Longitudinal and transverse photo-induced voltage in metallic photonic crystal slabs

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When a laser beam with angular frequency ω is incident on a material lacking a center of inversion symmetry, the second order nonlinear polarization of the material has $\omega + \omega = 2\omega$ and $\omega - \omega = 0$ components. The two terms are responsible for second-harmonic generation (SHG) and optical rectification, respectively. Conventionally the symmetry in this context refers to that in the atomic scale and therefore these effects are observed only in a certain class of material or at surface. The artificial structure with the scale of light wavlength, however, may also play a significant role.[1] Optical rectification in metallic photonic crystal slabs has been analyzed in terms of momentum conservation of light.[2] As such a structure contains very thin segments, which is rather difficult to control precisely in the etching process, we will discuss optical rectification phenomena in more well-defined structures in this talk.

The first simple example is a Au thin film with dielectric grating structure with period of 700 nm. When p-polarized light is incident on the sample, a surface plasmon polariton (SPP) mode is excited at a certain angle which depends on the laser wavelength. The SPP excitation manifests itself as a dip in transmission and reflection spectra. Optical rectification effect is observed as a voltage generated across the sample. We used an optical parametric oscillator as a tunable light source, and the voltage was measured with a digital oscilloscope through a fast amplifier for various wavelengths an incident angles. The pulse width is 5 ns and the repetition rate is 10 Hz. As the structure is simple, the electromagnetic field in the structure excited by the laser can be easily calculated with a transfer matrix algorithm.[3] Then it is straightforward to calculate DC electromagnetic force on free electrons. In such a plane metallic film conficuration, the scattering force is responsible for the voltage. The microscopic calculation reproduces experimental observation, while the momentum conservation argument predicts signals with opposite sign. Details will be discussed in a poster presentation by Hiroyuki Kurosawa in this forum.

The second example is a periodically perforated Au thin film. Our plasmonic crystal sample is 0.6 mm by 0.6 mm wide 40 nm thick Au film with square array of holes fabricated with an electron beam lithography technique. The period of the array and the diameter of the hole are 500 nm and 120 nm, respectively. Four electrodes are attached to the sides of the square sample as is shown in Fig.1 Two configurations are employed: In longitudinal configuration (a), the voltage along the incident plane is measured, while in the transverse configuration (b), transverse voltage is measured. At the surface plasmon polariton resonance for p-polarized light, the longitudinal voltage has a prominent peak. As for the transverse voltage, s- or p- polarized light do not give any signal, while a dispersive signal is observed around the surface plasmon resonance.[4] The sign of the signal flips as the sense of the circularly polarized light changes. As is different from the dielectric grating case, the gradient force can be the main source for the photo-induced voltage. It can be shown that transverse signal is generated as an interference between fields in the metal generated by s- and p-polarized light. It is noteworthy that the two fields are orthogonal unless the sample has appropriate shape of structure.

In order to understand the phenomena, two of us (Kurami and Nishimura) have carried out numerical calculation. Light intensity distribution in the plasmonic crystal slab is calculated with the fast multipole boundary integral equation method (FMBIEM). Boundary integral equation method (also known as boundary element method) is a numerical solver of partial differential equations which converts the original problem into an equivalent integral equation on the boundary of the domain. This method is particularly useful in wave scattering problems in an infinite domain. The efficiency of this method is further enhanced with the help of the fast multipole method. In this paper we use FMBIEM for periodic boundary value problems for Maxwell's equations developed in Reference[5].

Once the light field distribution is calculated in the metal, it is straightforward to evaluate the second order (in terms of field) force for free electrons. We will discuss the photo-induced voltage based on the numerically calculated field distribution.

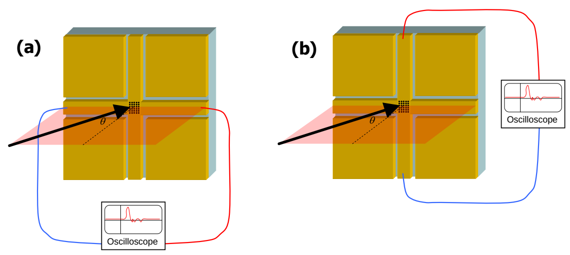

Fig. 1: Schematic setup for (a) longitudinal and (b) photo-induced voltage measurements. Plasmonic crystal slab of 0.6 mm x 0.6 mm is located at the center.

References

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