Effects of Finite Substrate Size of Membrane Structure on Antenna Performance at Terahertz Frequency

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***Abstract* –In this paper, we study the geometrical effects of a full-wavelength dipole antenna supported by a GaAs membrane structure. It was found through an optimization process that the finite substrate size of the GaAs membrane affect the overall performance of the antenna. The bulk GaAs substrate exhibits a certain range of size in which the antenna maintains high input resistance and high radiation efficiency. This investigation provides a good guideline in optimizing the overall performance of a terahertz photomixer antenna supported by a GaAs membrane structure.**

I. INTRODUCTION

The terahertz (THz) photomixer system is one of the most promising technologies among many different compact THz sources because of its compactness, widely tunable frequency range, and room temperature operation [1, 2]. It is usually integrated with a lens substrate with high dielectric constant and used as a THz emitter or detector. However, the antenna on a substrate with high dielectric constant has remarkably decreased input resistance, and thus causing quite low mismatch efficiency between the photomixer and the antenna. A GaAs membrane structure has shown a promising technique to solve these problems where the effective dielectric constant of the membrane structure is controlled by manipulating substrate geometry. Several advantages, such as loss and dispersion effect reductions, substrate mode suppression, and integrated subsystem possibility could be found with this design approach [3]. In addition, a back plane reflector can be used as a ground plane to enhance the directivity and make the pattern unidirectional. However, there has been very little attention on studying the membrane substrate geometry to optimize the overall antenna performance for THz photomixer.

In this paper, a THz photomixer antenna designed on a GaAs membrane structure is examined. Through the optimization process, an interesting property related to the bulk GaAs substrate size was found. The bulk GaAs substrate exhibits a certain range of size in which the antenna maintains high input resistance and high radiation efficiency.

II. ANTENNA GEOMETRY AND FINITE SUBSTRATE SIZE EFFECT

Figure 1 shows the antenna structure in which a full-wave length dipole is supported by a GaAs (ε_r=12.9) membrane structure. A pyramidal cavity with a taper angle of 45° was formed in the GaAs substrate. A Ti-Au thin film with conductivity of 1.6 x 10^7 S/m and thickness of 0.35 μm is used for the dipole and ground plane. For the antenna to resonate at around 1.0 THz, a 120-μm long, 3-μm wide dipole was chosen. The height of the substrate is H=10 μm and the thickness of the membrane is t = 3 μm.

We used a commercially available electromagnetic simulator based on the finite-integration time-domain technique, CST Microwave Studio, to investigate the geometrical effects of the GaAs membrane structure on the antenna performance. It should be noted that the radiation efficiencies and input resistances shown in the following figures are deduced from the antenna at the resonance frequencies. In the antenna design, the total efficiency ε_{total}, the product of the radiation efficiency $\varepsilon_{radiation}$, and the mismatch efficiency $\varepsilon_{mismatch}$ can be expressed as [4].

$$\varepsilon_{total} = \varepsilon_{radiation} \times \varepsilon_{mismatch} = \varepsilon_{radiation} \times \left(1 - |\Gamma|^2\right) \quad (1)$$

The reflection coefficient Γ in the mismatch efficiency in Eq. (1) is determined by the following equation:

$$\Gamma = \frac{Z_{antenna} - Z_{photomixer}}{Z_{antenna} + Z_{photomixer}}. \quad (2)$$

Hereafter, the mismatch efficiency is calculated by assuming a photomixer impedance of 10 kΩ, and the corresponding total efficiency is calculated using Eq. (1).

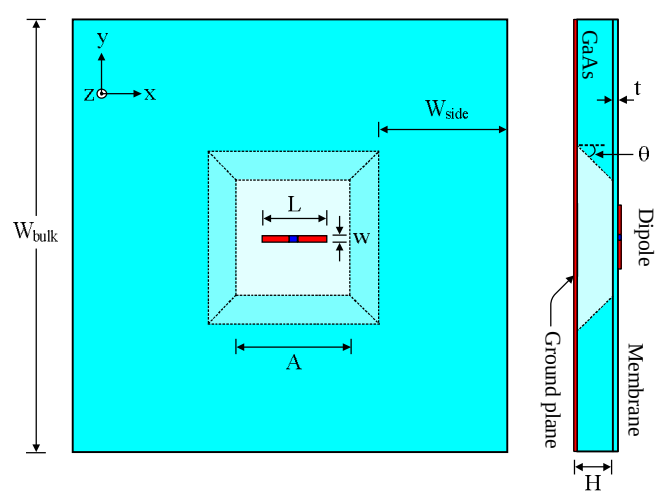

Fig. 1. Geometry of the antenna.

