New results on Extraordinary Transmission at infrared and optical frequencies.

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Abstract In recent papers [1]-[3] the authors presented quasi-analytical surface impedance and transverse waveguide analysis models for the characterization of Extraordinary Transmission (ET) through screens with a periodic array of subwavelength holes. At the present time, the ET phenomenon or diffraction by arrays of holes in general are in the edge of potential applications in optical sensors [4] or solar cells concentrators [5]. Despite the increasing strength of computers, numerical model can still provide fastest characterization and gain physical insight.

In this contribution new interesting results will be presented including the intermediate regime between ET and fishnet metamaterial (FM) potential applications of ET screens in molecular spectroscopy with angle tuning or refraction of Gaussian beams.

In Fig.1 transmission through 1, 2, 4, 8 and 16 screens is calculated and validated through full wave simulations. Dispersion diagram corresponding to an infinite stack is also shown. With only a few screens the transmission band forms as a superposition of individual resonances. Amplitude of the band does not decrease substantially with the number of screens. Thus, it seems that losses are not a limiting factor in fishnet metamaterials at optical frequencies.

Gaussian beams can be decomposed in terms of plane waves. The behavior of Gaussian beams passing through a stack of four arrays of screens at different frequencies and with different polarizations is shown in Fig.2. In case of incidence TM wave, the transmitted beam is always refracted towards positive values whereas in case of an incident TE beam the shift is positive or negative depending on the angle of incidence. This can be explained in terms of the transverse waveguide theory. For TM incidence it is always the backward to the excitation TM_{0-1} mode the dominant one, whereas for TE incidence the dominant mode change with the angle of incidence. For angles smaller than 26.57º it is the forward excited TM_{01} mode the dominant one and for angles greater than 26.57 it is the backward TM_{1-1} mode the dominant one.

Finally, we have simulated screens with the same parameters as the hole arrays in [2] except for the periodicity (7 μm) (see Fig.3). The problem is scaled to mid infrared frequencies. It is expected that when the frequency of operation of the screen coincides with some absorption frequency of the molecule to be detected, a change in the amplitude and position of the peak could be used as a detection mechanism [6].

References

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Figures

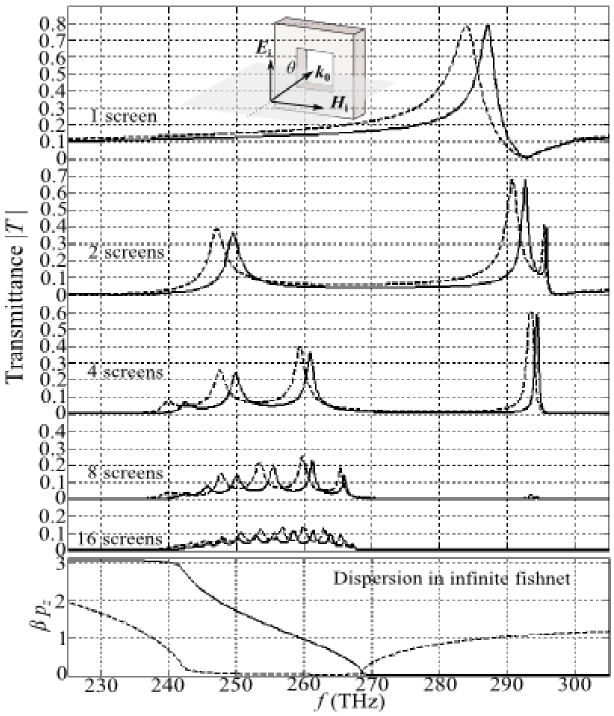

Fig. 1: Transmittance through 1, 2, 4, 8 and 16 silver screen with a periodic square array of square holes (in plane periodicities are 1µm, transversal periodicity is 100 nm and size of the holes is 250 nm) .Dispersion diagrams with normalized phase and attenuation constants corresponding to an infinite array of screens is shown below. In the transmittance spectra, continuous lines correspond to our model and dotted lines to CST simulations. In the dispersion diagrams the continuous line corresponds to the normalized phase constant and dotted line to the normalized attenuation constant; both calculated with our model.

