Diffractionless Propagation of Designer Surface Plasmons on Plasmonic Metamaterial Surfaces

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Metamaterials are new artificial materials to exhibit electromagnetic parameters not to find in nature, such as negative effective permittivity and permeability, in a certain wavelength range [1-3]. They have attracted much attention because of unusual electromagnetic phenomena in nature such as negative refraction [4], perfect lens [5], optical magnetic resonance [6], and invisible cloaking [7, 8].

A perfect metal film with a periodic array of holes has been regarded as a plasmonic metamaterial because of special optical properties not to find in a perfect metal film. For example, a perfect metal film with a periodic array of holes can support a surface bound wave, a designer surface plasmon (DSP) that is similar to a surface plasmon of a metal film [9], while a perfect metal cannot support a surface wave on it.

Diffraction occurs with all types of waves. But, waves can propagate without diffraction in artificial media which are designed to have large anisotropy. This phenomenon, called self-collimation (SC), has been observed in artificial periodic structures of dielectric composites [10]. Although metal surfaces with two-dimensional periodic sub-wavelength holes generate anisotropy for surface plasmons (SPs) [11], SC phenomena of SPs have not been observed because of strong intrinsic absorption by metal surfaces in optical range.

In this talk, we demonstrate in microwave range that DSPs on a plasmonic metamaterial can propagate without diffraction, forming a narrow Gaussian beam. Diffractionless DSPs on a surface of a plasmonic metamaterial composed of brass square tubes were depicted by measuring evanescent electric field intensity within the air side with two microwave monopole antennas and a network analyzer.

Possible new designs for the DSP dispersion relation hold the promise of SC frequency control of DSP on plasmonic metamaterial surfaces. In addition, DSP beam splitting and subsequent re-collimation of each split beam on a plasmonic metamaterial surface provide the possibility of DSP channeling without introducing any special channel structures. Likewise, the almost perfect conductive properties of conventional metals within a terahertz (THz) range inspires us to predict self-collimated propagation of THz DSPs, as well. Designing splitters, mirrors and filters to manipulate self-collimated DSP beam propagation will be challenging.

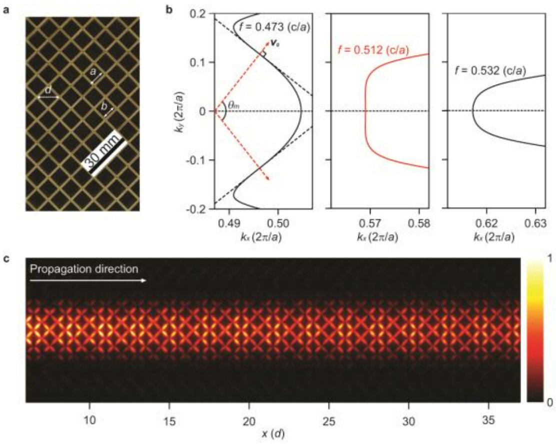

Figure 1. a, Photographic image of the top view of the array of brass tubes. The brass tube has outer side length (i.e. lattice constant) a = 10 mm, inner side length (i.e. hole size) b = 0.875a, hole depth h = 4a, and diagonal length of the unit-cell $d = \sqrt{2}\,a$. **b,** 45°-rotated and magnified views of the EFCs for f = 0.473, 0.512, 0.532 (c/a), respectively. Note that the ultra flat region exists at the SC frequency f = 0.512 (c/a) and also two flat regions are observed nearby the inflection points at the frequencies which are below the SC frequency. The maximum angle between the group velocity vector $\boldsymbol{v_g}$ and the k_x vector is $\theta_m/2$ in **b**. **c,** FDTD simulation of self-collimated propagation of a DSP beam at 15.36 GHz

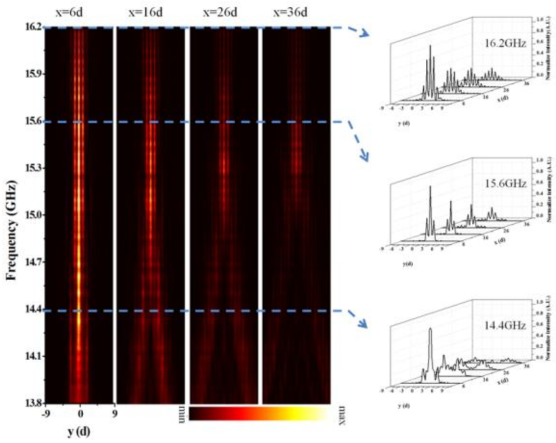

Figure 2. Measured horizontal field intensity distribution of DSPs as a function of frequency on the z = 0.5 mm plane where x = 6, 16, 26, and 36 d.

References

1. V. G. Veselago, Sov. Phys. Usp. 10, 509 (1968).
2. D. R. Smith, W. et al, Phys. Rev. Lett. 84, 4184 (2000).
3. V. M. Shalaev, Nat. Photonics 1, 41, (2006).
4. R. A. Shelby, D. R. Smith, and S. Schultz, Science 292, 77 (2001).
5. J. B. Pendry, Phys. Rev. Lett. 85, 3966 (2000).
6. S. Linden, et al., Science 306, 1351 (2004).
7. D. Schurig, et al., Science 314, 977 (2006).
8. J. B. Pendry, D. Schurig, and D. R. Smith, Science 312, 1780 (2006).
9. J. B. Pendry, L. Martin-Moreno, and F. J. Garcia-Vidal, Science 305, 847 (2004).
10. Kosaka, H. et al., Appl. Phys. Lett. 74, 1212 (1999).
11. Oh, S. S. et al., Opt. Express 15, 1205 (2007).