

DIELECTRIC RODS FOR TERAHERTZ ANTENNA ARRAYS

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ABSTRACT

A dielectric rod antenna is described as a possible element for a terahertz focal plane array. Results are presented of an analysis of a magnetic ring current inside the rod that excites the fundamental surface wave. It is shown that excitation efficiencies approaching 100% are possible by correctly choosing the rod and ring radii. Design implications for fabricating a dielectric rod antenna at terahertz frequencies are discussed and preliminary results are presented.

INTRODUCTION

Terahertz imaging has been demonstrated to be useful for a range of applications from skin cancer diagnosis to concealed weapon detection. Current terahertz imaging systems are limited to acquiring one or a few pixels simultaneously leading to impractically long image acquisition times. Large terahertz imaging arrays are required to realize practical systems and real-time imaging frame rates. Improved performance of existing imaging systems and better fabrication methods are also desired. Multiple high-gain beams are also expected to be required for terahertz communications and a dielectric rod array may be suitable for this purpose.

To address these needs, we are investigating an array of dielectric rod antennas. In this paper we present some of the design aspects of a terahertz dielectric rod antenna, the excitation using a magnetic ring current, as well as some preliminary fabrication results.

DIELECTRIC ROD ANTENNAS FOR TERAHERTZ APPLICATIONS

Dielectric antennas are commonly used at millimeter wave and terahertz frequencies due to their low loss and compatibility with micro-machining techniques commonly employed at these frequencies. Dielectric rod antennas belong to the class of traveling-wave dielectric antennas and have been shown to perform well in an array [1], are low loss and potentially broadband. Their gain can be controlled by adjusting their length and taper.

DIELECTRIC ROD EXCITATION ANALYSIS

Surface wave antennas such as a dielectric rod radiate electromagnetic waves by generating and launching a surface wave that propagates along its length and exits from the end. The surface wave on a cylindrical dielectric rod antenna can be excited in a number of different ways and is typically done using a circular waveguide and horn [2]. High excitation efficiency is considered important for efficient and broadband operation of the antenna. A planar method of excitation is also desirable for integration of the antenna into a focal plane array (FPA). It is envisaged that detectors would be connected to the rod input via a coupling circuit such as a circular slot. To determine if this leads to efficient coupling, we have investigated the reciprocal situation of a ring-slot antenna exciting the fundamental HE_{11} surface wave on a dielectric rod. We model the ring slot by a magnetic ring current of radius b and consider an infinite, lossless dielectric rod of permittivity ϵ_r and radius a , illustrated in Fig. 1a. A new closed form solution was derived for the previously unconsidered case in the literature where the magnetic ring is embedded in the rod (i.e. $b < a$). Previous reported work considered only the case when the ring slot was outside the

rod (i.e. $b > a$) [3]. The solution was derived by solving the boundary value problem for a magnetic ring current embedded inside a dielectric rod using the source form of Maxwell's equations. Further details of the derivation will appear in a subsequent publication [7].

Fig. 1b shows a plot of the launching efficiency of the fundamental mode HE_{11} versus the diameter of the rod for a high permittivity material such as silicon, which is of particular interest at millimetre-wave and terahertz frequencies. From the graph it can be seen that if a ring-to-rod radii ratio, b/a , of 0.6 is chosen, a peak excitation efficiency close to 100% can be achieved and launching efficiencies greater than 90% over a bandwidth greater than 20% can be accomplished.