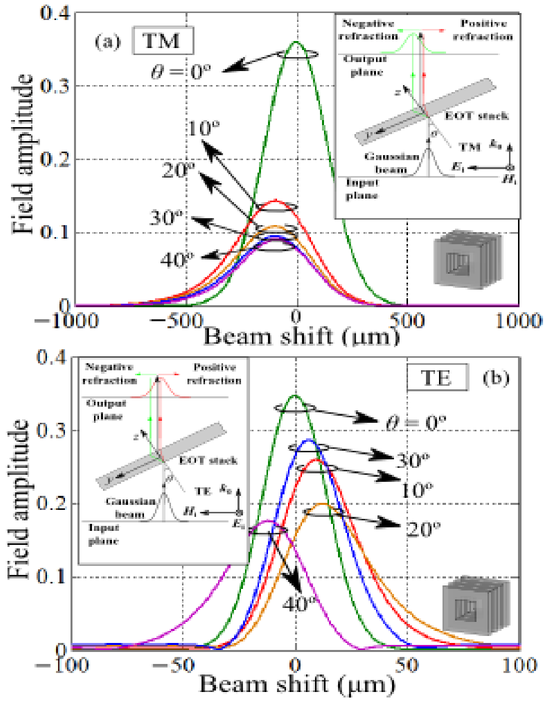

Fig. 2: Field amplitudes computed at the output plane of Gaussian beams impinging at different angles of incidence and passing through silver screens. In (a) field profiles correspond to the transmitted TM and in (b) to TE beams for different angles of incidence. For each angle of incidence, the fields are calculated at the frequency of the maximum transmission: 230.3, 204.5, 184.5 and 169.6 THz for incident beams with TM polarization (a) at 10, 20,30 and 40º; and 265.0, 274.5 288.6 and 281.6 THz for incident beams with TE polarization (b) at 10, 20, 30 and 40º. The input and output planes are placed 10 µm away from the central plane of the structure.

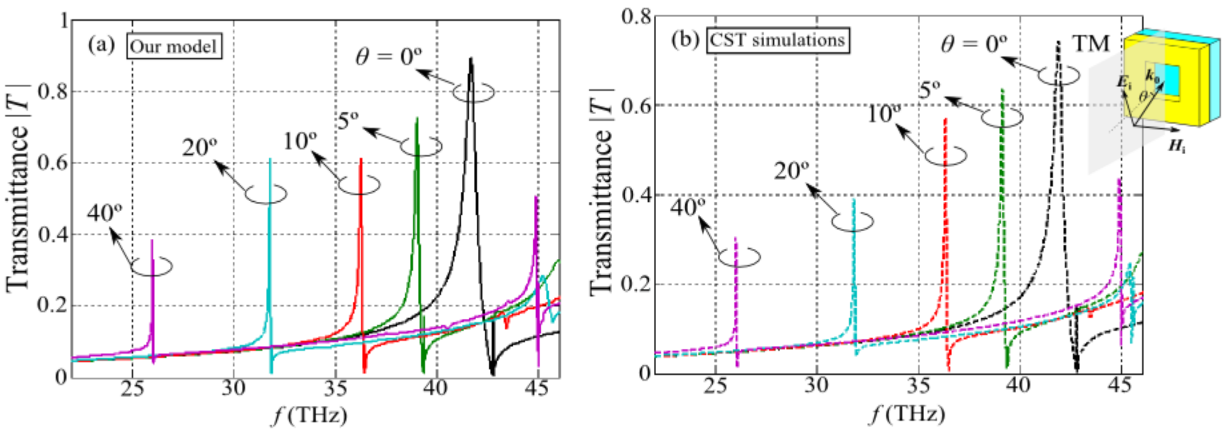

Fig. 3: Transmission through an array of square holes in an gold screen deposited on a adhesive titanium layer and a silicon nitride substrate under oblique TM incidence. Periodicity is 7m, size of the holes is 3m and thicknesses of the gold, titanium and substrate layers are 150, 5 and 70 nm respectively. Angle-tuning seems feasible in mid-infrared spectroscopic applications with arrays of holes. Continuous lines (a) correspond to our numerical model and dashed lines (b) to CST simulations.