Demonstration of a High-Efficiency Reflectarray Antenna at 1 THz Based on Dielectric Resonators

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***Abstract*—A reflectarray antenna composed of more than 87000 single-crystal silicon resonators on a gold ground plane is experimentally demonstrated to achieve efficient beam focusing at 1 THz. The functionality of the reflectarray as a collimator is also verified by the principle of antenna reciprocity. Because of the low-loss and nondispersive nature of high-resistivity silicon in the submillimeter regime, the losses of the reflectarray are negligible, a very desirable feature at such frequencies. Reflectarrays based on dielectric resonator antennas (DRA) have been relatively unexplored in the terahertz range, mainly because of the challenging fabrication process.**

***Index Terms*—reflectarray, terahertz, dielectric resonator.**

I. Introduction

A reflectarray antenna is usually composed of a feed and an array of elements optimized to work in reflection. The individual elements are adjusted so that the reflected waves interfere to produce a prescribed beam [1]. This beam can be focused in the near-field or collimated in the far-field, and depending on the application it can be fixed or dynamically reconfigured [2].

Reflectarray antennas with fixed beam have been widely studied in the microwave regime. In recent years this kind of antenna has also attracted great attention at higher frequencies, from millimeter-waves to the infrared region of the spectrum [3]-[10], mainly because of the broad variety of applications. In particular, submillimeter or terahertz radiation (0.3 to 3 THz) is very interesting because of its intrinsic non-ionizing nature, as well as the presence of unique spectral features to distinguish between different materials. Applications include noninvasive medical imaging for cancer diagnosis and dental care, short-range terrestrial communications, high-altitude telecommunications, surveillance and security screening, detection of defects and cracks, quality control in the pharmaceutical industry, among others [11]-[14]. All these applications require the development of high performance devices with the ability to efficiently manipulate terahertz waves. Thinner and flat-profile solutions, as the case of reflectarrays, are preferable for compact systems.

In this contribution, a high-efficiency reflectarray antenna composed of dielectric resonators is described and experimentally demonstrated at 1 THz [15]. The antenna has the functionality of an off-axis parabolic mirror, focusing a beam in the near-field of the array. By the principle of antenna reciprocity, the same device is capable of collimating a divergent beam in the far-field. Fig. 1 shows a schematic of the proposed reflectarray, as well as an expanded view of an optical microscope image corresponding to a section of the fabricated device.

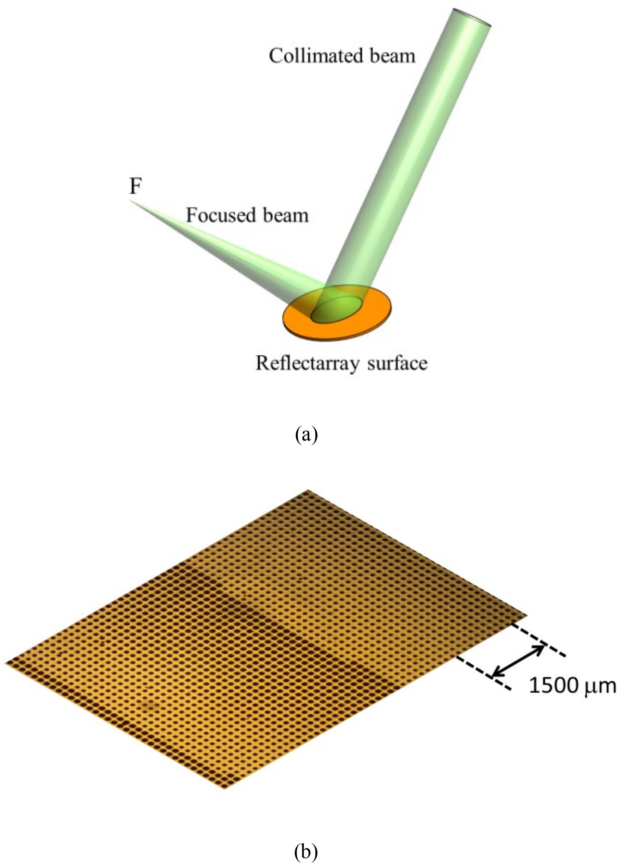

Fig. 1 Reflectarray antenna based on dielectric resonators. (a) Schematic of the proposed device. (b) Expanded view of an optical microscope image corresponding to a section of the fabricated device.

