THz 導波路伝搬特性の内壁金属コーティング材料・膜厚依存性

Dependence of material and film thickness for inner metallic coating of THz waveguides on its propagation property

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Introduction

It is essential to develop waveguides for propagation control of electromagnetic waves.. However, in terahertz (THz) frequency region, dimension of waveguides shrinks down to several hundred micrometers, resulting in manufacturing difficulty by the conventional machining of bulk materials. 3D printing is an adequate technology to fabricate complex structures, though the material of high-resolution 3D printing is limited to polymer. Therefore, hybrid THz waveguides composed of 3D-printed polymer coated by metal films have been developed [1]. This combined approach will also enable unique complex devices not feasible conventionally, such as a waveguide integrating bandpass filter and three-dimensionally arranged waveguides. Because it is difficult to find the deposition technology allowing uniform film formation on such complex and high-aspect dielectric structures, we recently developed the technology which is supercritical fluid deposition (SCFD) [2,3]. The film was smooth and uniform even on the micro-features with aspect ratio of 100, and free from contaminations, attaining long-term stability. Nevertheless, fundamental information on appropriate metallic material and its necessary thickness against THz waves has not clarified yet. We therefore evaluated the materials and thickness by measuring propagation property of THz waves through the stacked parallel-plate waveguides.

Experimental

Six metals are screened and examined based on the conductivity, permeability, and oxidation resistance; Au, Cu, Al, Co, Fe, Ti (Au and Cu was shown herein). For metal film deposition, magnetron sputtering was used, yielding high-purity film same as SCFD. The parallel-plate waveguide was a stacking of Si substrates with metal films on both sides with 280 μm intervals (metal/silicon-slit arrays) [4]. The waveguide length ranged from 2.5 to 7.5 mm (2.5 mm was shown herein). The transmittance was evaluated in TM mode by utilizing conventional terahertz time-domain spectroscopy (THz-TDS).

Results and Discussion

Figure 1 shows the transmittance of the 2.5 mm-long stacked parallel-plate waveguides with different Au and Cu film thickness. Those by simulation assuming bulk perfect electric conductor (PEC) are also shown. In both metals, the experimental spectra with sufficient thickness matched well with the simulations, suggesting our waveguides were eligible for evaluation. Cu showed similar transmittance to Au, indicating its great potential for THz waveguides application. The transmittance was almost unchanged for Au thicker than 35 nm and Cu thicker than 65 nm. Note that in THz frequency region the skin depths of materials have not been clarified. If applying general formula of skin depths in microwave frequency region, skin depths of Au and Cu calculated in 1 THz are 75 and 65 nm, respectively. For Au, film thickness above half of skin depth was sufficient for this 2.5 mm waveguide propagation. Meanwhile, for Cu, the transmittance decreases when the thickness is 30 nm. It would be mainly because its surface was natively oxidized inevitably due to their handing in air. Due to the complete matching of experiments and simulations for the thickness of 65 nm and 425 nm, Cu oxide layer did not influence the transmittance when the underlying metallic Cu thickness was high enough, thus Cu is still a principal candidate together with Au. Materials other than Au and Cu, propagation length dependence, and demonstration of Cu film made by SCFD will also be presented onsite.

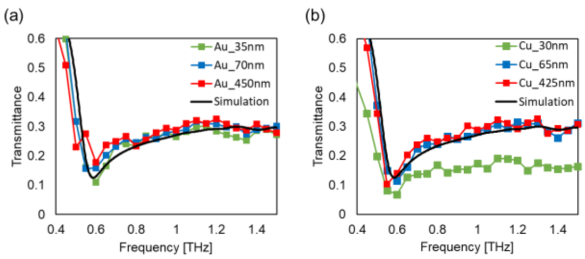

Fig.1. Transmittance of 2.5-mm-long stacked parallel-plate waveguides with different metal film thickness((a): Au, (b): Cu). Black lines show simulation with bulk PEC.

[1] W.J. Otter, Electronics Letters 53, 2 (2017). [2] T. Momose, 65th JSAP meeting (2018) 20a-A402-5. [3] K. Konishi, 65th JSAP meeting (2018) 20a-A402-4. [4] Y. Kishi, Appl. Phys. Express 8, 032201 (2015).