Experimental Beam-Steering Reflectarray Using Graphene

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***Abstract*—We demonstrate experimentally a beam-steering reconfigurable reflectarray antenna operating at terahertz frequencies (1 THz) using graphene. The antenna is composed of identical unit cells having reflection phase that can switch between 0 and 180°. Unit cells are composed of gold elements that enhance the electric field interaction with graphene. By varying the voltage on each reflectarray column of cells, we verify beam-steering with angular range of at least 25°, beam shaping, beam splitting and phase modulation.**

***Keywords*—graphene, reflectarray, terahertz, beam-steering.**

I. INTRODUCTION

Graphene has been considered in several publications as a very promising candidate to create tunable antennas for millimeter waves, terahertz and infrared applications [1-4]. This is due to the gate-tunable conductivity of graphene, which, thanks to the high mobility of this material, allows for larger absolute variation of the conductivity when compared to other materials. High quality exfoliated graphene supports plasmons polaritons at terahertz frequencies, which makes it appealing for miniaturized polaritonic antennas [3,4]. These plasmons are not supported in CVD graphene due to the higher carrier collision frequency, but this does not prevent achieving other types of functionalities relying simply on the change of the real part of the conductivity of graphene. This is exactly the case for the device presented in this paper, which uses graphene resistive switches embedded in a beam-steering reflectarray antenna operating at 1 THz.

II. REFLECTARRAY DESIGN AND FABRICATION

The reflectarray is an array of identical unit cells fabricated with gold elements and graphene switches on a reflective substrate. The reflective substrate includes a silver ground plane and a high resistive silicon 20 µm spacer, which at 1 THz is approximately a quarter of wavelength in silicon (Figure 1). An additional layer of Al_2O_3 is used as gate oxide to tune graphene. Gold and graphene patterns are defined on top of the substrate with e-beam lithography. Cells belonging to the same column are all connected together in this demonstrator, and each column is driven with a different gate voltage with respect to the silicon substrate. Even though silicon has a high resistivity, carriers are mobile in it, so that the voltage drop falls on the Al_2O_3 layer alone. The applied voltage is used to tune the number of carriers in graphene, changing its conductivity and in turn the THz response of the unit cell. The cells are optimized so that their reflection coefficients have opposite phase for the largest and smallest column voltage (V_{MAX} and V_{MIN} respectively).

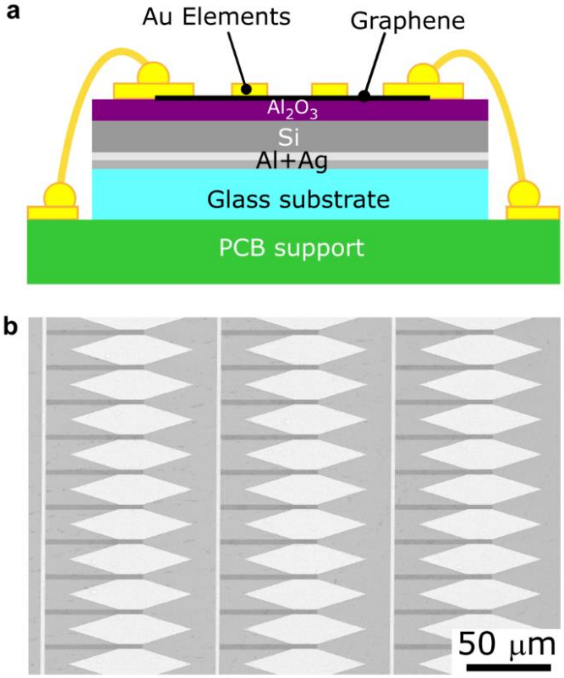

Fig. 1. Structure of the experimental reflectarray demonstrator. a) Cross section of the device. Thickness of the layers from bottom to top: glass substrate 525 µm, evaporated Al 100 nm and Ag 100 nm, Si 20 µm, Al_2O_3 200 nm, Au 100 nm (5 nm of Cr adhesion layer), and graphene is monolayer. b) Detail of the reflectarray unit cells, where a portion of three columns are visible.

