Anderson Localization in Terahertz Plasmonic Waveguides

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Abstract— **We present the first experimental demonstration of spatial localization (Anderson localization) of terahertz waves in plasmonic structures. The effect is brought upon by inclusion of disorder in a one dimensional plasmonic lattice. We discuss the effect of disorder on the propagation properties of the waveguide, the appearance of new modes beyond the stop band, and their transport properties. We also measure the spatial properties of the localized mode and compare the localization length to other experimental demonstrations. The results are consistent with prior published theoretical works.**

I. INTRODUCTION

Anderson or strong localization of waves is an interference phenomenon in a highly scattering or disordered medium. Although localization of electron waves was first proposed in disordered atomic structures [1], the phenomenon has been observed for matter waves and photons across a broad range of electronic and photonic structures in the scale of all dimensions [2-3]. Nevertheless, almost all experimental realizations have been reported using optical frequencies, since a number of materials exist that exhibit low loss. In general, such a condition is difficult to realize at terahertz (THz) frequencies. Here we report the first demonstration of localization of terahertz surface plasmon polaritons (SPPs) using one-dimensional (1D) arrays of disordered subwavelength holes on metal surfaces.

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II. RESULTS

In order to observe the effect of disorder, we fabricate THz plasmonic waveguides by creating 1D arrays of rectangular holes on metal films. The devices are fabricated via laser ablation of metal foils; the process has an inherent tolerance of less than 1 %. The transmission properties of waveguides with a 1D periodic array of holes have been investigated earlier [4]. Here, we introduce disorder in the waveguides by changing the periodicity of the holes by using a model $d = < d > \pm \sigma$, where d is the periodicity ($< d > = 250$ μm) and σ is a fraction of d, as shown schematically in Fig. 1. For each value of σ, eight independent waveguides were fabricated and tested. The average periodic spacing determines the first Brillouin zone, beyond which the propagating modes experience high loss, $\nu_B = c/2\,d = 0.6$ THz. Fig. 2(a) shows the transmission spectrum for waveguides with disorder ranging from 0% to 25 %. The three modes below 0.6 THz correspond to propagating modes associated with the dimensions of the rectangular holes. For $\sigma < 25\%$, we do not see any modes above ν_B. However, for two of the waveguides with $\sigma = 25\%$, we observe clear evidence of a mode beyond the Brillouin zone. Fig. 2(b) shows the behavior of the spectrally isolated mode for two different waveguides having 25% disorder. The spatial variation can be modeled using the expression $E(x) \sim E_0 \exp(-|L - L_0|/\xi)$, where ξ is the localization length and L_0 is the location on the waveguide where a spatial localized maximum is observed.

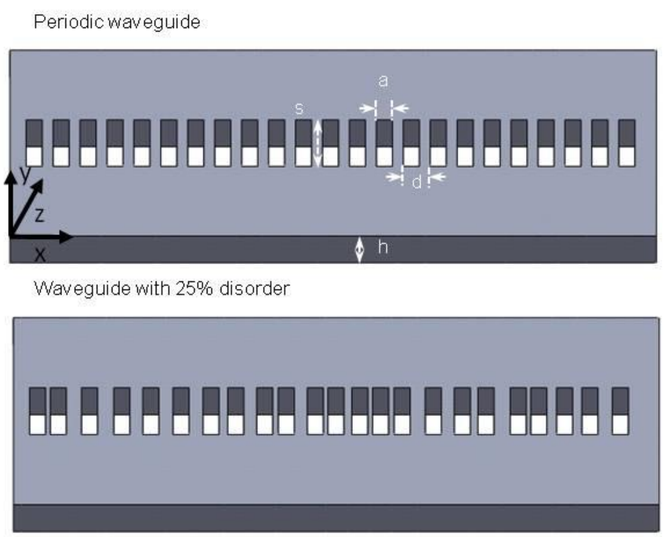

Fig. 1. Periodic waveguide schematic, 1D array of rectangular holes on metal plate. The dimensions of the rectangular grooves are s = 500 μm, a = 150 μm, d = 250 μm and h = 635 μm. The rectangular grooves act as coupled cavity resonator for the propagating wave. Waveguide with disorder is created by shifting the location of apertures either to the left or right from the mean value $< d > = 250$ μm upto σ % of d. Above is shown the schematic for σ = 25 %.

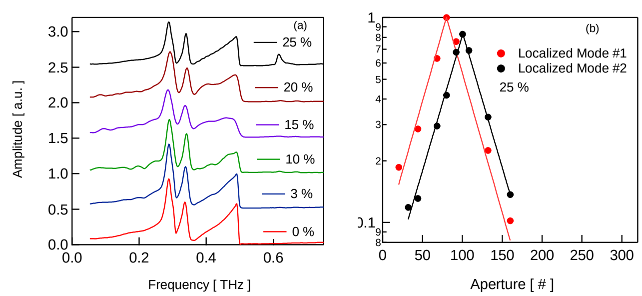

Fig. 2. Transmission spectrum of waveguides with varying degree of disorder and the behavior of localized mode (a) Spectral characteristics for transmission, as disorder increases the losses in system increases in addition to increased losses for 25 % disorder a new mode beyond the stop band appears. (b) The new mode beyond the stop band experiences a bi-exponential decay along the length of the waveguide.

REFERENCES

[1] Anderson, P.W. Absence of Diffusion in Certain Random Lattices. *Phys. Rev.* **109**, 1492-1505 (1958).
[2] Wiersma, D.S., Bartolini, P., Langedijk, A & Righini, R. Localization of light in disordered medium. *Nature.* **390**, 671-673 (1997).
[3] Wiersma, D. S. Disordered Photonics. *Nature. Photon.* **7**, 188-196 (2013).