Influence of Metal Resistivity on Transmittance of Checkerboard Patterns in Infrared Region

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***Abstract*—Checkerboard patterns (CPs) are a kind of metamaterials which are attracting much attention for their application to sensing devices. In this study, we have investigated the electromagnetic responses of the CPs in infrared (IR) region. We have fabricated the CPs with two different metals and measured the transmittance to clarify the influence of metal resistivity of the CPs on transmittance. As a result, we have successfully confirmed experimentally metal resistivity influence on transmittance characteristics of the CPs even in IR region not only terahertz (THz) region.**

I. INTRODUCTION

METAMATERIALS are attracting much attention at present, which are artificial structures much smaller than wavelength of incident electromagnetic waves [1]. Applying metamaterials to sensing technology utilizing subtle changes in optical properties caused by either subtle changes of material properties or geometries is also one of hot issues. Metamaterial or optical based sensing gives high sensitivity and fast detection since the electromagnetic wave characteristics changes before and after the metamaterials are only measured for the sensing [2]. In various fields, metamaterials are applied for sensing elements, for example, they are applied for microfluidic sensors [3], biological sensors [4] and so on.

One of metamaterials, for the application to sensing devices, we focus on nearly self-complementary checkerboard patterns (CPs). It has a simple structure formed by periodically arranged metal squares [5, 6]. It is reported that in THz region transmission spectra of CPs are changed drastically when the metal squares are brought into contact with each other from a noncontact state owing to the reactance changes between contact and noncontact state [7].

In this study, in order to confirm transmittance spectra changes of the CPs between contact and noncontact state in IR region, we designed, fabricated the CPs and measured transmittance.

II. FABRICATION OF CHECKERBOARD PATTERNS

The fabricated CPs are an inductive CP (I-CP), i.e. contact state, a capacitive CP (C-CP), i.e. noncontact state, and a nearly self-complementary C-CP. The metal thickness and the period of the CPs are 100 nm and 15 µm, respectively. Moreover, in order to clarify experimentally influence of the metal resistivity on transmittance in IR region, we fabricated the CPs with Au and Ti on Si substrate with SiO_2 film.

The fabrication process of the CPs is illustrated in Fig. 1. First, on the Si substrate with 100 nm thick SiO_2 film (Fig. 1(a)), the metal layers consisted of 50/100 nm thick Cr/Au are formed by sputtering (Fig. 1(b)). Next, array of the CPs are patterned using photolithography process (Fig. 1(c)). Finally, by using dry etching technique, the CPs are achieved (Fig. 1(d)). The photographs of the CPs obtained by fabrication process of Fig. 1 are shown in Fig. 2.

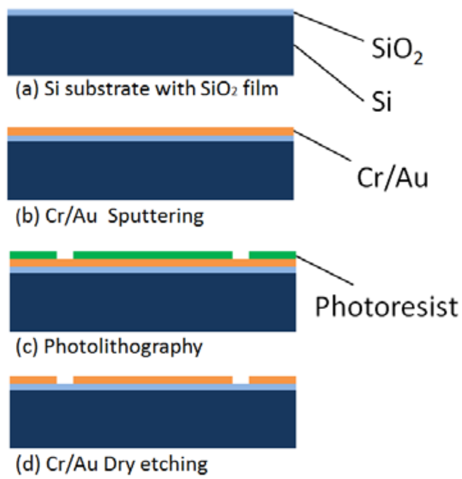

Fig. 1. Fabrication process flow of our checkerboard patterns.

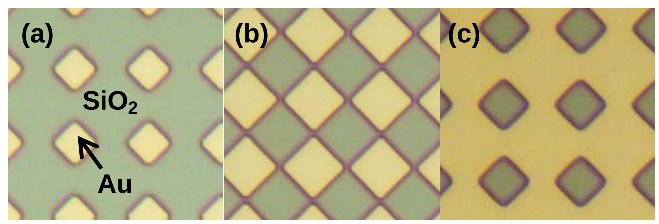

Fig. 2. Photographs of fabricated CPs: (a) C-CPs with 5 µm gap between squares. (b) C-CPs with 1 µm gap between squares, and (c) I-CPs with 5 µm lap between squares.

III. SIMULATION

The fabricated CPs were designed by finite element method (FEM) simulation using COMSOL Multiphysics software package. The transmission spectra of CPs for the Au and Ti were simulated at frequency range from 3 to 10 THz. We build up simulation models of the CPs consisted of Au or Ti on a Si substrate with a SiO_2 film. The Si substrate and SiO_2 film thicknesses were 500 µm and 100 nm, respectively. The simulation model is shown in Fig. 3. The metal thickness and the period of the CPs are 100 nm and 15 µm, respectively. The electromagnetic waves were radiated from the air. In the simulation, we utilized periodic boundary conditions to represent periodicity of the CPs.

The simulation results are showed in Fig. 4. We obtained a salient change of the transmittance at the resonant frequency of about 6 THz when the gap distance in CPs becomes closer. We could confirm gap distance influence of CPs on transmittance.

