Propagation length of mid-infrared surface plasmon polaritons on polycrystalline gold

Nobuyoshi Hiramatsu, Satoshi Ashihara, Fumiya Kusa, Akinobu Takegami, Kotaro Imasaka, Ikki Morichika, Kazuhiko Hirakawa, and Takuji Takahashi

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1 Introduction

Mid-infrared plasmonics on metal is beneficial for a number of applications including surface-enhanced spectroscopies, plasmonic circuit, supersensitive detection, thermal radiation control, and photoelectron emission[1]. Their functionalities rely on the degree of electric-field enhancement, induced by Surface Plasmons (SPs), namely, Localized Surface Plasmons (LSPs) and Surface Plasmon Polaritons (SPPs), which is strongly limited by loss rate or decay time of the SPs.

The SPs' loss is either radiative or irradiative. The former loss rate is the strength of coupling with propagating light that depends on the size and shape of the metal[2]. The latter microscopically originates from electron-electron scattering and electron-lattice scattering, reflecting the material morphology, being expressed by the dielectric constant of metal. Propagation length of SPPs essentially characterize the latter loss, which measures the distance the SPPs diminish to $1/e$ of its initial value in power[3].

Gold is often used for a plasmonic material in visible and mid-infrared range, due to its high optical conductivity and stability under ambient condition[4]. However, the propagation length of mid-infrared SPPs on gold has not been measured as far as we know, whereas Shiba *et al.* reported on copper[5].

In this study, we quantitatively investigated the propagation length of mid-infrared SPPs bound to a gold-air interface. Material morphology of the gold was also correlatively discussed, indicating the strong influence to the propagation length. For direct evaluation of the propagation length, optical experiment was conducted using multiple sets of a waveguide with different lengths sandwiched by paired gratings on a sample, at CO_2 laser wavelength. Annealing was applied to the sample twice at different temperatures for controlling the material morphology, and the optical experiments were conducted for the sample three times before and after annealing. For a each step, as soon as the optical measurement was done, Atomic Force Microscopy(AFM) probing were conducted for the characterization of the surface morphology of the sample. This study is not only valuable for the plasmonic applications to enhance the functionalities, but also for fundamental understanding of the loss mechanism.

The remainder of this paper is organized as follows: In Sec. 2, experimental method and annealing procedure are described. In Sec. 3, design and fabrication techniques of the sample are illustrated. In Sec. 4, surface characterization method and their results are introduced. In Sec. 5, the propagation length of SPPs measured by the optical experiment are shown. In Sec. 6, we discuss the relation between the propagation length and the material morphology of the sample. In Sec. 7, we draw conclusions from the results of this research.

Device
Design and Fabrication

2 ~~Experiment~~

SPPs are coupled with propagating light within a grating structure which satisfies the phase-matching