II. Unit Cell

At terahertz frequencies, reflectarray antennas have typically been implemented using metallic resonators as unit cells, but drawbacks to this approach have included significant dielectric and conductor losses [5]-[7]. A high-efficiency solution is the use of dielectric resonator antennas, which operates on resonance of displacement current rather than conduction current. Fig. 2(a) shows a cylindrical resonator made of high-resistivity silicon ($\varepsilon_r = 11.68$, $\tan\delta < 0.00004$) on a ground plane made of gold. The cell size is $a = \lambda/2$ (150 µm) and the height of the cylinder is $h = 50$ µm. Fig. 2(b) shows the amplitude and phase of the reflection coefficient as a function of the radius when a TE-polarized wave impinges with an incident angle of 45°, assuming Floquet's boundaries to take into account the mutual coupling between elements. By fixing the radius range between 37.5 µm and 57 µm, only the first two resonances are used for implementing the reflectarray. A phase range of more than 360° with losses smaller than 0.32 dB is obtained. It is worth mention that the first resonance ($HEM_{11\delta}$ mode) corresponds to a horizontal magnetic dipole field distribution, while the second one ($TE_{11\delta}$ mode) corresponds to a vertical magnetic dipole.

III. Reflectarray Design

The focusing reflectarray antenna is designed by a simple inverse process, whose validity is sustained on the reciprocity theorem. A collimated beam impinges on the reflectarray surface with an angle $\theta = 45°$, $\varphi = 0°$, and is focused to a point F oriented to $\theta = 45°$, $\varphi = 180°$, and located at a focal length of 150 µm from the array center. This near-field point is replaced by a virtual feed that illuminates the surface. In this way, the elements of the array are optimized to transform the spherical wave impinging from the virtual feed into a collimated beam. This method makes it possible to design the focusing reflectarray using the conventional theory of reflectarrays acting as collimators. The reflectarray surface is circular with a diameter of 49.95 mm and more than 87000 elements. Fig. 3 shows the phase distribution required to collimate the beam towards $\theta = 45°$, $\varphi = 0°$, when the virtual feed is in the focal point. From the scattering response of the resonators, the radius of each cylinder is adjusted to generate the required phase.

IV. Results

The device is fabricated following an unconventional microfabrication process, as described in [16], where a uniform array of similar resonators has been used to implement high-efficiency artificial magnetic conductors. Fig. 4 shows an electron micrograph of the cylinders with different radii. The manufactured reflectarray is employed to focus a collimated beam, and the focal point is characterized using terahertz time-domain spectroscopy (THz-TDS). Fig. 5 shows the magnitude of the measured field at 1 THz. As expected, a focal spot is clearly defined. As previously mentioned, the same device can be employed to collimate a divergent beam. The simulated radiation pattern for this operation mode is shown in Fig. 6, in both azimuth and elevation planes.

