Raman spectroscopy using photonic waveguides

Ashim Dhakal[a,b*], Ananth Z. Subramanian[a,b], Nicolas Le Thomas[a,b] and Roel Baets[a,b]

[a] *Photonics Research Group, INTEC-department, Ghent University - imec*
[b] *Center for Nano- and Biophotonics, Ghent University*

Abstract: We propose and demonstrate the use of CMOS-compatible integrated photonic waveguides for Raman spectroscopy. A droplet of isopropyl alcohol is evanescently excited and detected using single-mode silicon-nitride strip waveguides. Dependence of Raman signal with the length of waveguide is also reported.

1. Introduction

We propose Raman sensing using a CMOS compatible integrated photonics platform and report the first definitive experimental results of measurement of Raman signals on them. The proposed waveguide sensor is based on Raman scattering due to analyte molecules present in the cover region of the waveguide, whereby the waveguide carries the pump beam and also collects the Stokes light [1]. This technique exploits the enhancement effects inherent to high-index-contrast waveguides [2] and to a long interaction length. The combined effect leads to an increased light-matter interaction, resulting in a higher sensitivity as required by spectroscopic applications, especially in the context of spontaneous Raman spectroscopy.

Recently, we investigated the scattering efficiency of a particle located in the vicinity of a channel waveguide for several geometries [1], and determined the overall efficiency (η) of scattering from a guided mode and subsequent emission coupled back to the fundamental mode (both TE and TM) of a rectangular channel waveguide by uniformly distributed particles in its surrounding. We showed that under typical conditions, the maximal conversion efficiency (defined as the ratio of the emitted power collected by the waveguide and the incident pump power in the mode) for silicon nitride (SiN) waveguides for a molar solution to be in the order of 10^{-8} which is, as per our calculations, about two orders of magnitude larger than in conventional confocal Raman microscopes, as also shown in context of liquid core waveguides [3].

2. Experimental

A CW Ti-sapphire laser set at a wavelength of 785 nm, and 90 mW power is coupled to the waveguide by end-fire coupling (coupling loss: ~11 dB/facet) using an aspheric lens of effective focal length 8 mm (NA=0.5). The co-propagating Raman signal (Stokes) collected by the waveguide is then collimated via a 60x (NA=0.9) objective towards an edge filter, with the edge wavelength at 790 nm. The collected Stokes signal is then focused to a singlemode optical-fibre using a parabolic mirror of 15 mm effective focal length (NA=0.2) and measured using a commercial spectrometer (Avantes SensLine). We use SiN waveguides (with a cross-section of 800 by 220 nm) on top of a 2.4 µm silica cladding on a silicon substrate [2] as our sensing platform. The waveguides of lengths 1.6, 2.5, 4.4, and 8.1 cm spiralled with a 50 µm radius were used as the sensing device for the experiment, where isopropyl alcohol (IPA) drops were applied on top. The Raman signals before and after application of IPA was measured. The spectra after subtracting the background Raman acquired before application of IPA are shown in figure 1 for several waveguide lengths. We observe that the signal strength increases from 1.5 cm to 2.5 cm and then decreases as we go to longer waveguide lengths. The initial increase is due to longer interaction length between the waveguide evanescent field and the IPA molecules. The consequent decrease in the signal strength is due to pump depletion and propagation loss of the signal in the waveguide. The propagation loss of the pump and signal is estimated to be between 1 and 2 dB/cm from independent measurements [2]. The measured dependence of signal strength with waveguide length agrees with our model within the accuracy of the measurements.

3. Conclusions

We experimentally demonstrated for the first time, to the best of our knowledge, the measurement of Raman signal using singlemode integrated optical waveguides whereby both the pump and the collection is done through the evanescent tail of the waveguide mode.

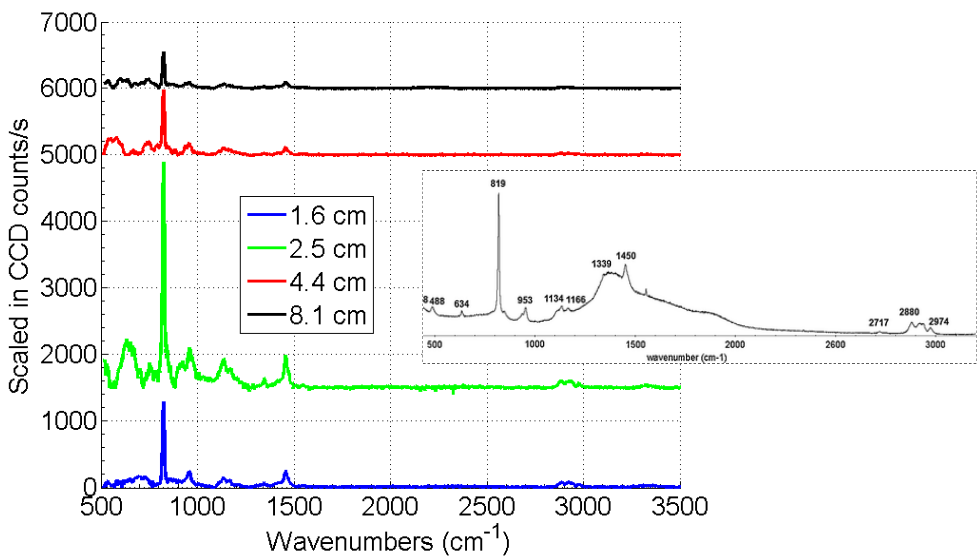

Figure 1 The background subtracted Raman spectra of IPA measured using photonic waveguides of lengths 1.6, 2.5, 4.4 and 8.1 cm (from bottom to top respectively, shifted vertically for clarity with zero at 3200 cm^{-1}). Raman spectrum of IPA [4] is provided in the inset for comparison.

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