Passive electric monopole array for terahertz surface wave launcher

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***Abstract*—Micron-scale passive grounded quarter-wave electric monopole antennas can be constructed by direct-drawing a polymer into micropillars, followed by metallization. This technique is proposed for the realization of a homogeneous 2D array of passive electric monopoles, with an operating frequency of 500 GHz. The array utilizes grating lobes, as opposed to phased array techniques, to couple obliquely incident radiation to a surface wave in the transverse plane. Numerical simulations verify the operation of the antenna array as a surface wave launcher.**

I. Introduction

The quarter-wave electric monopole is one of the most fundamental and widely used antennas [1]. Whilst it has seen extensive use in radio and microwave applications, there are significant challenges at higher frequencies, as the downscaling in size makes fabrication of the topology difficult. For this reason, monopole antennas have previously been demonstrated only as high as the sub-mm range [2]. In this work we propose a passive grounded quarter-wave electric monopole antenna with an operating frequency of 500 GHz, comprised of a polymer micropillar with a gold metal coating. These monopoles are deployed in a homogeneous array configuration that behaves as a terahertz surface wave coupler.

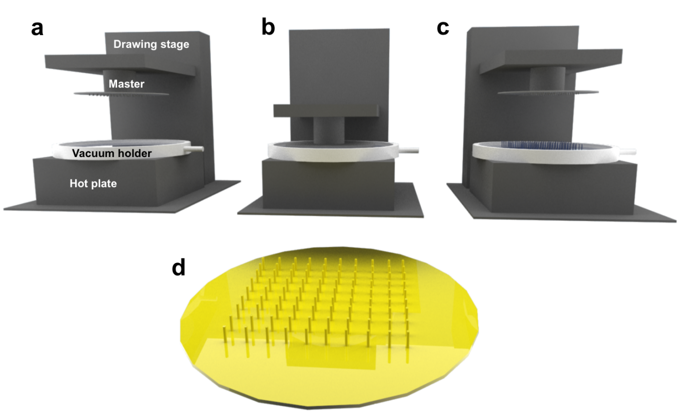

Fig. 1. Direct-drawing technique, (a) direct-drawing apparatus, (b) master stamp makes contact with liquid-phase elastomer, and draws out micropillars, (c) fully cured micropillars are detached from master, and (d) gold is deposited on structure.

II. Methods

Polymer micropillars can be fabricated by drawing them out in liquid phase prior to fully curing, in a process known as direct-drawing [3]. A detailed schematic of the fabrication process is given in Fig. 1. First, a master stamp of the array layout is constructed via photolithography and deep reactive ion etching (DRIE). The master is mounted on a translation stage, above the liquid-phase elastomeric polymer, which is placed on a hot plate. The elastomer is drawn out into micropillars by the master, whilst simultaneously being heated from below in order to start the curing process. Once the micropillars are formed, the elastomer is hard-baked in order to fully cure it, and hence detach the micropillar features from the master stamp. Finally, the micropillars are coated in gold via physical vapour deposition.

Given the high frequency of operation, the skin depth is low, and hence only a thin film of metal is necessary. Additionally, the fact that the field does not penetrate beyond the metallization layer means that the material properties of the polymer are unimportant, and hence it may be selected based solely on the basis of mechanical properties and microfabrication compatibility. For this reason, polydimethylsiloxane (PDMS) was identified as being suitable, as its moderate dielectric loss [4] will have no effect on overall performance.

A 2D array of identical direct-drawn metal-coated polymer monopoles is designed to operate as a surface wave launcher.

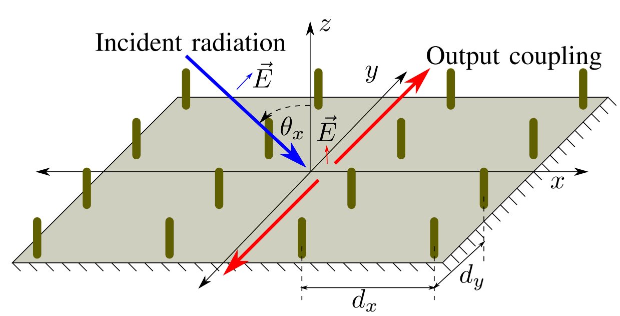

Fig. 2. The regularly spaced monopole elements on the ground plane couple the obliquely incident wave (blue) into a surface wave in the transverse plane (red). In this instance, d_x = 848 µm, d_y = 600 µm (= λ), and $\theta = 45^\circ$.

