TeraFoils: Design and Rapid Fabrication Techniques for Binary Holographic Structures in the Terahertz Region

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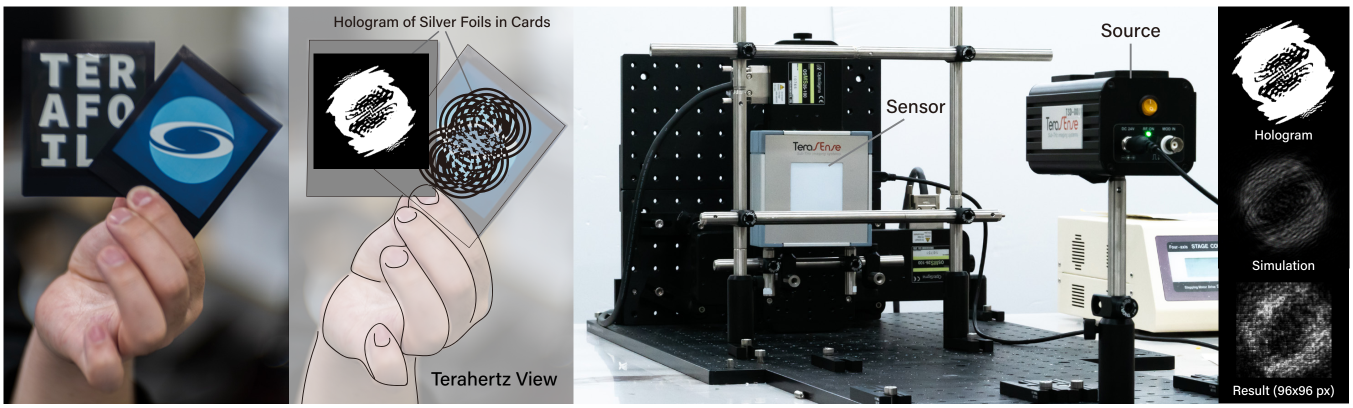

Figure 1: Left: holographic tag card of TeraFoils. Center: experimental setup with sub-terahertz detector array and sub-terahertz source. Right: hologram generated by the proposed method, simulated result, and captured result (SIGGRAPH logo).

ABSTRACT

In this paper, we introduce TeraFoils, a method for designing and fabricating material-based structures using binary holograms in the terahertz region. We outline the design, fabrication, imaging, and data processing steps for embedding information inside physical objects and exploring a method to create holographic structures with silver-foiled paper. This paper is a sheet on which silver foil is pasted where the ink is printed, using a home-use laser printer and an electric iron. Wave propagation calculations were performed to design a binary-amplitude hologram. Along with the designed pattern, we fabricated silver-foiled binary holograms in the sub-terahertz range (0.1 THz) and confirmed their functions using a two-dimensional THz sensor.

CCS CONCEPTS

• **Human-centered computing** → *User interface toolkits.*

KEYWORDS

digital fabrication, terahertz, hologram, data encoding, material

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1 INTRODUCTION

The development of light sources in the electromagnetic frequency band of approximately 0.1−10 THz (wavelength of 3 mm-30 μm) has progressed [Lee 2009] and called "Terahertz" region. Electromagnetic waves of these frequencies can penetrate various materials such as paper, plastic, fibers, and semiconductors. The research for applications in the terahertz range is actively being conducted in several fields, such as PoS systems [Willis and Wilson 2013], foreign substance inspection [LEE et al. 2012], communication [Federici and Moeller 2010], medical sensing [Siegel 2004], and more. However, limited commercial applications exist for terahertz range waves [Banerjee et al. 2008]. Frameworks and design methods are required for identifying practical, everyday applications for computer human interactions.

To realize a simple pipeline in the terahertz region, we proposed TeraFoils—which helps create a material-like holographic structure by attaching a silver foil to paper—applying the technique of creating electronic circuits using silver foil [Segawa et al. 2019]. Using a home-use laser printer and an electric iron (as shown in

Figure 2: Left: designing an amplitude-modulated hologram. Center: fabrication flow. Right: results of our method (SIG letter).

Fig. 2), we achieved a faster and more economical method than that employed in a 3D printer. Wave propagation calculations were performed to design a binary amplitude hologram, and the designed hologram pattern was simulated. With the designed pattern, paper and silver foil were used to produce holographic structures, and their functions were confirmed with the experimental setup shown in Fig. 1.

2 PROPOSED METHOD AND RESULTS

Light wave propagation was calculated to design a binary amplitude hologram and simulate the reconstructed image from the hologram pattern, as shown in Fig. 2 (left). First, light wave back-propagates from the image plane $g_1(x_1, y_1)$ to the hologram plane $f_1(x_2, y_2)$ as follows:

$$f_1(x_2, y_2) = \mathcal{F}^{-1} \quad \mathcal{F}[g_1(x_1, y_1)]\mathcal{F} \quad \exp \quad \frac{i\pi p^2}{\lambda z} \quad x_1^2 + y_1^2 \qquad . \tag{1}$$

Next, a binary amplitude hologram $f_2(x_2, y_2)$ is calculated by binarizing the amplitude of the propagated plane:

$$f_2(x_2, y_2) = binarize(f_1(x_2, y_2)). \tag{2}$$

The propagation calculation is performed again using Eq. 1, and the reconstructed image $g_2(x_1, y_1)$ is derived to simulate the image reconstruction with the binary amplitude hologram.

A hologram structure is fabricated by thermo-compression bonding silver foil to paper on which the designed pattern is printed with ink, as shown in Fig. 2 (center). The fabricated hologram, the actual propagation result, and the simulation results are shown in Fig. 2 (right). The actual propagation result is captured by moving a two-dimensional THz sensor on the XZ stage, as shown in Fig. 1. Although the actual propagation result is noisy, the experimental results are in agreement with the simulation results.

3 CONCLUSION AND FUTURE WORK

This paper proposed a design and manufacturing method for TeraFoils. In this method, a structural design is obtained based on hologram calculation, and thermo-compression bonding of silver foil is used for the fabrication process. Because silver foil does not transmit terahertz waves, the hologram must be binarized. The designed holographic structure was created, and the propagation result was confirmed using a two-dimensional THz sensor. Although there was noise in the image after propagation, we could obtain results similar to those of the simulation.

However, some improvements can be made in the future. First, the accuracy of the hologram should be improved via optimization. Second, concrete applications should be created using this method. We believe that such improvements can further contribute to TeraFoils as a rapid fabrication method for new holographic structures in the terahertz region.

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