A Near-field Spoof Plasmon THz Probe Using Metallized 3-D printed Plastic

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Abstract—This paper presents the design, fabrication and characterization of a terahertz (THz) spoof surface plasmon based near field probe. It is built using a single side metallized bulls-eye plastic structure with a micro-lens at the aperture. 3-D printing is used in the fabrication of the plastic structure followed by a thin film metal coating. Details analysis is carried out using FEM simulation tool. The structure is measured over a wide band using frequency based THz measurement system.

I. INTRODUCTION

Over last decade, terahertz (THz) system applications have garnered significant interest in the areas of communications, security, biomedical imaging, non-destructive evaluation, and spectroscopy [1]. One area of significant interest is in the sub-wavelength imaging of structures in the reflection or transmission modes. The inherent wavelength of THz is small and provides very fine resolution. Further resolution can be attained by sub-wavelength focusing through plasmonics.

Surface plasmonics have been utilized to enhance transmission through sub-wavelength apertures at optical and terahertz frequencies. This is due to the constructive interference of resonating plasmonic modes (also termed spoof plasmon) on a concentric rings of metal corrugations [2, 3]. These transmitted modes can be reformed both spatially and temporally through structural discontinuities such as hole and trench. Such systems produce enhanced, narrow-beam transmission while requiring only single wavelength geometric sizes [3-5]. Significant analysis is presented in literature for different types of geometries made from metal structures. In this paper, we demonstrate a new structure based on metal/dielectric combination to further enhance transmission efficiency. Also, a 3-D plastic printed is utilized in the fabrication of the plastic base structure.

II. DESIGN AND SIMULATION

The structure of the proposed near-field plasmon THz probe is shown in Fig. 1. It consists of a dielectric layers with corrugations and a micro-lens. The corrugation region is coated with a thin metal film having an opening at the probe tip (a lens region). The width (W) and height (h) of the probe are 20.7mm and 0.9 mm, respectively. The period and width \( W_1 \) and \( W_2 \) of the corrugations are designed to match approximately three quarter wavelength at the operating frequency. Table 1 shows the dimensions of the designed structure. Fig. 1 (b) shows the simulation result of the near field probe at \( f = 0.3 \) and 0.325 THz. Simulations were carried out using Ansoft HFSS v.14. At 0.3 THz (maximum transmission), the transmitted electromagnetics wave travels along the periodic structure within the dielectric medium and constructively builds up at the center of the aperture. The wave is then guided into the probe tip having a lens element at the end of the tip. However, at 0.325 THz minimum signal transmits through, and it is largely reflected back.

The base structure is built from a plastic material, ABS (Acrylonitrile Butadiene Styrene, \( e_r = 2.79, [6] \)). One side is flat and the other side has circular corrugations and a micro-lens element. The corrugations are used to excite spoof-plasmon to concentrate the wave at the center of the structure. The thickness of the plastic was designed to maximize transmitted signal. A micro-lens at the tip helps in concentrating the transmitted signal.

Table 1. Dimensions of a designed near-field THz probe.

<table>
<thead>
<tr>
<th></th>
<th>W1</th>
<th>0.45 mm</th>
<th>remarks</th>
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<tr>
<td>width</td>
<td>W2</td>
<td>0.45 mm</td>
<td>( \lambda = 0.6 ) mm at 0.3 THz (ABS material)</td>
</tr>
<tr>
<td></td>
<td>Wtip</td>
<td>1.8 mm</td>
<td>• thickness of Cu =1μm</td>
</tr>
<tr>
<td>height</td>
<td>hgroove</td>
<td>0.36 mm</td>
<td></td>
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<tr>
<td></td>
<td>htip</td>
<td>1.8 mm</td>
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III. FABRICATION

A 3-D plastic printer (Object Connex 350) was used in the fabrication of the base plastic structure. The printer can deposit plastic material with high resolution (resolution < 100μm). The front side (a side to incident wave) is the plastic with no metallization. The back side of the structure, with corrugations, is metallized by sputter depositing thin titanium (Ti) and copper (Cu) layers. The Ti layer helps to enhance the adhesion of the Cu to the acrylic layer. Fig. 2 shows the
pictures of the fabricated probe structure.

![Fig. 2. Photographs of a fabricated near-field plasmon THz probe, (a) front side and (b) backside – metallization and a probe tip.](image)

IV. MEASUREMENT

Measurements of the probe were carried out using Emcore PB-7200 frequency domain measurement system. To characterize the probe, three experiments were carried out: (i) Transmitted signal as a function of frequency, (ii) measurement of beam waist at the exit of the lens probe tip and (iii) transmission efficiency. Fig. 3 (a) shows the first measurement setup; here the wave is incident from a THz source onto the front side (non-metalized side, see Fig. 2 (a)) of the probe. The probe is placed near the THz detector and the transmitted signal through the probe is measured as a function of frequency. The structure is placed in an aluminum holder which helps align and block off any stray signal from the sides. Fig. 3 (b) shows a setup to measure beam waist at the exit end (from the probe tip). Here a thin metal plate with sharp edge (knife edge to reduce scattering) is mounted on a micromanipulator. The transmitted signal with varying position from the center of the probe tip is measured. The plate was placed approximately 2 mm from the tip.

![Fig. 3. Photographs of the (a) transmission measurement and (b) beam waist measurement setup.](image)

Fig. 4 shows the measured and computed transmitted signal through the probe. Simulations were carried out using HFSS. The measured maximum transmitted signal is at 0.245 THz, and the half power bandwidth is 22 GHz (between 0.239 to 0.261 THz). A reference with small pin-hole same size as the aperture showed no transmitted (signal below the noise floor). This measurement clearly shows that the transmitted signal is enhanced over a narrow band of frequency dictated by the periodicity of the corrugations in the plastic structure. Compared to the simulation results, the measured operating center frequency is shifted down by approximately 55 GHz; this is largely due to the manufacturing tolerance (± 50µm) of a 3-D printer.

The transmitted beam waist was measured by varying the position of the edge of the plate with respect to the center of the tip. Data was collected at 250 µm resolution in position of the plate. By taking the slope of the measured signal with respect to position, the beam waist was determined at half-power. It was determined to be approximately 3 mm at a distance of 2 mm from the probe tip. This is larger than the aperture of the probe tip (1.8 mm) and shows that the beam spreads out upon exiting the probe tip. Also, part of the scattering is from the edge of the metal plate. The transmission efficiency was measured to be approximately 11% at 0.245 THz. This is the transmitted signal through the aperture with respect to the total power incident on the probe (dia. = 20.7mm). Total power was measured through a hole in aluminum holder with diameter of 20.7mm.

![Fig. 4. Measured transmitted signal through the probe. Measurement setup is depicted in the indented figure.](image)

V. SUMMARY

In this paper, a new near-field probe is demonstrated. It is built form 3D printed plastic with thin metal coating on one side. The dielectric layer helps trap the wave within the structure and enhances transmitted signal. Also, a micro-lens at the tip helps focus and guide the beam at the exit end. This structure will find applications in non-destructive evaluation, near field probing and antenna elements. The structure is simple to fabricate and can readily be adopted in such applications.

REFERENCES