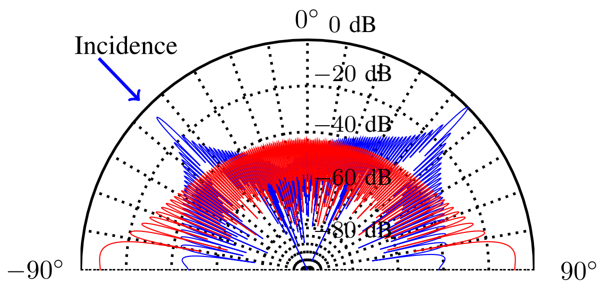

Fig. 3. Radiation pattern of monopole antenna array. Incidence plane is shown in blue, transverse plane in red.

The passive, homogeneous nature of the antennas precludes the use of phased array and reflectarray techniques. We therefore utilize grating lobes [1] in order to re-radiate obliquely incident radiation into a surface wave, as per the diagram in Fig. 2. Grating lobes are well suited to this form of passive antenna array, as they do not rely on the phasing of each individual element, but rather on the periodic spacing between the homogeneous antenna elements. More specifically, if the spacing between elements is equal to a wavelength, the array factor will have a maximum in the in-plane direction, and if it is greater than a wavelength, the maximum will shift to an oblique direction. Hence, by having wavelength-spacing in the y-dimension, and greater-than-wavelength spacing in the x-dimension, the array is capable of coupling to obliquely incident radiation in the xz-plane, and re-radiating it along the y-axis.

III. Simulation

An incidence angle of $\theta_x = 45°$ was chosen for this device. A finite array, of 42.0×42.4 mm^2, was simulated by combining unit cell analysis with array theory. A plane wave excitation, with an incidence angle of 45° in the xz-plane, was imposed upon a unit cell of the structure in order to determine the radiation pattern of a single element. The overall radiation pattern was then determined using array theory. All simulations were performed with the commercially available software package Ansys HFSS.

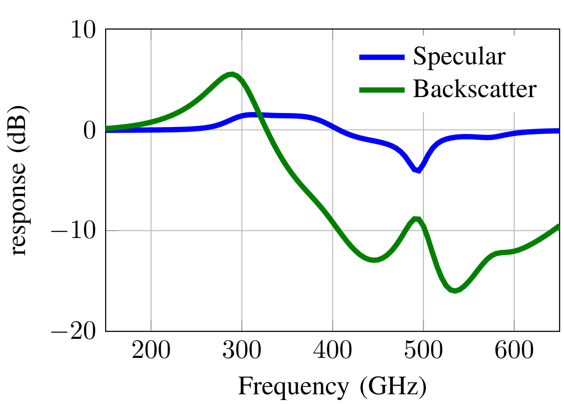

Fig. 4. Normalized response of monopole array.

The simulated radiation pattern given in Fig. 3 clearly shows maxima in the specular (45°) and back-scatter directions (-45°) in the incidence plane, and the surface waves (±90°) in the transverse plane. There is, notably, very weak radiation in the surface-normal direction (0°), even though this is a maximum of the array factor. This is due to the choice of electric monopole as array element, as it is well known that the radiation pattern of both electric dipoles, and grounded electric monopoles, is toroidal. In this way, significant energy is not lost to the surface-normal direction.

In order to gain further insight into the nature of the resonance, simulations were performed to extract the response of the array in the specular and back-scatter directions. The response, normalized against a featureless perfect electrical conductor (PEC) ground plane of the same unit cell size, and in the same array configuration, is given in Fig. 4. It can be seen that, around the resonance frequency of 500 GHz, there is a local maximum in the back-scattered response, and a local minimum in the specular response. This confirms the resonance, as it is the frequency at which a maximum of energy is transferred from the incident field into currents on the monopole, and hence re-radiated in directions of array factor maxima, as opposed to being simply reflected by the ground plane. Another feature of interest in the response is the fact that both the specular and back-scatter response exceed unity below 400 GHz. These features are likely due to edge-coupling effects in the simulation. Energy is coupled to the monopole from its neighbouring elements, and this contributes to the amount of power re-radiated by each element. Even if the monopoles are not at their resonance frequency, they still scatter some energy. However, the array is of finite extent, and the array theory analysis utilized assumes that the field radiated by all elements is identical. A consequence of this is that elements at the edges of the array are effectively excited by coupling with fictional neighbours.

IV. Conclusion

We propose a direct-drawing technique for realising grounded quarter-wave electric monopole antennas in the terahertz range. The antenna is used to design an array that couples obliquely incident radiation into a surface wave. Numerical simulations confirm the functionality of the device, and robustness to tolerance.

References

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