金属被覆誘電体テラヘルツ波平行平板導波路における伝搬損失メカニズム
Propagation loss mechanism in metal-coated dielectric terahertz wave parallel-plate waveguide

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Introduction

To cope with an increasing demand for high-capacity wireless communications, use of electromagnetic waves in sub-terahertz and terahertz regions is expected in beyond 5th and 6th generation (B5G and 6G) networks. To control and guide such high-frequency waves, sub-millimeter scale three dimensional (3D) structures, which are generally high-aspect-ratio and complicated, are mandatory. It is, however, challenging to fabricate these devices using conventional technologies due to their size, aspect ratio, and complexity. 3D printing of dielectrics (i.e. polymer) emerges as a potential solution due to improved resolution down to ten micrometers.[1] Therefore, combination of 3D printing of polymer and metallic film coating enable to design and fabricate various passive THz wave devices. A suitable coating methods are under development, such as our developing supercritical fluid deposition (SCFD),[2] and will be screened considering conformality, deposition rate (and necessary thickness), film quality, and cost. In short, desired performance of metal-coated dielectric THz waveguides is achievable via the appropriate device design and relevant technology development, for both of which metal film property against the THz wave propagation is essential. We previously specified the suitable metal (Cu and Au) and necessary thickness (175 nm at 0.72 THz) by analyzing the propagation loss in the metal-coated dielectric parallel-plate waveguides (PPWGs).[3] Further information is still necessary to determine the film thickness considering the acceptable propagation loss and frequency in use, which was investigated herein.

Scope

The propagation loss is a consequence of two loss components i.e. penetration loss due to THz waves passing through the metal film and ohmic loss due to an electric current dissipating in the metal film. The necessary thickness to eliminate the penetration loss will descend with frequency according to a decreased skin depth. In contrast, that for the ohmic loss will ascend with frequency, because electrical conductivity of very thin films is a function of film thickness (smaller for thin films) due to scattering of electrons at their surface/interface, which is called the thin-film effect. Thus, in the THz region, it is expected that both of these effects need to take into account to determine the necessary thickness.

Methodology

The physical model for anticipating the propagation loss in the metal-coated dielectric PPWG [3] was used for investigation. For quantitative discussion, critical film thickness was defined, at which the loss was 10% larger than that in the thick-enough (500 nm) film.

Results and Discussion

Figure 1 shows the propagation loss of Au-coated PPWG depending on film thickness in TE_1 mode at 0.72 THz, with the three components; penetration loss, ohmic loss by bulk conductivity (bulk σ), and ohmic loss by a decrease of conductivity (Δσ) due to the thin-film effect. The critical thickness was 175 nm for our sputtered Au films at 0.72 THz, which was not determined by the penetration loss but ohmic loss by Δσ. It means high-quality film (i.e. smaller Δσ and higher bulk σ) is essential to suppress the critical thickness and also the propagation loss above the critical thickness, and thus use of coating processes capable of yielding high-quality films is highly recommended, such as SCFD.[2] Dependence of the critical thickness on frequency will be discussed onsite. Our physical model is also applicable to the metal-coated dielectric THz waveguides with other geometries after the modification, enabling to anticipate the critical thickness considering the acceptable loss, frequency, and film quality.

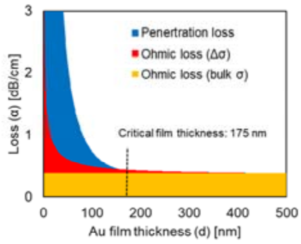

Fig. 1. Propagation loss in our Au-coated PPWG at 0.72 THz in TE_1 mode and their loss components.

References: [1] W.J. Otter, *et al.*, Electron. Lett 53 (2017) 7. [2] T. Momose, *et al.*, 65th JSAP meeting (2018) 20a-A402-5. [3] Y. Huang, *et al.*, 68th JSAP meeting (2021) 18p-Z09-12.