Fabrication of electromagnetically-induced-transparency-like metamaterials in the near-infrared region

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Metamaterials have attracted a great deal of attention as artificial materials having exotic optical characteristics, such as negative refractive index, compared with natural materials.[1] Because a wide range of refractive indices from negative to positive values can be obtained by the metamaterials, a variety of innovative applications, which are optical communication systems, optical storages, cloaking devices, and solar cells, have been expected. The metamaterial structures, such as split ring resonators, fishnet structures, and electromagnetically induced transparency (EIT) metamaterials,[2-4] have been reported. The EIT metamaterial generates an EIT-like effect which is the coupling in plasmonic circuit between a bright element and a dark one, arising from surface plasmon polaritons (SPPs). Although the split ring resonators and the fishnet structures have large optical absorption because of metal losses, the EIT metamaterials can reduce the absorbance of the light over a narrow spectral region because of a quantum interface effect.[2] In addition, the EIT metamaterials play a role in a slow-light medium because of a drastic modification of the dispersive properties. Although there are several reports on numerical study of the EIT metamaterials at optical frequency,[4] few experimental demonstrations have been reported.[2, 3]

In this abstract, planar EIT metamaterials consisting of dipole resonators (bright elements) and quadrupole resonators (dark elements) are fabricated and the controllability of EIT-like effects is measured. As far as we know, the fabricated EIT metamaterial has the shortest resonant wavelength. The EIT-like effect is changed by the coupling efficiency of SPPs, according to a gap distance between the dipole and quadrupole resonators.

Figure 1 shows the designed planar EIT metamaterial array. The unit EIT metamaterial consists of a single wire and a pair wire on a silica substrate. The single wire and pair wire play a role in the dipole and quadrupole resonators, respectively. There is the gap with the distance *g* in between the single wire and the pair wire as shown in Fig. 1(a). When *g* approaches nearly zero, the strong coupling between the single wire and the pair wire occurs and the EIT-like effect can be generated strongly. When *g* becomes larger, on the other hand, because the coupling between the single wire and the pair wire becomes weaker, the single wire and pair wire play roles in each resonator separately. A dipole resonance arising from the single wire can be generated but the quadrupole resonance is not generated on the pair wire. Figure 1(b) shows the schematic of the unit of periodic structures. An incident light impinges along the normal direction to the substrate surface from the upper side. The polarization direction is along the y-axis.

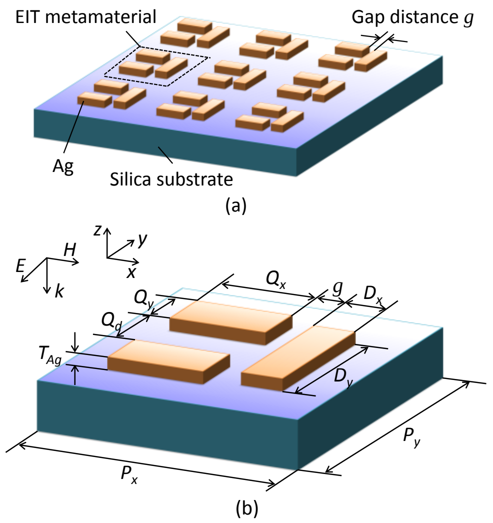

Fig.1. A schematics of (a) a planar EIT metamaterial array and (b) a unit of the EIT metamaterial structure with the geometrical parameters: D_x = 100 nm, D_y = 195 nm, Q_x = 170 nm, Q_y = 80 nm, Q_d = 80 nm, and T_{Ag} = 45 nm. The periods in both the *x* and *y* directions, P_x and P_y, are 470 nm.

Figure 2 shows a fabrication process of the EIT metamaterials. The EIT metamaterials were fabricated on a silica substrate. A thickness of the silica substrate is 500 μm. An electron beam (EB) resist (ZEP520A, Zeon) was spin-coated on the silica substrate. The resist thickness was around 120 nm. The metamaterial arrays were patterned by a high resolution EB lithography system (ELS-G125S, Elionix) operating at 130 kV. The region of each metamaterial array is 100 μm × 100 μm. Next, using an EB evaporation system, chromium with a 1 nm-thickness was deposited as an adhesion layer, followed by a deposition of silver with a thickness of around 45 nm. Finally, the metamaterial arrays were fabricated by a lift-off method.

Figure 3(a) shows a scanning electron microscope (SEM) image of the fabricated EIT metamaterial. Figure 3(b) shows the measured transmittance spectra by using a microspectroscope. At *g* of 17 nm and a wavelength of 820 nm, because the dipole and quadrupole resonators are coupled strongly, the EIT-like effect is generated and a high transmittance of 67% is then observed. At *g* of 90 nm and a wavelength of 820 nm, on the other hand, because the coupling between the dipole and quadrupole resonators is disappeared and the only dipole resonance is excited, the EIT-like effect is not observed and the transmittance is decreased to 22%. With increasing of *g* from 17 nm to 90 nm, the EIT-like effect is gradually disappeared.

In summary, we experimentally demonstrated planar EIT metamaterials at the wavelength around 820 nm. The EIT metamaterial mainly consisted of the single wire and the pair wire. The single wire and the pair wire play a role in the dipole resonator (the bright element) and the quadrupole resonator (the dark element), respectively. There is the gap between the single wire and the pair wire. Optical characteristics according to the change of the gap distance were measured with the microspectroscope. At the gap distance around under 48 nm, the EIT-like effect was observed and the transmittance was increased up to 67%. At the gap distance of 90 nm, the dipole resonance was observed and the transmittance was decreased to 22%. The EIT-like characteristic is expected for realization of low-loss metamaterials and slow-light devices in the near-infrared wavelength region.

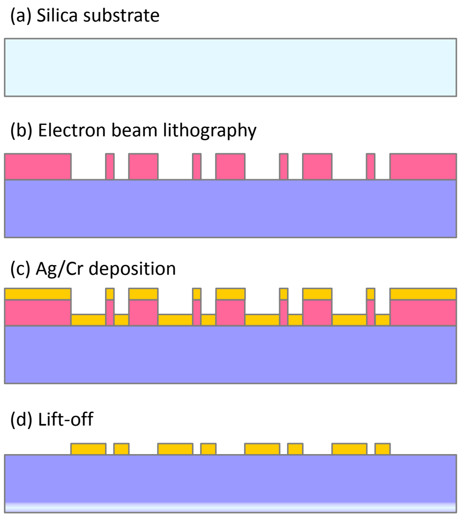

Fig.2. Fabrication process.

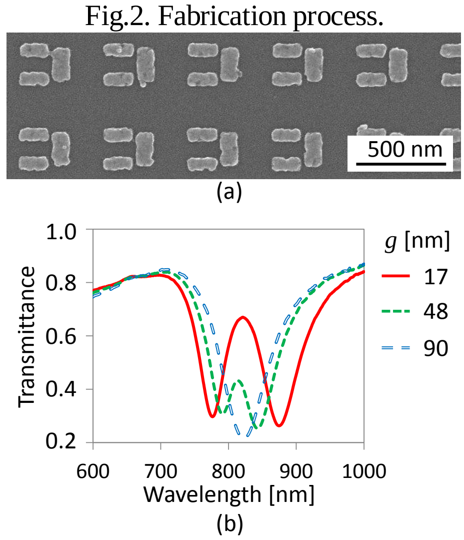

Fig.3. (a) SEM image of the fabricated EIT metamaterial. (b) Measured transmittance spectra.

Acknowledgements

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