Strongly subwavelength cavities in multilayer hyperbolic metamaterials based on nanometric steps

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Abstract- Using well-known hyperbolic multilayer metamaterials, we show a new and very simple design of deeply subwavelength cavities based on nanoscale steps between the layers. We demonstrate that the transmission in these structures is similar to a waveguide side-coupled with a classical cavity. Subsequently, by judiciously tuning the distance between two of these nanosteps one can create very tight transmission resonances.

Hyperbolic metamaterials are a class of engineered materials that are interesting for many applications thanks to the large density of states and the extreme confinement of light [1]. Typical hyperbolic metamaterials are a periodic metal-dielectric multilayer structure and an array of cylindrical metallic nanorods in a dielectric host. We study the propagation of light in a multilayer made of silver (Ag) (thickness d_{Ag} = 10 nm) and TiO_2 (thickness d_{Tio2} = 20 nm) when light encounters a nanoscale step in the layers. Because of the transverse periodic nature of the system, no radiation occurs. In addition to the wavelength, we found that two other parameters strongly determine the reflection and transmission of light: the vertical offset A and the horizontal shift B of the step (Figure 1, left). We establish with rigorous numerics that a narrow combination of the parameters A and B gives rise to a strong reflection (up to 100%) of the mode at the step (Figure 1, right). This resonance effect is similar to the one obtained for a waveguide coupled to an adjacent cavity (Figure 2, right, red solid curve). [2]

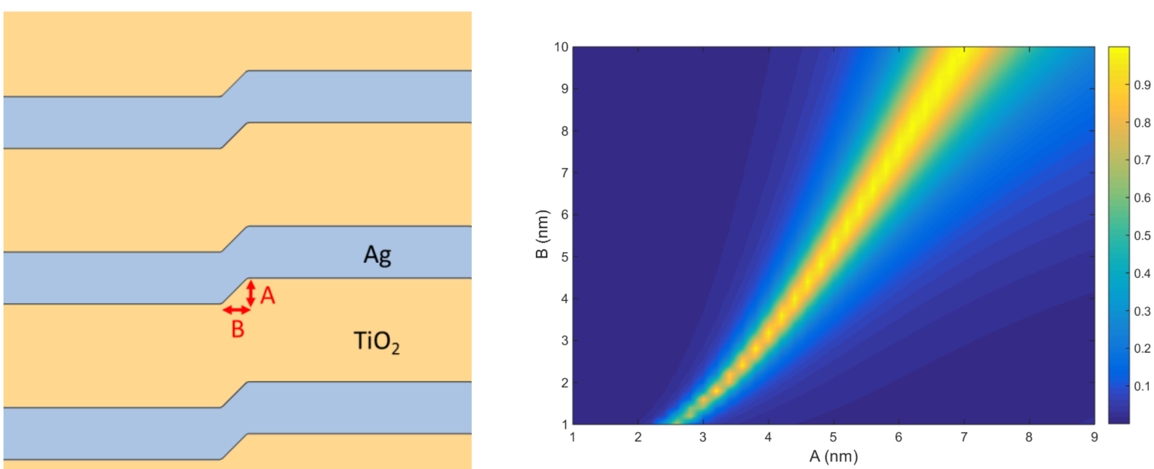

Figure 1: Left, structure under study: nanometric step in the Ag/TiO_2 multilayer structure. The parameter A represents the vertical offset and B the horizontal shift. Right, reflection of light as a function of the geometric parameters A and B for a wavelength λ = 700 nm.

We also study a symmetric structure made of two nanosteps with a distance L between them (Figure 2, left). We choose the vertical offset of the step to be A = 5 nm and the horizontal shift B = 5 nm in order to have the resonance (no transmission) at a wavelength of 700 nm (Figure 2, right, red solid curve). As in the case of a waveguide side-coupled with two cavities, according to the distance between the steps it is possible to tune the frequency at which the transmission is total (while it was quasi zero with only one step). For instance, as shown on the right side of Figure 2, the transmission at 700 nm changes from 2% with only one step to 100% with two steps with interdistance L = 86.8 nm, and the transmission at 705 nm changes from 7% to 100% for an interdistance L = 100 nm. It should be noted that the width of the peak of transmission is larger the more distant one operates from the single-cavity resonance.

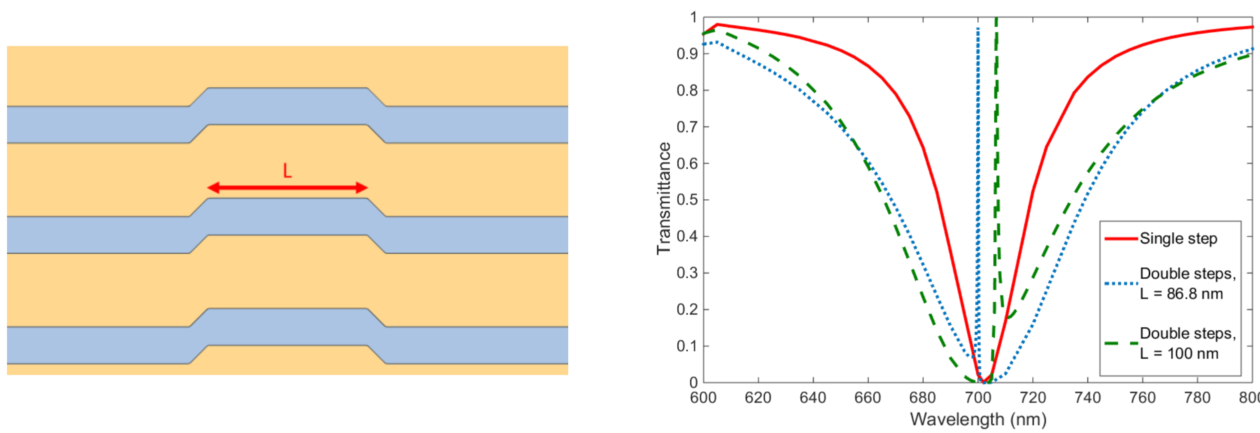

Figure 2 : Left, symmetric structure made of two nanoscale steps. L is the distance between the two steps. Right, transmittance of light when passing through a single step (red solid curve), through the structure with two steps and L = 86.8 nm (blue dotted curve) and L = 100 nm (green dashed curve). For all three curves, A =5 nm and B = 5 nm.

This work reports the first case, to our knowledge, of strong reflection by nanometric metallic edges and allows for a great control of light propagation in metamaterials.

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