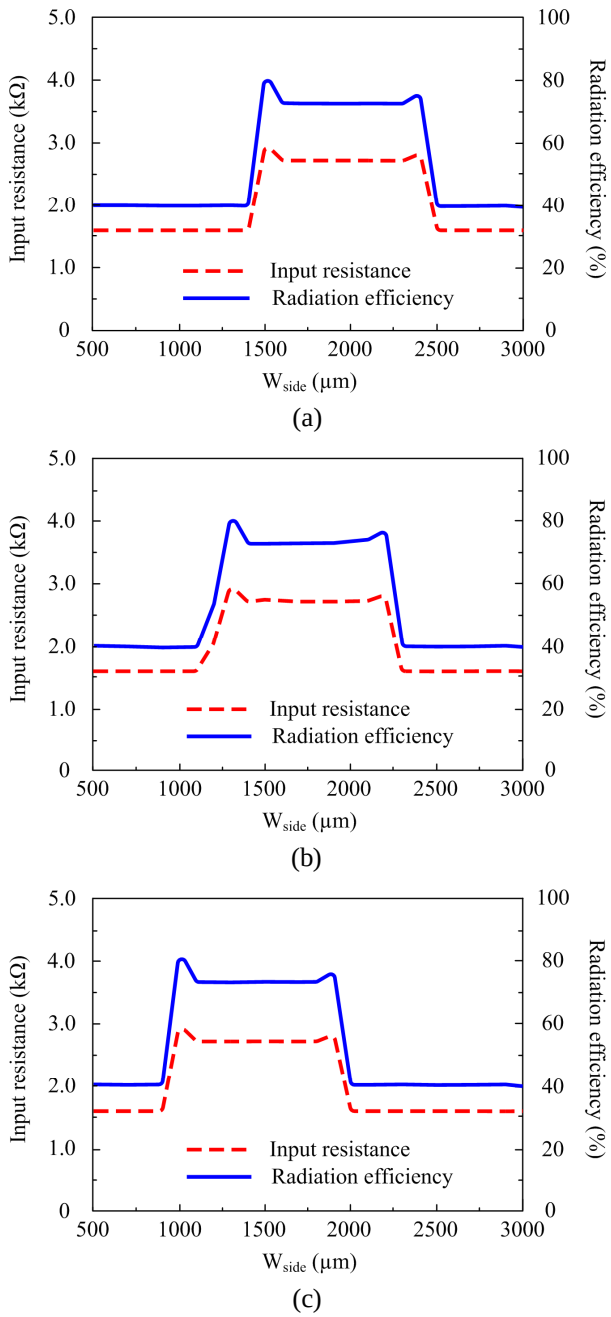

Fig. 2. Antenna characteristics with respect to W_{side} variations for three different cavity sizes A: (a) 500 μm, (b) 1000 μm, and (c) 1500 μm.

Figure 2 shows the effect of the finite size of bulk GaAs substrate on the input resistance and radiation efficiency of the antenna for three different cavity sizes, 500 μm, 1000 μm, and 1500 μm, with respect to lateral size, W_{side}. The ranges of W_{side} required for the antenna to obtain both high input resistance and high radiation efficiency were different for different-sized cavities. The W_{side} ranged from 1500 to 2400 μm for A = 500 μm, from 1300 to 2200 μm for A = 1000 μm, and from 1000 to 1900 μm for A = 1500 μm. Generally, it was observed that the bulk substrate size, W_{bulk}, required to have high input resistance and radiation efficiency of the antenna, irrespective of the cavity size *A*, ranged from approximately 3500 μm to 5400 μm. Obviously, significant improvements in terms of input resistance and radiation efficiency were achieved for substrates in this size range, i.e., more than 2700 Ω input resistance and 73% radiation efficiency, compared with less than 1600 Ω input resistance and 40% radiation efficiency for substrate sizes outside this range. Although these prominent effects could be achieved at the lower and upper boundaries of the W_{side} range, the narrow size tolerance could risk antenna performance in actual devices.

Figure 3 compares the radiation patterns for three different cavity sizes with a fixed bulk substrate size of 4000 μm, i.e., W_{side} of 1750 μm, 1500 μm, and 1250 μm for *A* of 500 μm, 1000 μm, and 1500 μm, respectively. The main lobes of the antenna patterns with the larger cavity were more immune than the smaller to rippling, which was observed in both the *x*–*z* and *y*–*z* planes. In addition, a slightly improved directivity was observed for the 1000-μm and 1500-μm cavities as compared with the 500-μm cavity.

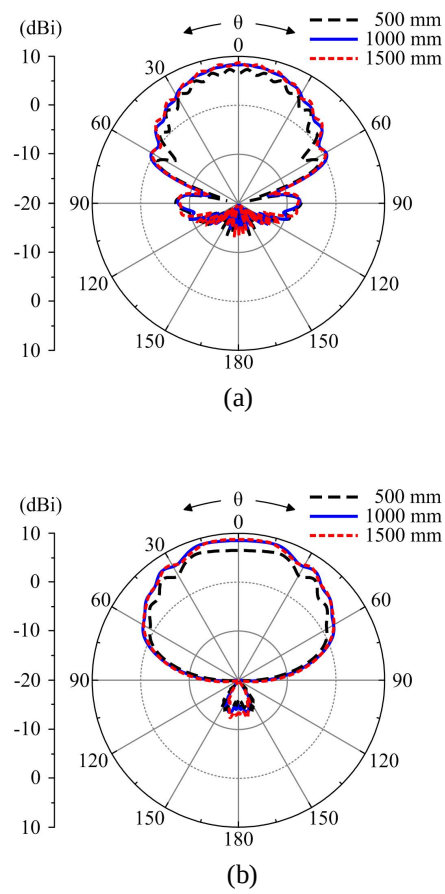

Fig. 3. Radiation pattern comparison with the fixed bulk GaAs substrate size W_{bulk} of 4000 μm for three different cavity sizes *A*: (a) x–z plane, (b) y–z plane.

III. CONCLUSIONS

We examined the antenna characteristics such as input impedance and efficiency of a full-wavelength dipole supported by a GaAs membrane structure. The substrate exhibits a certain range of size, irrespective of cavity size, in which the antenna maintains high input resistance and high radiation efficiency. In addition, the large cavity is preferred within the limits of fabrication capability. These investigations provide good guidelines in optimizing overall performance of a THz photomixer antenna supported by a GaAs membrane structure.

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