CTh1D.6.pdf CLEO Technical Digest © OSA 2012

Mechanically Stretchable and Reversibly Deformable Liquid Metal-Based Plasmonics

Jinqi Wang,[1] Shuchang Liu,[2] Z. Valy Vardeny[1] and Ajay Nahata[2*]
[1]Department of Physics, University of Utah, Salt Lake City, UT, 84112, USA
[2]Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112, USA
[*]nahata@ece.utah.edu

Abstract: We demonstrate that liquid metals are attractive materials for active plasmonic devices at terahertz frequencies. Using a liquid metal injected into an elastomeric mold, we measure the static and stretched transmission properties of aperture arrays.

OCIS codes: (050.1220) Apertures; (240.6680) Surface plasmons; (260.3090) Infrared, far; (160.3900) Metals

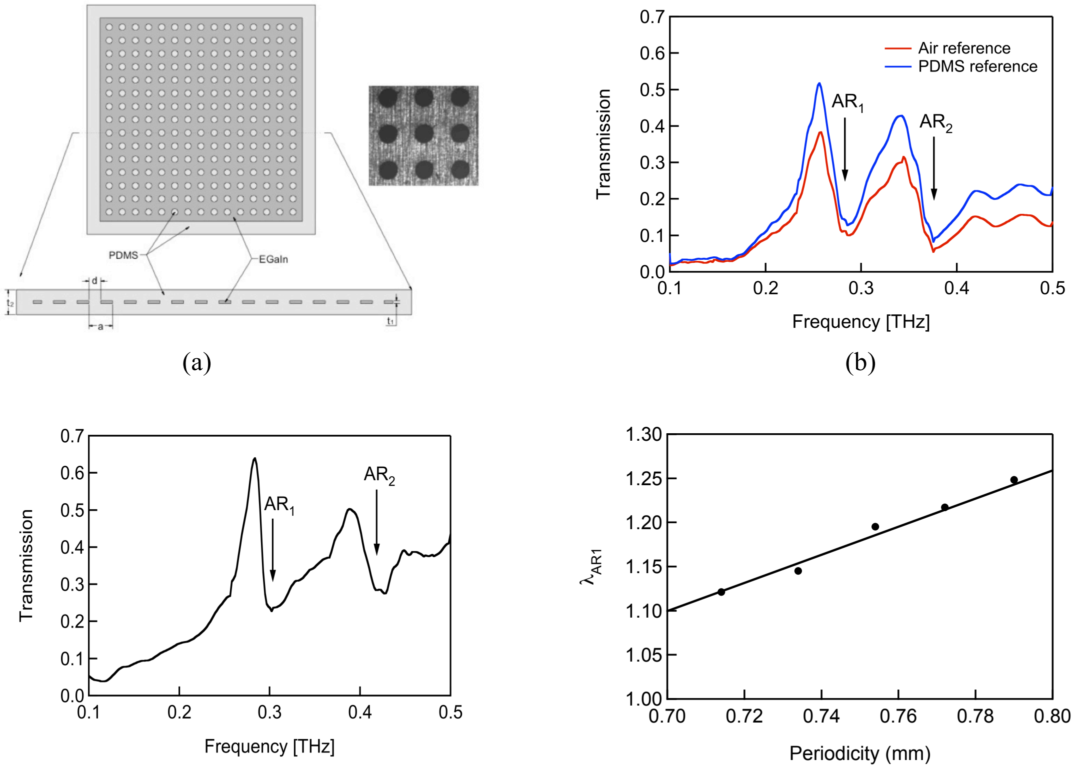
Research in the field of plasmonics has been a topic of growing scientific over the last decade, since it offers a number of unique capabilities for manipulating and guiding electromagnetic radiation [1]. At THz and microwave spectral ranges, conventional metals typically exhibit high conducting and corresponding low propagation loss. Moreover, highly conducting non-metals, including semiconductors, conducting polymers and graphene, have been shown to support the propagation of SPPs. Such materials are attractive since the conductivity can be varied via electrical, optical, thermal and chemical means. However, such changes usually affect only the magnitude of the resonance [2]. Therefore, a plasmonic medium that is tunable and reconfigurable is highly desirable.