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The incident beam direction is fixed to $\theta_i = -45°$, with TE polarization and electric field vertical with respect to Figure 1b. The voltage of each gate is chosen to be either V_{MAX} or V_{MIN} and periodic patterns are created alternating V_{MAX} columns with V_{MIN} columns. If the pattern periodicity is of P columns, then the direction θ_d of the deflected beam is given by:

$$\theta_d = -\arcsin(\sin\theta_i + \lambda/PL) \tag{1}$$

where λ is the free space wavelength and $L = 100\ \mu m$ is the column width. By changing the periodicity of the pattern, the angle of the beam is changed. Apart from integer numbers, any arbitrary fractional value of P can be approximated with a quasi-periodic sequence of voltages, allowing fine beam-steering.

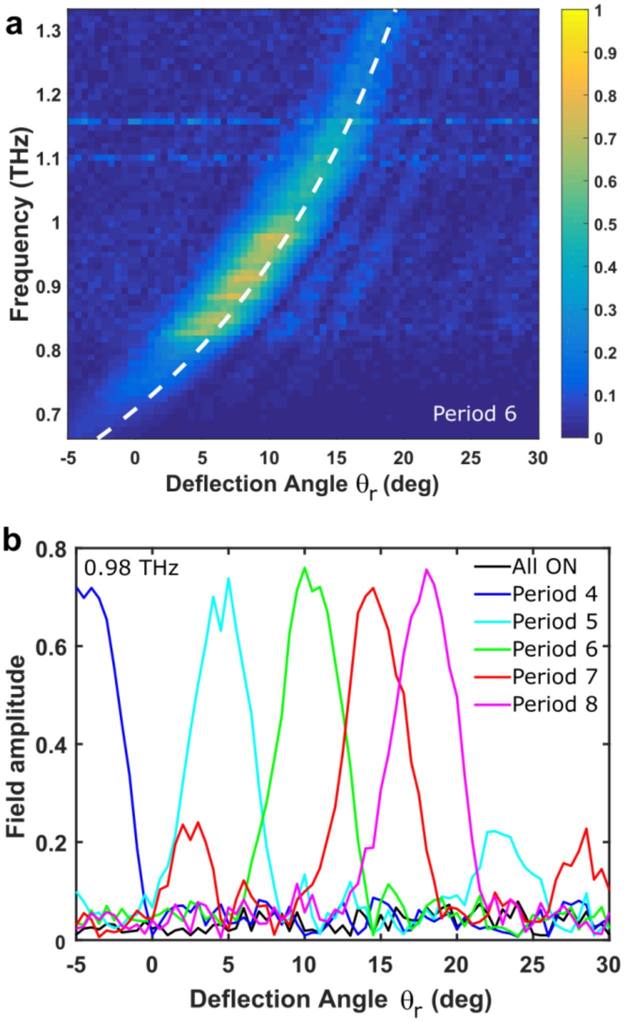

Fig. 2. Measured deflected beam from the reflectarray. a) Normalized frequency vs deflection angle intensity plot, using a pattern with periodicity of 6 columns. Incident light comes from the -45° direction. The dashed line represents the expected theoretical angular dispersion given by Equation 1. b) Plot of beam-steering at 0.98 THz. Amplitude is normalized as in a), and the beam is shown for patterns with different periodicities.

III. MEASUREMENTS

The reflectarray is wire-bonded to a PCB chip and each column is connected to a driving transistor controlled by an Arduino board, that is used to control independently all columns to form the desired control patterns. Measurements are performed with a time domain terahertz time domain system, and collimated beams are used to ensure maximal angular sensitivity. A reference measure is taken on a mirror fabricated on the same reflectarray chip, which is used to correct for the frequency dispersion of the system.

Measurements are then performed using a motorized rotary stage for the detector to scan the detection angle, and an XY translational stage for the sample to alternate between the reflectarray and the mirror. Figure 1 shows the full angle vs frequency characterization of a particular periodic pattern ($P = 6$) as well as the achieved beam-steering at the frequency of 0.98 THz. With this example of parameters, a scanning range of 25° is easily achieved, mostly limited by geometrical constraints of the used measurement setup (the beam in fact could be scanned further for negative angles).

In addition to these measurements, we demonstrated fine beam-steering, beamforming and focusing, beam splitting, amplitude and phase modulation and close to perfect absorption, all with the same device.

IV. CONCLUSIONS

These experiments confirm that graphene can be practically used for a number of functionalities which are expected to have a significant impact on terahertz technology. Electronic beam-steering can replace fragile rotating mirrors in terahertz scanners for security applications, for more reliable and faster scanning. Amplitude and phase modulation could be useful for telecommunications applications, while dynamic focusing opens interesting scenarios for 3D imaging and spectroscopy.

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