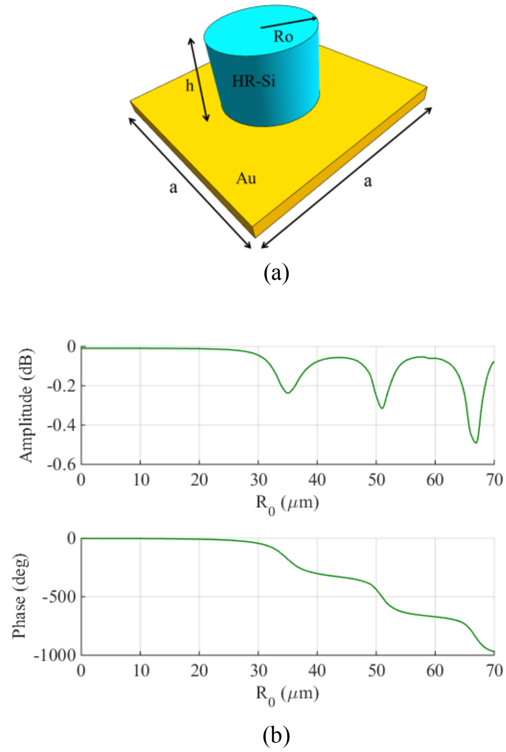

Fig. 2 Dielectric resonator unit cell. (a) Generic geometry. (b) Amplitude and phase of the reflection coefficient as a function of the cylinder radius, at 1 THz.

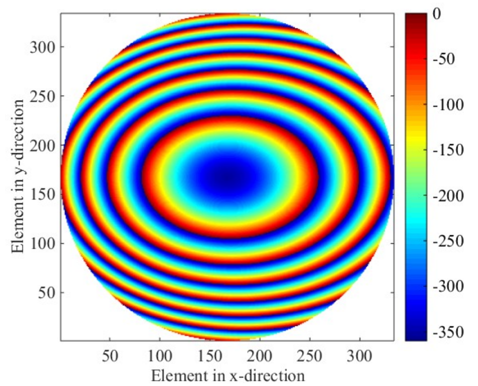

Fig. 3 Phase distribution on the array surface.

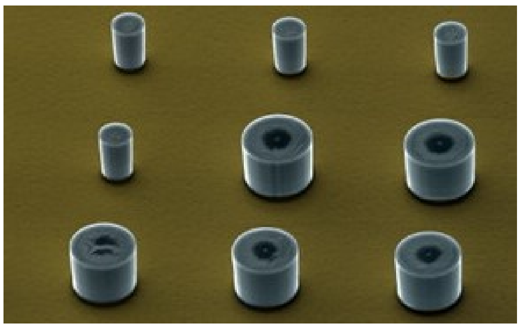

Fig. 4 Electron micrograph (false-color) showing the details of the cylindric resonators. The center to center distance is 150 µm.

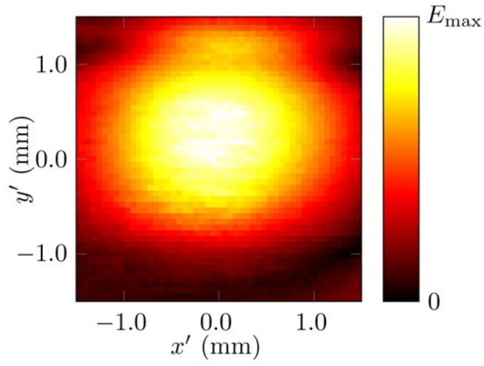

Fig. 5 Measured field magnitude for the focused beam.

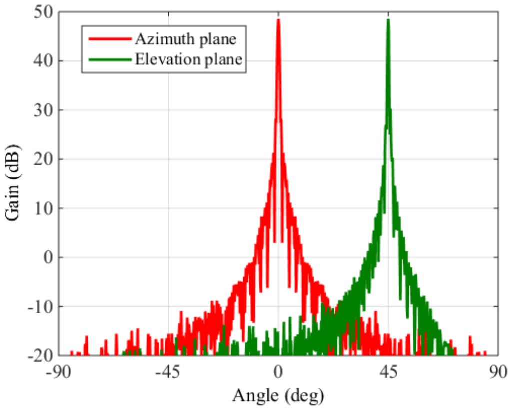

Fig. 6 Far-field radiation pattern for the reflectarray antenna as a collimator.

V. Conclusions

A high-efficiency reflectarray antenna that operates in the terahertz range has been presented and experimentally demonstrated. The flat-profile antenna can be used to control the reflected beam according to requirements in both the near- and far-field with negligible losses. The proposed reflectarray antenna opens the way for design of more advanced devices to be used in the terahertz range.

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