Cu コート THz 導波路の表面酸化による伝搬特性への影響

Impact of surface oxidation on wave propagation of Cu-coated THz waveguides

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Introduction

Terahertz (THz) waveguides are one of the important subsystems in THz technology. Conventional metallic waveguides face a difficulty in fabrication due to sub-mm-scale smaller aperture size. Hybrid waveguides, consisting of 3D-printed polymer coated with metal film, provides great potential for THz devices. However, there is lack of fundamental information regarding suitable coating material and required film thickness. We previously evaluated coating material, in which Cu showed the highest transmittance in 2.5-mm propagation, endorsing Cu as a principal material considering its cost and availability [1]. However, different from Au, Cu is known to be oxidized in the oxygen-existing environment *i.e.* in air. Therefore, to prevent it, Cu film capped by Au is thereby used occasionally. Hence, it is important to investigate the impact of surface oxidation of Cu on THz wave propagation experimentally. In this study, we intentionally oxidized the Cu film formed on inner wall of silicon-based stacked-plate waveguides and evaluate how it affect the propagation property.

Experimental

Cu film was coated with sufficient film thickness (300 nm) on both sides of 280-μm silicon substrate by magnetron sputtering. They were then stacked 10 times with 280-μm-intervals to form stacked parallel-plate waveguides. Two different lengths of waveguides (2.5 and 5 mm) were prepared. (results of 2.5-mm-long waveguide alone shown herein) Transmittance of the waveguides was evaluated by conventional THz time domain spectroscopy (THz-TDS) in TM mode. To oxidize the as-deposited Cu film, the substrates were annealed at 80°C for 2 h in atmosphere. To recognize the thickness of oxidized Cu film, depth profiling by X-ray photoelectron spectroscopy (XPS) with Ar sputtering was conducted.

Results and Discussion

In Fig. 1(a), oxygen was found in Cu films with and without oxidation. The sputtering time to reach half maximum of oxygen concentration were 0.6 and 3.8 min, respectively, which was equivalent to 1.2 and 7.6 nm, respectively, considering the sputtering rate of 2 nm/min in this condition. The 1.2 nm-thick Cu oxides without oxidation was native oxide. Empirical equation on oxidation rate of Cu at room temperature is reported to be [2],

$$x = 4 + 6.5\log_{10}t,$$

where "x" is oxide film thickness [Å] and "t" is annealing time [min]. It means that Cu was oxidized with 1.2 nm in thickness in the initial 17 min at room temperature in air. It is reasonable because we measured the thickness just after the film deposition. Oxidation proceeds forever but very slowly, for example, 4.3 nm after 2 years. In this context, out sample with 7.6 nm-thick oxides was regarded as the waveguide after a long-term usage (above 10^5 years). Figure 1(b) shows the electric field amplitude in 2.5-mm-long Cu-coated waveguides with and without oxidation. Same level of amplitude indicated that increased oxide thickness had negligible impact on wave propagation, for the case that metallic Cu film with enough thickness underlay the oxides. It also suggested that, since oxidation rate of Cu is quite slow, and Cu oxide is nearly opaque against THz waves, propagation capability would not be deteriorated even if Cu is not capped by Au. In summary, as Cu oxides are not influential to the THz propagation, Cu can still be considered as leading candidate for coating material of hybrid THz waveguide. This conclusion was made by the sputtered Cu film but would be extendable to high-quality film made by other technologies including supercritical fluid deposition [3].

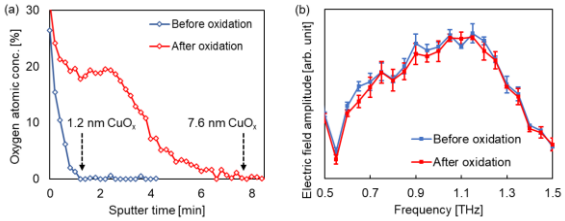

Fig. 1. (a) XPS depth profile of Cu film with and without oxidation. (b) Electric field amplitude of Cu-coated parallel-plate waveguides with and without oxidation.

References

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