Plasmon excitation by the Gaussian-like core mode of a photonic crystal waveguide

Maksim Skorobogatiy, Andrei V. Kabashin

Ecole Polytechnique de Montréal, Génie Physique, Montréal, QC H3C 3A7, Canada
email : maksim.skorobogatiy@polymtl.ca

Summary

We describe a resonant excitation of a plasmon over a metal film by a leaky mode of a single mode photonic crystal waveguide. We show that small changes in the ambient refractive index outside the metal lead to strong variations in the losses of the waveguide mode, making such a device a good candidate for sensor applications

Introduction

Propagating at the metal/dielectric interface, surface plasmons are extremely sensitive to changes in the refractive index of the dielectric. This feature constitutes the core of many Surface Plasmon Resonance (SPR) sensors [1]. Typically, these sensors are implemented in the prism geometry to direct p-polarized light through a glass prism and reflect it from a thin metal (Au, Ag) film deposited on the prism facet. The presence of a prism allows phase matching of an incident electromagnetic wave with a plasmonic wave at the metal/ambient dielectric interface at a specific combination of the angle of incidence and wavelength, which is resonantly dependent on the refractive index of an ambient medium. In SPR biosensors, refractive index changes due to biological reactions are controlled by monitoring angular [1], spectral [2] or phase [3] characteristics of the reflected light.

In this presentation, we consider novel plasmon architectures based of photonics crystal waveguides. In particular, we demonstrate efficient SPR excitation with a Gaussian-like core mode of a PC waveguide. Compared to single mode planar waveguides [4], such configuration makes the plasmon excitation possible at steeper angles of modal incidence in the presented case), and lower frequencies, improving the sensitivity and enlarging the probe depth of a sensor.

In particular, we consider plasmon excitation by a Gaussian-like TM polarized mode of an anti-guiding photonic crystal waveguide (Fig. 2) where light confinement in a lower refractive index core is achieved by a surrounding multilayer reflector [5]. As incoming laser beam is typically Gaussian-like, power coupling efficiency into the core mode is high due to good spatial mode matching. Moreover, coupling to such waveguides can be further simplified by choosing waveguide core size to be significantly larger than the wavelength of operation. This is possible as antiguiding waveguides operate in the effectively single mode regime regardless of the core size. Leaky core mode can be easily phase matched with a plasmon mode by design, as effective refractive index of such a mode can be readily tuned to be well below the value of a core index. Another important aspect of a proposed setup is a freedom of adjusting coupling strength between the core and plasmonic modes. As penetration of a leaky mode reduces exponentially fast into the multilayer reflector, coupling strength between the plasmon and core modes can be controlled by changing the number of reflector layers between the core and a metal film.

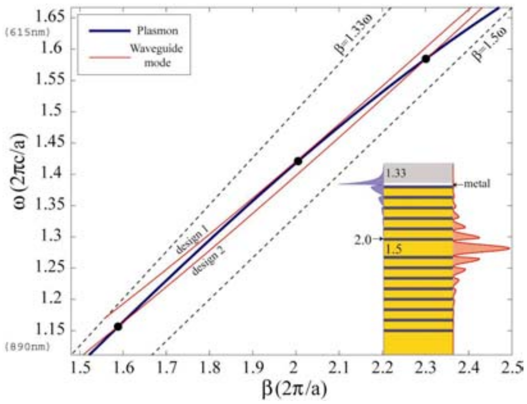

Fig. 1 Band diagrams of the core mode of a PC waveguide (red) and plasmon (blue). Two waveguide designs are presented demonstrating that phase matching point (circles) can be chosen at will. Inset – coupler schematic; /H_y/ of a plasmon (left) and a core mode of a PC waveguide (right).

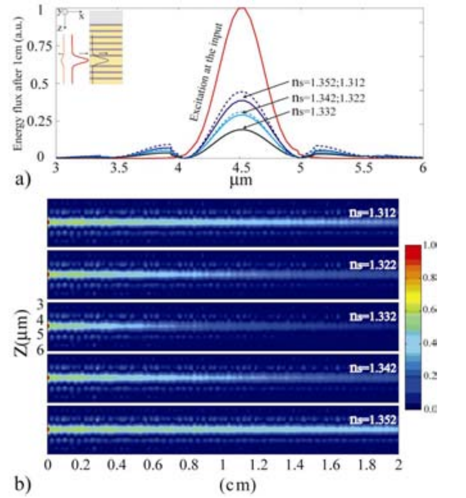

Fig. 2 S_x energy flux in a multilayer waveguide for various values of the ambient refractive index: a) distribution across waveguide cross section after 1cm of propagation b) distribution over 2 cm of propagation

To verify mode analysis predictions field propagation was performed. A TM polarized 2D Gaussian beam (*H* field along Y direction) was launched into a waveguide core from air (inset in Fig. 2(a)). At the air-multilayer interface incoming Gaussian was expanded into the fields of all the guided and leaky, and some evanescent multilayer modes (60 altogether), plus the field of a reflected Gaussian by imposing continuity of the Z and Y field components at the interface. Optimal coupling of 71% of an incoming power into the Gaussian-like core mode was achieved with a Gaussian beam of waist $0.8d_c$ centered in the middle of a waveguide core. Reflection from the air-multilayer interface was less than 3%. In Fig. 2(b) distribution of an X component of the energy flux S_x in a propagating beam is shown for various values of an ambient refractive index. From the figure it is clear that beam propagation loss is very sensitive to the changes in the ambient refractive index. To quantify sensitivity of our design in Fig. 2(a) we present S_x distribution across a waveguide cross section after 1cm of beam propagation. From this figure we calculate that change in the integrated energy flux as a function of the ambient index deviation from 1.332 of a pure water can be approximated as $\Delta P = P_{1.332} \sim 60/n_a - 1.332/$; thus, an absolute variation of 0.001 in the ambient refractive index would lead to a ~ 6% variation in the transmitted power which is readily detectable. Similar calculations can be carried out assuming that refractive index of water stays unchanged, while on the top of a metal layer one deposits a very thin layer of thickness d_{bio} of a biological material with refractive index

References

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