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Suitability of metallic materials for metal-coated dielectric terahertz waveguides

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Introduction

Terahertz wave devices are the essential components for controlling THz waves, which were aimed for the application of beyond 5th and 6th generation communication systems. The devices have sub-millimeter-scale three-dimensional (3D) and high-aspect-ratio structures. Consequently, it causes difficulties for fabricating these devices by conventional methods such as bulk machining owing to their complexity, size, and high-aspect-ratio features. Recently, 3D printing of dielectrics (i.e. polymer) becomes a potential solution due to its improved resolution down to ten micrometers. [1] Thus, the combination of 3D printing of polymer substrate and metal film coating enables fabrication of metal-coated dielectric THz wave devices. A suitable coating method is under development, such as the supercritical fluid deposition (SCFD) we proposed. [2] In addition, clear-cut understanding of the film thickness to achieve desired performance of metal-coated dielectric THz waveguides is essential. We previously developed the physical model for anticipating the two key parameters determining waveguide performance, which were critical film thickness performing like metallic waveguides and the propagation loss in films with thicknesses greater than critical film thickness (α_{CT}). [3] Therefore, the suitable metallic material is the remaining concern. Since dominant factors to determine the propagation loss were different in GHz and THz regions, which were penetration loss in GHz, while ohmic loss in THz (i.e. thickness-dependent conductivity), suitable metals in THz region should be carefully determined. We, therefore, selected suitable metallic material using our model under the assumption of the same film quality.

Methodology

The physical model for anticipating the two key parameters in the metal-coated dielectric PPWG [4] was used. The model applied thickness-dependent electrical conductivity (σ_f) of metal films by using Fuchs–Sondheimer (F-S) theory and Mayadas–Shatzkes (M-S) theory [5], as follows:

$$\frac{1}{\sigma_f} = \left[0.375(1-p) + \frac{1.5R}{1-R}\right]\left(\frac{\lambda}{\sigma_b}\right) \times \frac{1}{t} + \frac{1}{\sigma_b} \qquad (1),$$

where t, λ, σ_b, p, and R are the thickness, mean free path of an electron, the bulk conductivity, specularity coefficient, and grain boundary reflection coefficient in/of the metal film, respectively. Note that $([0.375(1-p)+1.5R/(1-R)](\lambda/\sigma_b)$ corresponds to the strength of the thin-film effect, of which smaller value indicates higher film quality. For a fair selection of suitable metal films, the following assumptions were made. The $[0.375(1-p) + 1.5R/(1-R)]$ was assumed to be 0.66 representing high-quality films, and σ_b and λ were taken as the literature values [6-7]. For quantitative discussion, the 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 critical film thickness and α_{CT} of various metal films (Au, Ag, Cu, Al, Ni, Cr, and Ti). The frequency was at 0.72 THz and was in TE_1 mode. All the metals showed the proportional trend, and Cu was found to have the smallest critical thickness and comparable α_{CT} with Ag that has the smallest value. Considering that the material cost and availability, Cu was considered to be a suitable material. As both of critical film thickness and α_{CT} depend on film quality, impact of film quality on these parameters will also be discussed onsite. Note that Cu suffers from oxidation, but its impacts on THz wave propagation were previously found negligible. [3]

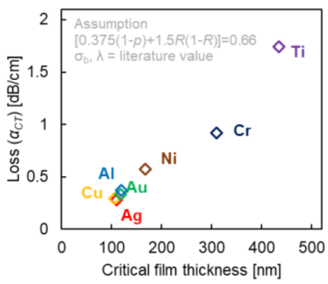

Fig. 1. Critical film thickness and films thicker than α_{CT} for various metals. We assumed that $[0.375(1-p) + 1.5R/(1-R)]$ was 0.66, and frequency was 0.72 THz.

References

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