Controlling the phase and amplitude of plasmon sources at a subwavelength scale

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Surface plasmons polaritons (SPPs) are collective excitations of electrons coupled to an electromagnetic field at the interface between a dielectric and a metal [1]. Their evanescent nature along the normal to the metal/dielectric interface allows a subwavelength confinement that can be significantly smaller than diffraction limited optical waves in bulk media. SPPs, therefore, are ideal candidates for the construction of subwavelength optical devices. In the past few years, SPPs have also been identified to be the major physical mechanism involved in the extraordinary transmission of light (ETL) through metal films with subwavelength holes which was first reported by Ebbesen et al [2]. Subsequent studies have been made on uniform periodic arrays of holes, slits, and more complex shapes fabricated in metallic films. Those studies demonstrate that one can take advantage of the interferences between plasmons generated on metal films by uniform periodic sources (e.g., slits or holes in metal films) to, for instance, focus or disperse light, or realize ETL. Naturally, for flexible control and manipulation of light by such metal films, it is necessary to evolve beyond the uniform periodic sources and introduce the rich possibilities afforded by non-uniform source.films.

When light enters a subwavelength dielectric structure in a metallic film, a significant fraction, if not all, of the light propagates through the film as surface plasmons that are confined at the metal/dielectric interfaces. For example, transverse magnetic (TM) polarized light impinging on a silver film containing air gaps gives rise to waves known as gap plasmons (GPs), whose properties are closely related to the dimensions of the gaps: the smaller the gap width, the larger the wavenumber of the GP. This way, one can design sources of plasmons with tuned phase by adjusting the width of the gap. Similarly, one can fill the air gaps with different dielectrics hence inducing an optical path length between the generated plasmons. Those two approaches are quite inflexible and practically hard to fabricate.

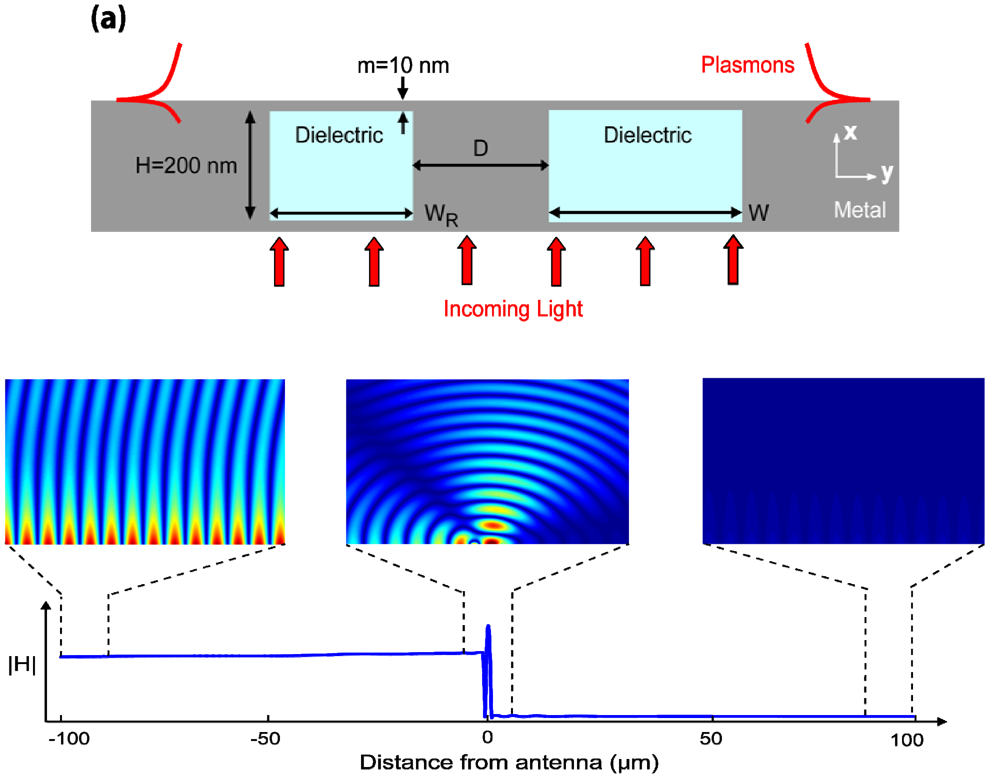
In order to realize surface plasmon sources with tunable phase and amplitude, our approach utilizes the gap plasmon dispersion relation along with Fabry-Perot (FP) resonances in a cavity. Air gaps in metal films typically display low-efficiency FP resonance that, as we will show, can be increased by introducing highly reflective "mirrors" on both sides of the metal film. Sharper resonance results in longer propagation of the GPs in the gaps due to constructive interference and multiple reflections in the cavity. Hence, the relative phase accumulation at the output side for slits of varying widths is increased regardless of the metal film thickness. Our cavity design corresponds to a forced mechanical oscillator: when driven below, at, and above the resonance frequency, the response lags, matches, or leads in phase. Namely, tuning the width of the gap, or equivalently the GP wavenumber, allows a control of the phase and amplitude of the generated SP.

To illustrate this new mechanism, we present a simple design consisting of only two parallel cavities of different widths (see figure). We show that such a system realizes a unidirectional plasmonic antenna similar to the one that was studied very recently by F. López-Tejeira et al. [3]. In our unidirectional antenna, however, the lateral size can be reduced to half a plasmon wavelength (compared to a minimum size of several wavelengths in [3]). Additionally, the top surface of our antenna is flat, which may prove useful for many applications such as sensing. Furthermore, using both the gap plasmons dispersion relation and the metal mirrors allows us to provide a design that does not use unrealistic slit width, nor very difficult fabrication procedures such as filling different slits with different dielectrics.

References:

1. H. Raether, Surface Plasmons: On Smooth and Rough Surfaces and on Gratings Springer, (Berlin, 1988).
2. T. W. Ebbesen, H.J. Lezec, H.F. Gaemi, T. Thio and P.A. Wolff, Nature, **391**, 667 (1998).
3. F. Lopez-Tejeira, S.G. Rodrigo, L. Martin-Morino, F.J. Garcia-Vidal, E. Devaux, T.W. Ebbesen, J.R. Krenn, I.P. Radko, S.I. Bozhevolnyi, M.U. Gonzales, J.C. Weeber and A. Dereux, Nat. Phys., **3**, 324 (2007).

Figure:



Scheme of the unidirectional plasmonic coupler and field by the antenna.
The field at the antenna's position has been devided by 10 to fit the same colorbar.