Plasmonic slow light in metal film waveguides

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Slow light is light with a remarkably low group velocity, which is generally slower than 1/100 of the light velocity in vacuum, *c* [1]. Slow light offers the opportunity for the dramatic field enhancement by the spatial compression of optical energy [2]. One of the recent researches in slow light has been based on surface plasmon polariton (SPP) [3-5]. SPP has the possibility to control the group velocity v_g, and show the high characteristics of slow light from the dispersion relations. Moreover, SPP offers large wave vectors and high field confinements on a metal surface beyond the diffraction limit, hence slow SPP, which we call plasmonic slow light (PSL), leads to the accumulation of optical energy and giant local fields in nanoscale regions.

In this paper, we report PSL in metal film waveguides (Fig. 1). We found out that the metal film waveguide shows PSL with a remarkably high group index and the group velocity dispersion (GVD) = 0, by controlling the dispersion relation. The PSL will be a new effective approach for field enhancement, thus opening the way to developing new applications.

A metal film waveguide is regarded as a thin metal layer (Ag) sandwiched between semi-infinite dielectric layers (Si). In the metal film waveguide (Si-Ag-Si), the SPPs propagate as a complementary coupled mode, and show the bending dispersion line, which represents PSL. To investigate the property of the PSL, we calculated the dispersion relation, the group index n_g and the GVD, including a loss factor, using the relative permittivity of a metal and a dielectric, defined by the Drude model and the Sellmeier equation, respectively. The n_g shows a slow-down factor from *c*, and the GVD value is used for assessing pulse distortion. As shown in Fig. 2, the Si–Ag–Si waveguide with a film thickness *h* of 40 nm, has n_g = 460 at a wavelength of 605 nm, corresponding to the point GVD = 0 where a no pulse distortion occurs. The n_g is about one order of

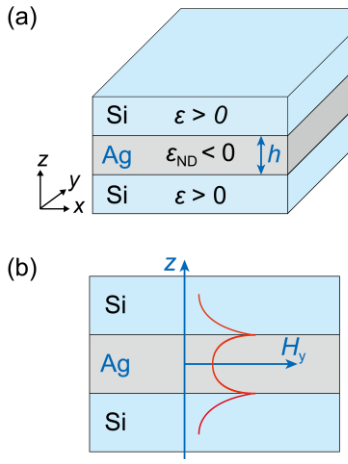

Fig. 1. (a) The schematic diagram of metal film waveguides (Si-Ag-Si). (b) The magnetic field distribution H_y.

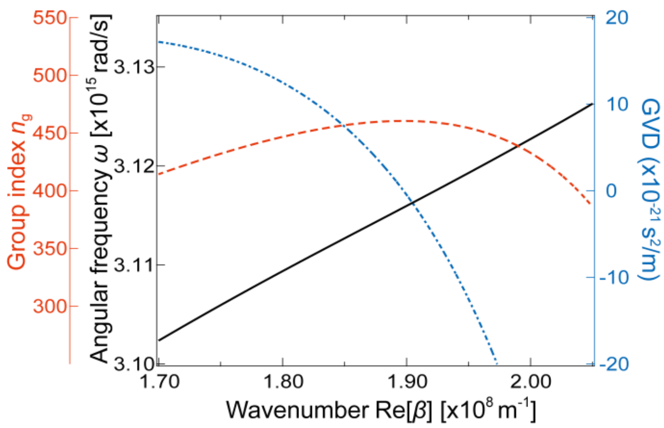

Fig. 2. The dipersion relation (solid line), the group index (dashed line) and the GVD (dashed-dotted line) in the Si-Ag-Si waveguide with *h* = 40 nm.

magnitude higher than that obtained in an ordinary slow light device, i.e. photonic crystals.

We simulated pulse propagation in the Si–Ag–Si waveguide with an infinite film width and h = 40 nm by the finite-difference time-domain (FDTD) method. We excited the PSL with a pulse width of 500 fs at a center wavelength of 605 nm by a grating coupler, and observed the PSL temporal pulse shapes (Fig. 3(a)). The time shift of the PSL between the propagation distance of 15 nm and 20 nm, is 7.2 fs (Fig. 3(b)), and we obtained ng = 430, which shows good agreement with the numerical analysis.

In conclusion, we reported the PSL with a remarkably high n_g and the GVD = 0 in the metal film waveguides. The PSL will induce field enhancement due to spatial energy compression, which leads to the dramatic enhancement of nonlinear optical effects. We expect that our findings will open the way to the development of various optical devices with slow light.

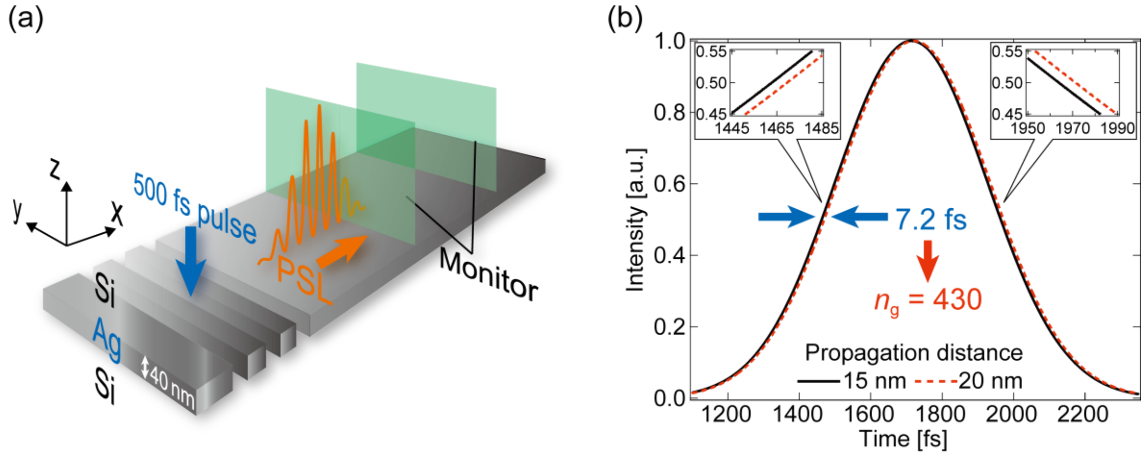

Fig. 3. (a) The simulation model. (b) The SPP temporal pulse shapes at the propagation distance of 15 nm (solid line) and 20 nm (dotted line).

References

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