Power Budget Analysis for Waveguide-Enhanced Raman Spectroscopy

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Waveguide-enhanced Raman spectroscopy (WERS) represents an attractive form of enhanced analytical technique for surface chemistry. Comparisons of surface enhanced spectroscopies are hampered by ill-defined enhancement factors. In this work, a full power budget analysis, incorporating dielectric waveguide optimization, is presented for WERS as an approach towards defining a rigorous performance measure.

Introduction

Surface-enhanced Raman Spectroscopy (SERS) is a powerful tool for chemical analysis which can suffer from poor repeatability due to the sensitive nature of plasmonic interactions. Waveguide-enhanced Raman spectroscopy (WERS) is emerging as a competitive analytical tool which avoids nanostructured noble metal surfaces but which potentially provides comparable surface enhancements in a sensorised format [1,2]. Comparison of these approaches suffers from ill-defined definitions of surface enhancement. We present a power budget analysis of WERS, relating the received power in a Raman emission line to the incident pump laser power, using waveguide surface intensity and Raman cross-section, allowing WERS optimisation and clear comparison of surface-enhanced techniques.

Results

Simulations were made for 1mW power per 1mm width at 633nm travelling in a Ta_2O_5 waveguide (n≈2.1) on silica (n≈1.46) with an air superstrate. The modes of the waveguide structure have been solved using a complex transfer matrix approach. The core thickness has been optimised in order to achieve the highest surface intensity at this wavelength as shown in Fig 1 for the fundamental mode in TM polarisation. Comparisons show that for a $1mm^2$ area of illumination the waveguide yields a 1000-fold increase in surface intensity compared with direct illumination of a surface with the same power.

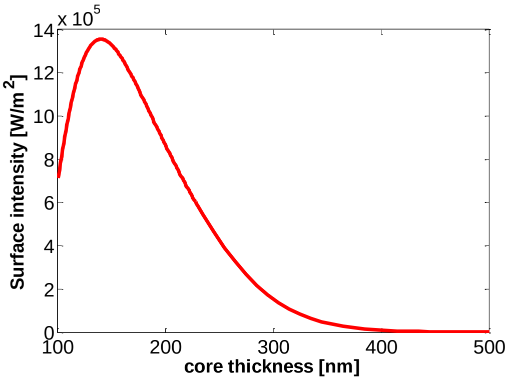

Fig 1. Waveguide surface intensity

A power budget analysis is then employed to determine the power (per unit surface area) emitted in a specific Raman line for unit power in the waveguide. In the case of a semi-infinite toluene superstrate for the waveguide optimized in Fig 1, the emitted power in the $1000cm^{-1}$ line gives a Raman power of 1.1fW. This methodology, which will be extended to waveguide collection as well as excitation, allows unambiguous comparison of Raman configurations. In SERS, factors of 10^6 enhancement are achieved through similar (factor 1000) enhancements for both excitation and emission. Waveguide collection (as opposed to normal collection) of Raman signals in WERS can be expected to achieve similar efficiencies to SERS, without the losses inherent in metal structures.

Summary

Waveguide-enhanced Raman spectroscopy offers advantages over SERS in terms of repeatability and robustness if similar signal enhancements can be achieved. SERS and WERS need rigorous methods to aid comparison. Here a power-budget analysis for WERS is proposed, which can readily be extended to other configurations, and detailed examples will be given of numerically derived enhancement factors.

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