach the group has synthesized a silane-functionalized reporter molecule which self-assembles on the nanoparticle surface and can then be crosslinked through the addition of tetraethyl orthosilicate (TEOS) to form a silica-encapsulated nanoparticle with a well controlled ratio of reporter to nanoparticle.[10] This is an important step forward in the synthesis of tuneable SERS labels which can subsequently be functionalized to provide unique vibrational codes for a number of different target species. The approach was exemplified using an antibody targeting its antigen in a tissue sample, however there are many alternatives which can be used based on this initial work.

In summary, the field of SERS has witnessed noteworthy advances in recent years which have provided new approaches to surfaces for the Raman enhancement; moreover, the nanoparticles involved can also be used as labels for target species. These examples indicate great confidence that the field is growing in terms of innovation and acceptance in the scientific community and looks set to continue its dramatic advancement over the coming years.

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