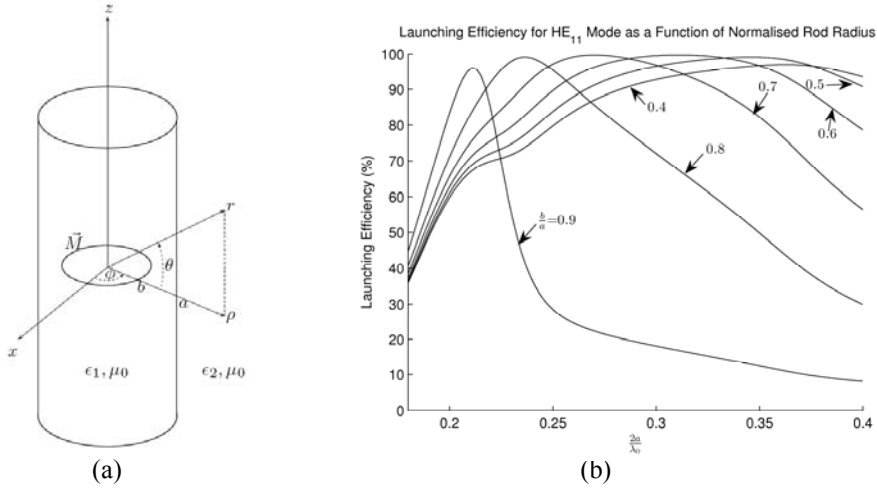


Fig. 1: (a) Magnetic ring current exciting an infinite dielectric rod; and (b) HE_{11} mode launching efficiency for a dielectric rod with $\epsilon_r = 10$.

TERAHERTZ DIELECTRIC ROD DESIGN

Dielectric rod antenna designs scale with wave number; however, a problem unique to the terahertz regime is the materials available to fabricate the rod. The materials commonly used in this regime typically have a high permittivity such as silicon ($\epsilon_r \sim 11.7$) and magnesium oxide ($\epsilon_r \sim 9.65$). Dielectric rod antennas are generally made from low permittivity materials leading to a small permittivity contrast between the surrounding air and the rod. This allows the wave traveling towards the end of the rod to be easily matched to free-space with a slight rod taper, thus avoiding a reflection. This is equivalent to ensuring the wave propagation constant along the rod, β_z , gently approaches β_0 , the free-space propagation constant, at the end of the rod. Fig. 2 shows the propagation constant for a wave traveling along the rod versus the rod diameter for two different rod permittivities. It can be seen that in contrast to the low permittivity case, the high permittivity rod has a sharp transition region where the propagation constant rapidly approaches that of free-space. For design purposes this implies that a dielectric rod made from a high permittivity material should have a sharp taper for broadband matching purposes.

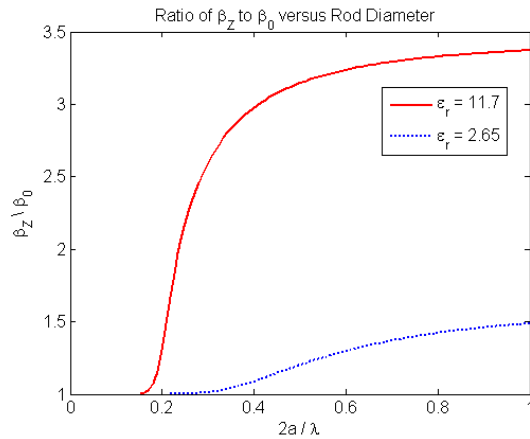


Fig. 2. Propagation constant versus rod diameter for different permittivities.

INTEGRATION OF DETECTION CIRCUITRY

We propose to excite the dielectric rod with a ring slot printed on the bottom of the substrate, shown in Fig. 3a. This will allow an integrated structure between the radiator and the receptor/transmitter. The ring slot is formed from evaporated gold on top of an adhesion layer. The ring slot radius was chosen to have a b/a ratio of 0.45 to allow it to operate in its first resonant mode whilst providing a high excitation efficiency for the dielectric rod. The impedance bandwidth is 13%. The ring slot antenna is designed to have a zero bias Virginia Diodes diode, shown in Fig. 3b, bonded across the slot. The ring slot antenna has an integrated low pass coplanar waveguide filter allowing the DC signal from the diode to be read. The integration of the diode will allow the radiation pattern of the antenna to be measured [4]. The large rectangular pads are used for wirebonding to provide a connection to an external amplifying circuit.

