Surface plasmon effects induced by uncollimated emission of semiconductor microstructures

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The inherent surface sensitivity of the surface plasmon resonance (SPR) effect has made it highly attractive for biochemical analysis of processes localized on metal surfaces. Many SPR devices have been developed and made commercially available for that purpose in the past 20 years. However, most of them are relatively bulky and a monolithically integrated SPR microchip, which could be easily integrated with specimen processing hardware for a wholly automated analysis, has yet to be demonstrated. We have recently proposed an innovative SPR microstructure comprising a metal coated SiO_2 layer deposited on top of a photoluminescence (PL) emitting quantum well (QW) wafer. Nano-scale grating fabricated in the metal layer allows for the extraction of the SPR signal. The entire device, thanks to the built-in light source and the application of a SPR imaging technique, has the potential to become a highly compact SPR biosensor for simultaneous detection of numerous biomolecules. Although the proof of concept of the QW-SPR device has already been demonstrated [1], a full understanding of its operation has yet to be developed, a step critical to our ability in designing a fully optimized and functional integrated SPR architecture for specific biosensing applications.

The functioning of the QW-SPR device is based on the uncollimated, and usually incoherent, emission of QW. Therefore, any given point of the metal-dielectric interface is exposed to the whole range of wavevector spectra and thus, coupling of all the SPR modes supported by the architecture is expected to take place. The multiple SPR coupling along the metal-dielectric interfaces distinguishes our QW-SPR device from other "macro" SPR devices, where only one wavevector is excited at a time.

In this communication, we discuss the results of our calculations aimed at the description of surface plasmons generated at SiO_2/Au/Photoresist (PR) interfaces irradiated by an uncollimated emission from a semiconductor QW [1]. The calculations were carried out using a Rigorous Coupled-Wave Analysis (RCWA) algorithm and a scattering matrices approach. This allowed us to predict the coupling of QW PL and describe the propagation of SP in both the Near- and Far-Fields. It has been determined that the two SPs (Au/PR and Au/SiO_2) could couple in the 0^{th} and higher diffraction orders where the injected in-plane wavevectors from the GaAs-AlGaAs QW structure can always meet SPR conditions. As a dramatic result, the coupling efficiency of SPs can be up to 10^2 times higher when coupling of all SPs occurs in the 0^{th} diffraction order.

An $\omega(k_{||})$ map (angular frequency versus in-plane wavevector) of the analytical far-field dispersion relation for the investigated microstructure is shown in Fig. 1. Such a map could be determined experimentally using, e.g., a spectro-angular SPR system [2]. A normalized QW PL intensity at 820 nm for this microstructure [1] has been plotted in Fig. 2 and compared with calculated values. A very good agreement has been achieved, which provides validation of our calculations. In addition, our calculations enabled us to provide accurate interpretation of experimental data concerning other semiconductor-based SPR microstructure, with PL emission from Si nanocrystals [3]. We will discuss the perspective of the reported approach for designing a monolithically integrated SPR device for specific bio-sensing applications.

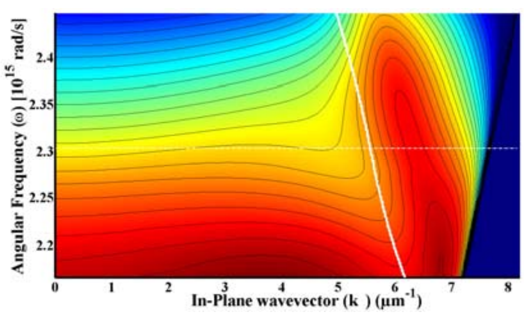

Fig 1. Dispersion relation map (angular frequency versus in-plane wavevector) for the QW-SiO_2/Au/Photoresist microstructure. SPR follows the white solid line.

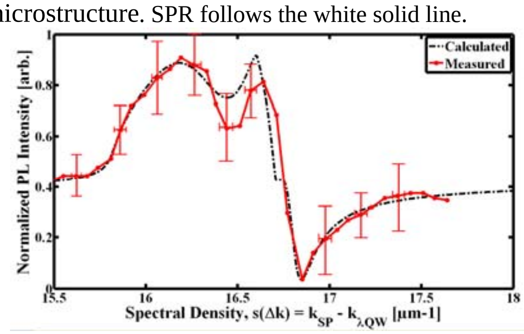

Fig 2. A QW PL emission at 820nm illustrating a match in calculated and measured in [1] intensity modulation.

[1] D. Lepage et al, APL **91**, 163106 (2007)
[2] C.J. Alleyne et al, Opt. Exp. **16**, 19493 (2008)
[3] E. Takeda et al, APL **89**, 101907 (2006)

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