

Surface-enhanced Raman spectroscopy

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Modern analytical tools should enable highly specific identification and characterization of inorganic and organic matter with minimal effort for sample preparation. Raman spectroscopy is one such highly specific method that enables identification of molecules through their specific molecular fingerprint information. Unfortunately the sensitivity of Raman spectroscopy is quite low, meaning that it cannot be used for the analysis of samples with low analyte concentration. One possible solution to this problem is the use of metal nanostructures or particles to enhance the intrinsically weak Raman effect. This method is known as surface enhanced Raman spectroscopy (SERS) and it combines the specificity of Raman with high sensitivity which enables analysis of samples with minimal analyte concentration. However, to develop SERS further and to convert it in a standard analytical tool several problems have to be solved. A major issue for routine application of SERS is the production of reproducible SERS substrates, which have predictable and reliable enhancement factors, because the enhancement of the Raman effect is highly dependent on the structure of the SERS substrates.

The rapid development of nanotechnology has helped develop new concepts for the production of reproducible SERS substrates. In their review Ren et al. describe and compare different methods for production of SERS sub-

strates. Further, they analyze existing methods for determination of the enhancement factors of substrates and propose, on the basis of the results from this analysis, guidelines to obtain these factors.

Extremely high enhancement factors can be achieved by using dimers of gold nanoparticles, whereby the enhancement factor depends on the spacing between the two particles. Using finite element method calculations Schatz et al. investigate the optimal spacing of particles.

Another possible SERS substrate consists of planar gold nanostructures, which are made by Electron Beam Lithography. These structures can be reproducibly fabricated but have an interparticle spacing which is much bigger than the optimum described by Schatz and co-workers. Using different analytical methods, the plasmon dynamics and evanescent field distributions of these substrates have been investigated. Besides employing SERS substrates, an alternative approach for the realization of SERS sensors is the use of optical fibres. Inspired by the success of optical fibre systems implementing conventional Raman spectroscopy, there is growing interest in the development of SERS-active fibres. In their review Stoddart and White discuss the development of technologies for the production of such fibres and also show the potential and challenges in these recent developments.

Probably one of the most widely used type of SERS substrate employs metal colloids and their aggregates. These colloids can be used in solution and also quench the fluorescence signal of the analyte in the course of surface enhanced resonance Raman spectroscopy. This enables the highly sensitive detection of dyes in aqueous solution as described by Shadi et al. By combination of metal colloids and microfluidics, tools can be created that enable the automated and sensitive detection of substances. In their contribution Choo et al. use this approach to detect

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mercury(II) ions in water in droplets with volumes in the picoliter range. The strong interaction between the gold nanoparticles, which act as SERS substrates, and mercury (II) ions causes a change in the SERS signal of the reporter molecule Rhodamin B, which is adsorbed by the gold nanoparticles. Through the binding of dyes or other Raman labels metal nanoparticles can be used as labels. The combination of different dyes, even on the same particle, enables the creation of a variety of labels which can be read in parallel as indicated by Gellner and Schlücker. Specifically modified particles can be even used for the mapping of yeast cells, as described by Itoh et al.

Silver and gold nanoparticles are also used by Ozaki et al. to investigate the influence of localized surface plasmon resonance on the SERS process. Ozaki et al. use these substrates for detection of proteins and propose a new strategy for detection of biomolecules. The use of SERS for the identification and characterization of proteins and protein–ligand interactions is reviewed by Han and co-workers. A specialized use of SERS to investigate the changes in cytochrome P450 upon binding of fatty acids is described by Deckert et al. Through changes in the measured spectra they were able to differentiate between substrate-free and substrate-bound enzyme. This illustrates nicely the potential of SERS for investigation of protein–ligand interactions.

By combining SERS with AFM or similar technologies spatial resolution in the nanometre range can be achieved. In their review Hartschuh et al. describe recent experimental studies using tip-enhanced near-field optical microscopy (TENOM) for investigation of single-walled carbon nanotubes. This technique enables optical and topographical imaging with a nanometre resolution and thus enables insight into the spectroscopic properties of materials on the nanoscale. Hayazawa and co-workers give an example of how tip-enhanced Raman spectroscopy (TERS) can be used. They use TERS for investigation of different semiconductors and quantum dots and for strain analysis in semiconductors.

Surface-enhanced Raman spectroscopy is one of the most versatile analytical tools, as demonstrated by the contributions in this special issue. In the next few years it

will be interesting to watch the technique mature and to see if SERS indeed develops into a widely used standard technology. SERS undoubtedly has the potential to do so!



Jürgen Popp is a full professor at the Friedrich Schiller University of Jena, Germany, where he holds a chair of physical chemistry. In June 2006 he also became Scientific Director at the Institute of Photonic Technology. His work has been awarded the Faculty Prize of Chemistry (1995), by the “Bayerischer Habilitationsförderpreis” (1997), the “Förderpreis der Würzburger Korporationen” (2001), and the Kirchhoff–Bunsen Award (2002). J. Popp’s research interests are mainly centred

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