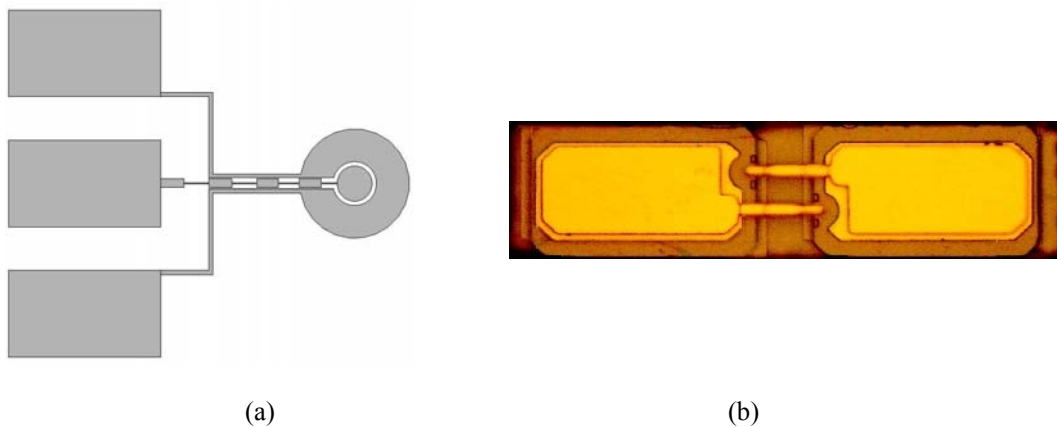


Fig. 3. (a) Ring-slot excitation design; and (b) THz diode detector.

DIELECTRIC ROD FABRICATION

The length of the dielectric rod and the surface tolerances required preclude the use of conventional milling or photolithographic fabrication techniques for forming the rod. To overcome these limitations a fabrication process using laser ablation was developed [5]. The dielectric rods were formed by removing material from the dielectric substrate to leave free standing rods. The process was adapted to allow a gentle taper to be formed on the rods allowing for broadband operation and greater gain. Magnesium oxide (MgO) was chosen as the substrate material

because of its low absorption in the terahertz region, its suitability for laser ablation and future compatibility with superconducting detectors [6]. Laser ablation was carried out using a frequency quadrupled Nd:YAG system (266nm) with 200 μ J pulses at a 1kHz pulse repetition rate. Fig. 4a shows a side view of one of the rods and Fig. 4b shows a view from the top of the substrate. Rod lengths over 1mm have been fabricated, allowing gains of around 10dBi. The fabrication process is expected to be scalable to larger array sizes.

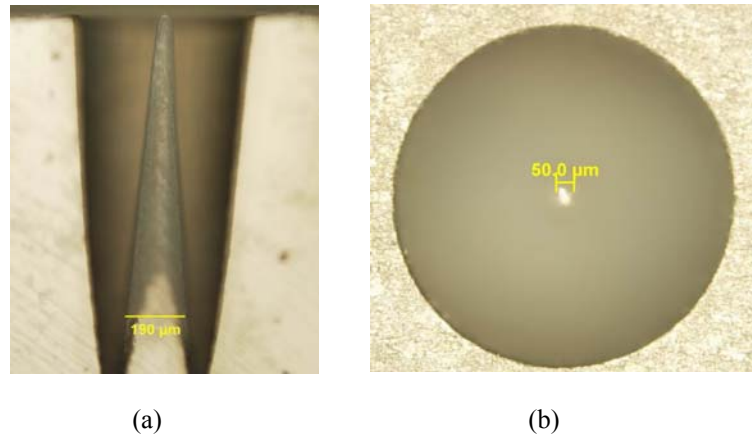


Fig. 4. (a) Side view of dielectric rod; and (b) top view of the dielectric rod with the ablated surrounding region.

CONCLUSION

A dielectric rod antenna is proposed as a possible element for a terahertz array. The design and fabrication of a terahertz dielectric rod antenna was presented. The results of an analysis for a magnetic ring current inside the rod exciting the fundamental surface wave show that excitation efficiencies approaching 100% are possible with a ring-slot that is 0.6 times the rod diameter. Laser micromachining fabrication results were also presented and these showed that tapered rods can be produced. Initial computed results indicate an acceptable radiation performance can be achieved. A prototype array element is being built and this will be integrated with a commercial diode detector.

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