THz 導波路における伝搬ロスの金属コート膜厚依存性

Film thickness dependence on propagation loss of coated metal in terahertz waveguides

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Introduction

It is important to develop terahertz (THz) waveguide for propagating THz waves. However, as an aperture size of such waveguides is in sub-mm scale, fabrication from bulk metal is difficult. Therefore, development of metal-coated dielectric waveguide using 3D printing and metal coating is concentrated in recent years. In metal coating, electroless plating followed by electro plating has commonly been adopted, yet its film quality is not necessarily sufficient, and poor step coverage is also not suited for high aspect-ratio waveguides. We therefore proposed to employ supercritical fluid deposition (SCFD), which enables high-quality film formation onto high-aspect-ratio features [1]. In addition, we previously screened Au and Cu over six metals due to the highest transmittance as perfect electric conductor (PEC) [2]. However, the necessary film thickness (a function of propagation length and acceptable loss) is quantitatively still unclear. In this study, we investigated the necessary film thickness by evaluating the attenuation coefficients in the silicon-based multiple waveguides with different length and different coated film thicknesses. Theoretical model to reproduce propagation loss was also eventually developed.

Methodology

Cu was studied as screened previously [2]. The films were coated by magnetron sputtering on both sides of 280-µm silicon substrates, which was then stacked 10 times with 280-µm intervals to form stacked parallel-plate waveguides. Cu film thickness ranged from 30 to 440 nm, and waveguide length ranged from 2.5 to 5 mm. The transmittance was measured in TM mode by using conventional terahertz time-domain spectroscopy (THz-TDS). Attenuation coefficient was estimated from transmittance obtained from 2.5- and 5-mm-long waveguides. Theoretical model to estimate attenuation coefficient of THz waveguides was developed by incorporating reflection of THz waves at the both interfaces of the thin Cu layer into the calculation model for propagation in metallic waveguide [3, 4]. Metallic property of Cu was described by Drude model.

Results and Discussion

Figure 1(a) shows experimental and theoretical attenuation coefficients in the parallel-plate waveguides with 65 nm-thick Cu. The measured attenuation coefficient was reproduced by the developed theoretical model calculated with the resistivity measured by the four-point probe (solid line). The measured resistivity was consistent with previous reports (not shown) [5]. Attenuation coefficient calculated with the bulk resistivity was largely deviated from the experiments because the resistivity of the film whose thickness is equivalent or below the mean free path of electrons is increased by surface scattering and/or grain boundary scattering [5]. Figure 1(b) shows film thickness dependence of attenuation coefficients in the Cu-coated waveguides (experiments for 1 THz and calculation for 1 to 3 THz). Good matching of experiments and calculation at 1 THz also validated our methodology. It was evident that, at 1 THz, the attenuation coefficient does not depend on the film thickness when the film thickness is more than twice of its skin depth (65 nm). Furthermore, this model makes it possible to predict precisely the film thickness to achieve the required attenuation coefficient. Note that materials studied in this study was Cu alone, but the model develop can consider any materials, thus applicable for other devices that utilizes THz waves including meta materials.

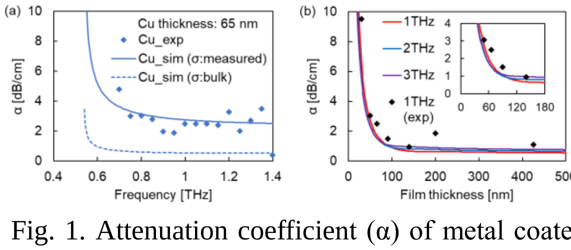

Fig. 1. Attenuation coefficient (α) of metal coated parallel-plate waveguides; (a) frequency dependence and (b) film thickness dependence for Cu. Symbols show experimental results, while solid lines and dashed line show calculation results by measured and bulk resistivity, respectively.

References

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