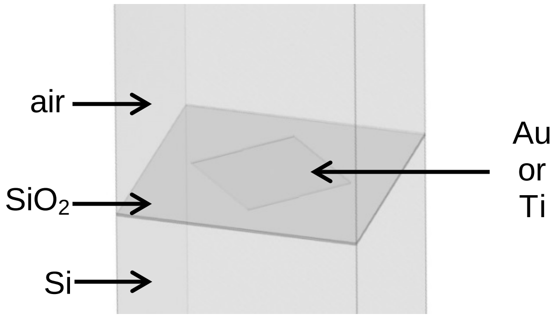

Fig. 3. A finite element method simulation model of C-CP.

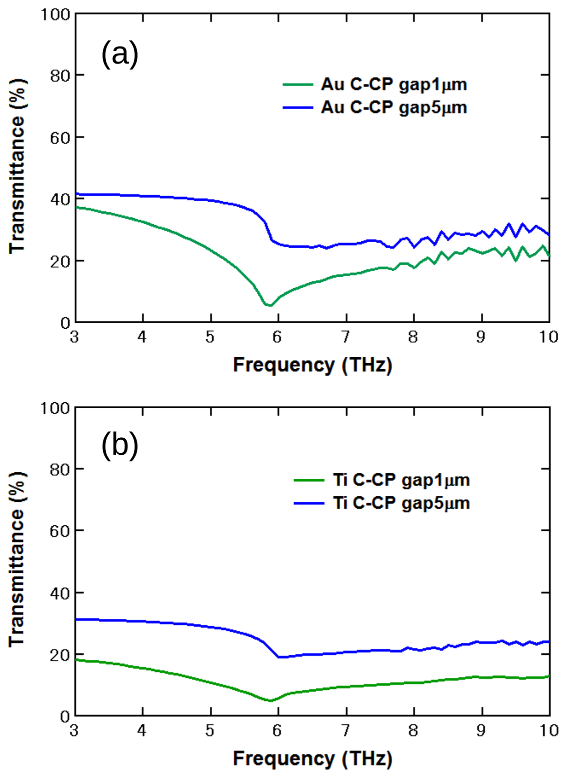

Fig. 4. FEM simulation results of transmittances of two types of CPs in IR region for (a) Au and (b) Ti, respectively. Green and blue lines represent C-CPs with gap of 1 μm and 5μm, respectively.

IV. Measurement Results

We have performed measurement for six different fabricated CPs. The C-CP has four types, which have gaps of 1 μm or 5 μm between metallic squares formed by Au or Ti, respectively. The I-CP has two types, which have laps of 5 μm between the metallic squares formed by Au or Ti. The transmittances of CPs are measured by Fourier-transform infrared spectroscopy (FTIR) system and their measurement results are showed in Fig. 5. According to the difference between metal resistivity of Au and Ti, we obtained remarkable changes in transmittance. Moreover, we also obtained the salient change of transmittance at resonant frequency of about 6 THz when the gap distance in CPs becomes closer, which agrees with simulation result. The transmittance over the resonant frequency showed constant value.

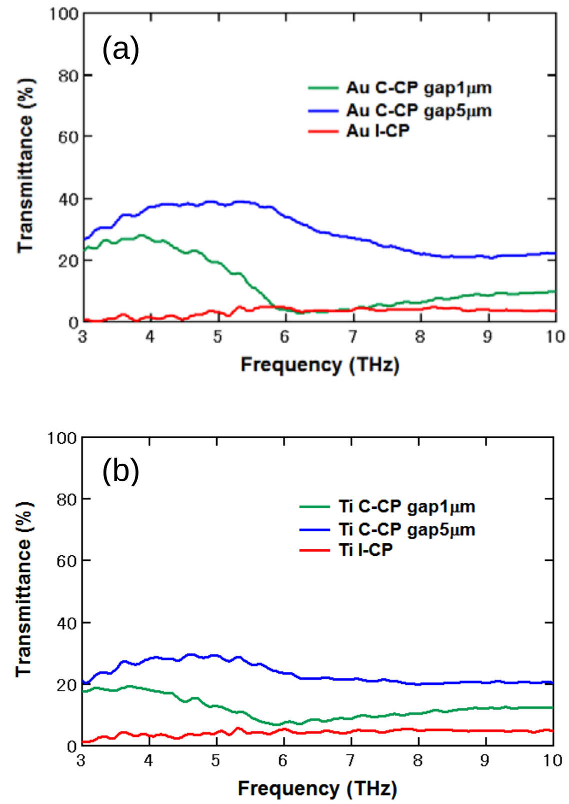

Fig. 5. Transmittances of six types of CPs in IR region. CPs formed by (a) Au and (b) Ti. Green and blue lines represent transmittance of C-CPs with gap of 1 μm and 5μm, respectively. Red line represents transmittance of I-CPs with lap of 5 μm.

V. Summary

We have investigated the electromagnetic responses for the CPs in IR region. We have designed, fabricated and measured the CPs and have successfully confirmed experimentally metal resistivity and gap distance of CPs influences on transmittance in IR region.

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