In this submission, we experimentally demonstrate the use of liquid metals injected into elastomeric PDMS mold that allows for tunable and reconfigurable device architectures. A schematic diagram of the device with the relevant dimensions and the micrograph of the fabricated liquid metal aperture array are shown in Fig.1 (a). The aperture diameter d = 357 μm, the periodic aperture spacing a = 714 μm. The outer PDMS mold is fabricated using standard soft lithography techniques. Eutectic gallium indium (EGaIn) is injected into the air void inside the mold, yielding periodic arrays of subwavelength apertures based on an encapsulated liquid metal. We used THz time-domain spectroscopy (THz TDS) to measure the optical transmission spectra of the liquid metal arrays. Two separate reference transmission spectra were taken: one with a blank metal frame (air reference) and one with the 1 mm thick planar PDMS film in the frame (PDMS reference).

In Fig. 1(b), we show the measured transmission amplitude spectra for the liquid metal array. As we have shown previously, it is only the AR frequencies (and not the resonance frequencies) that remain fixed when the aperture diameter is varied. From the figure, the two AR frequencies occur at ν_{AR1} = 0.27 THz and ν_{AR2} = 0.38 THz. In order to understand the properties of the transmission spectra, we measured the complex refractive index of PDMS using THz TDS. The real component of n was largely frequency independent and had an average value of 1.57; similarly, the imaginary component of n was largely frequency independent and had an average value of is about 0.04. Based on the real component of the refractive index of PDMS, The two lowest order AR frequencies are expected to occur at ν_{AR1} = 0.27 THz and ν_{AR2} = 0.38 THz [3], in excellent agreement with the experimental data. Furthermore, the imaginary component of the refractive index accounts for the ~20% transmission difference between the two spectra in Fig. 1(b). In order to assess the quality of this device, we also fabricated a 15×15 array of 400 μm diameter apertures on a square grid with an aperture spacing of 1 mm on a free standing 75 μm thick stainless steel foil, since this geometry yields similar AR frequencies. The absolute transmission magnitude associated with the lowest order resonance for the stainless steel sample, shown in Fig. 3(b), is greater than that for the liquid metal sample. However, it is important to note that the liquid metal has a DC conductivity that is three orders of magnitude smaller than conventional metals.

An important characteristic of these flexible materials is that In order to demonstrate the advantage of PDMS and liquid metals in plasmonics applications, we measured the THz transmission properties of the 15×15 liquid metal array as a function of mechanical stretching. For the lowest order resonance, λ_{AR1} has linear relationship with periodicity, $\lambda_{AR1}/P = n_{SPP.}$ As shown in Fig. 1(d), the linear least-square fit has a slope of 1.58, which is in good agreement with the measured THz refractive index of PDMS.

In summary, we presented the first experimental demonstration of plasmonics using liquid metals through fabricating periodic arrays of subwavelength aperture with EGaIn injected into an elastomeric PDMS mold. We measured the enhanced THz transmission properties of aperature arrays. An important aspect of the constituent materials is that they are amenable to stretching and flexing. We exploit this characteristic by measuring the transmission properties of the structures while being stretched. This represents a simple demonstration of mechanically tuning the resonance properties of the device.



(a) (b)

(c) (d)

Fig. 1. (a) Schematic diagram of the top view (above) and cross-section (below) of the liquid metal aperture array encapsulated in PDMS. The aperture diameter d = 357 µm, the periodic aperture spacing a = 714 µm, the liquid metal thickness t_1 = 80 µm and total device thickness t_2 = 1 mm. Right photograph showing an expanded view of a portion of the array. (b) THz electric field transmission spectra, t(ν), of 15x15 liquid metal array with 357 µm diameter apertures periodically spaced by 714 µm. Air and a 1 mm thick PDMS film are used as references. (c) 15x15 array with 400 µm diameter apertures periodically spaced by 1 mm in a 75 µm thick free-standing stainless steel foil with air as the reference. (d) Change in the transmission AR wavelength as a function of stretching using a 15x15 array of subwavelength apertures. In the absence of stretching, the periodicity is 714 µm. The maximum stretched period of 790 µm corresponds to a 10.6% elongation of the device along the stretch axis. The slope of the linear least-squares fit is 1.58.

References:

[1] W. L. Barnes, A. Dereux, and T. W. Ebbesen, Nature **424**, 824–830 (2003).
[2] J. Gómez Rivas, P. H. Bolivar, and H. Kurz, Opt. Lett. **29**, 1680-1682 (2004).
[3] T.W. Ebbesen, H.J. Lezec, H.F. Ghaemi, T. Thio and P. Wolff, Nature **391**, 667-669 (1998).