Investigation of Surface Plasmons Coupling via Guided Modes in Metal/Dielectric/Metal Photonic Crystal Slabs

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The extraordinary optical transmission (EOT)[1] has been widely studied in the last decade. This phenomenon is mainly referred to the resonance modes caused by the coupling of the induced surface plasmons on the two metal/air surfaces through the periodic holes array. Therefore, the surface material is considered to be a crucial role for the studies of EOT phenomena and optical applications[2,3]. One may extend the idea to a system that consists of a dielectric photonic crystal slab (PCS) sandwiched by two metal films, in which an interaction of the surface plasmons coupling between two metal films and the guided mode resonance of PCS may give rise to a great interest. Herein, a Si_3N_4 PCS consisting of air holes array sandwiched by the top/bottom gold-film of 20 nm thick has been fabricated. In addition to the EOT phenomena observed in the optical transmission spectra, the interaction of the coupling of surface plasmons on both-side of the Au-film and guided mode resonances of Si_3N_4 PCS has also been identified.

First, a double-side polished and coated with 100nm-thick low-stress silicon nitride silicon wafer was prepared. The photolithography was employed to define a window with hundreds of micrometer square on one side and the exposed silicon nitride film was sequentially removed by using reactive ion etching (RIE), followed by soaking into 25wt % KOH solution to etch out the silicon substrate until a free standing silicon nitride membrane is formed. Then, an electron beam lithography was used to delineate a 2-D periodic pattern, followed by a RIE processing to transfer the pattern of holes array into the silicon nitride membrane. Sequentially, a 20 nm thick Au-film was coated on the front sides of Si_3N_4 PCS and an ion beam etching was utilized to modify the holes array into a tapered sidewall, resulting to the top- and bottom-hole diameters of 400 nm and 300 nm, respectively. Notice that the etching causes a holes array on the front side and rings array near the bottom side, as shown in figure 1(a). Finally, a 20 nm thick Au film was coated on the back side to obtain the metal/dielectric/metal PCS. For the measurement part, the optical transmission spectra were carried out by a normal incident halogen light source as shown in figure 1.

Figure 2 shows the normalized transmission spectra, in which guided mode resonances of Si_3N_4 PCS are observed at wavelength between 540 to 600 nm[4] and those modes are suppressed after coating 20nm-thick Au on the front side and etched. The coupling of induced surface plasmons from the front- and back-side occurs and this EOT phenomenon exhibits a drastic transmission arisen after coating 20nm-thick Au on the other side. In addition, an evidence of the surface plasmons coupling via the guided mode resonance at this metal/dielectric/metal PCS is resolved. Details of this phenomenon will be elaborated.

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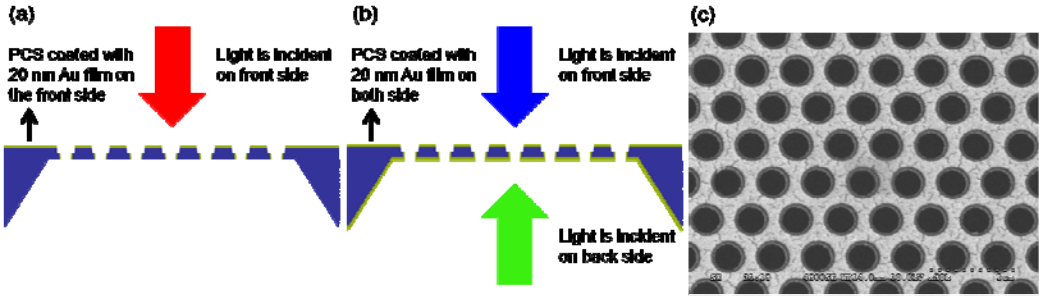

Figure 1: The schematic draws of the cross section of PCS with 20 nm thick gold-film coated on (a) front-side followed by an RIE etching and (b) double-side. Normal incident light is utilized for transmission measurement as depicted. (c) A SEM micrograph of the Au-coated PCS with period of 552 nm and tapered hole diameters of 400/300 nm of the front/bottom side.

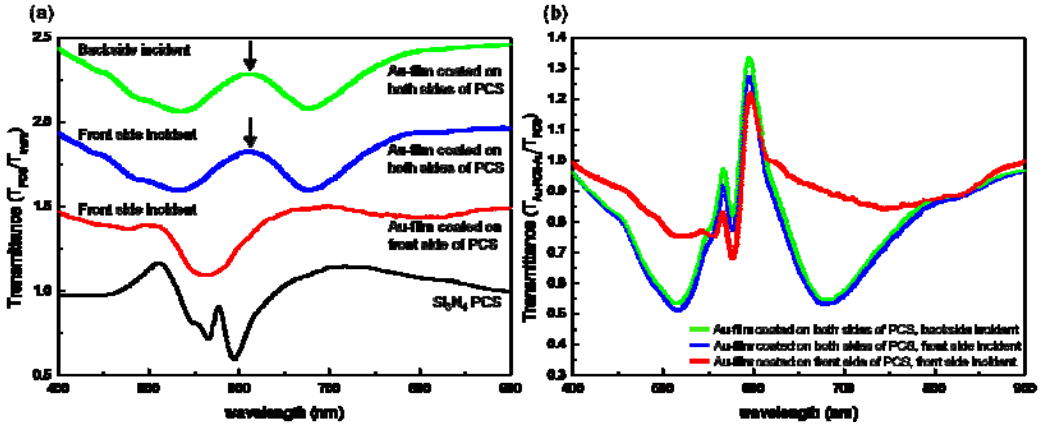

Figure 2: The normalized transmission spectra of the various PCSs. (a) shows the spectra measured from various samples. Notice that guided mode resonances are suppressed in the spectrum of Au film front-side-coated followed by RIE etching (red line) and both-side coated (blue and green lines). The arrows indicate the strong coupling of induced surface plasmons from both sides. (b) plots the spectra of the Au-film front-side- and double-side-coated PCSs that were normalized to the spectrum of Si_3N_4 PCS itself. These observed peaks and dips are associated with the surface plasmons coupling via guided mode resonances.