PhD: Plasmon-Soliton coupling

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Prerequisites: **electromagnetism, photonics, nonlinear phenomena, numerical simulations, fundamental physics**

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1 Introduction

During the last few years, the fabrication and study of nanoscale metal structures leads to the development of *plasmonics* as a part of photonics [1]. The main advantage of the involved waves (Surface Plasmon Polarition SPP) in these structures is their tight spatial confinement near the metal/dielectrics interface. Several applications have already been proposed or realized [2]. To extend the capabilities of these structures, one way is to consider the coupling between the plasmons and optical solitons. This way is not studied yet except in one article which mentions their coupling but focusing only on the soliton properties [3]. The solution we propose would allow us to control optically the plasmon-based nanodevice using the field intensity in the nonlinear region. These hybrid devices would also allow to eliminate or to reduce the limitations of conventional SPP-based structures, generated by the high losses due to the metals.

2 Plasmon-soliton coupling

One of the important problems of these devices using plasmons is the excitation of these SPP waves using conventional light sources [2]. Actually, a plasmon propagating along the metal/dielectrics interface has an effective index greater than the refraction index of the dielectric part. It can only be excited with evanescent waves generated by using a total internal reflection or by an adapted diffraction gratings. Nevertheless, another possible excitation mechanism, proposed very recently, is the coupling to an optical solitons [4]. Optical solitons have been studied since several tens of years [5] and many theoretical and experimental results are available[6]. On the other hand, their coupling to plasmon is still to be studied. This is the main goal of this research project. Due to the intrinsic nonlinear nature of soliton, the coupling is nonlinear by itself. We have the power of the soliton at our disposal to adjust the coupling with the plasmon. One can see this in terms of effective indices: the one of the soliton depends of its amplitude which involves that the resonance condition between the plasmon and the soliton will depend on the amplitude of this last for a fixed nanostructure. One can also view this phenomenom as an avoided crossing between "modes" where the control paremeter is no longer the wavelength but the soliton amplitude.

3 Implementation

We plan to start our study by the modeling of two structures. The first one is a multilayer metal/linear dielectrics/nonlinear dielectrics. The second one is a multilayer metal/nonlinear dielectrics. In both cases, we will consider a Kerr type nonlinearity due to its very fast time constant and due to the fabrication possibilities.

3.1 Theoretical results and numerical modeling

In order to get a phenomenological description of this problem, we plan to use the recent results obtained by Bliokh and his colleagues [7]. In this frame, our Spanish colleague, the Professor Albert Ferrando of the University of Valencia, has proposed to adapt the Bliokh's results to the configurations involved in this research project. In this case, we would have a simplified approach of the problem which will guide numerical simulations based on more complete and realistic models of the planned devices. For the more numerical issues, we have already developped a finite element method during the thesis of Fabien Drouart [8] to compute some of the nonlinear solutions in waveguides. Thanks to this method, we were able to generalize the Townes soliton taking into account the size and shape of the nonlinear structure [9]. The published results were dedicated to the scalar only. Nevertheless, in the PhD thesis, we describe the method for the vector case and give the corresponding results. Futhermore, this method can deal with the material losses that exists in real metals. Consequently, we have a vector method which, after some modifications and improvements, that will allow us to modelize the metal-dielectrics nonlinear structures considered in this research project.

In a second step, we will develop from existing methods (split-step Fourier method used to solve the nonlinear Schrödinger, beam propagation method, Finite Difference-Time Domain for example) one or several numerical tools allowing us to compute the time evolution of the electromagnetic fields in the planned nonlinear metal-dielectric structures. We have a strong expertise in electromagnetics modeling [9, 10]. During the last eight years we developed or co-developed three numerical methods to study photonic structures: the multipole method, the fast Fourier factorization method applied to mode searching, and a finite element method for linear structures and recently extended to the nonlinear case (see previous paragraph).

In a third step, the study of the structuration of the metal layer can be started. our research team the CLARTE team of the Fresnel Institute, has a strong kown-how in this field.

3.2 Experimental realizations and characterizations

This project may contain an experimental part even if the PhD student is not the researcher realizing it. The RCMO research team of the Fresnel Institute, managed by Professor Michel Lequime is able to build the needed metal/dielectrics nanostructures. To get them, the used nonlinear material could be a chalcogenide glass named 2SG ($Ge_{15}Sb_{20}S_{65}$). This high index glass is fabricated by the "Verres et Céramiques" team of the Chemistry laboratory of the University of Rennes (CNRS laboratory 6226) by Virginie Nazabal. We have tight links with this laboratory of Rennes since 2006 in the frame of several research contracts (ANR, DGA, CNRS).

The hybrid metal/dielectrics/nonlinear dielectrics we want to study, since they can solve the problem of the short propagation distance of plasmons and give an additional control parameter through the soliton amplitude, can allow breakthroughs in plasmonics applications like bio-sensors. The participation of our Institute in an applied research consortium OPTITEC dedicated to photonics can be useful for this ultimate phase of the PhD.

References

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