Microelectronic Engineering 136 (2015) 42–47

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Fabrication of polarization-insensitive, multi-resonant metamaterial absorber using wafer bonding of glass dielectric substrate

Duck-Hyun Lee, Kenyu Ling, Sungjoon Lim, Chang-Wook Baek *

School of Electrical and Electronics Engineering, Chung-Ang University (CAU), 221 Heukseok-Dong, Dongjak-Gu, Seoul 156-756, Republic of Korea

ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 18 March 2015
Accepted 2 April 2015
Available online 6 April 2015

Keywords:
Metamaterial absorber
Polarization insensitivity
Wafer bonding
Glass dielectric substrate

ABSTRACT

We present the design, fabrication and characterization of a terahertz multi-resonant metamaterial absorber showing polarization-insensitive characteristics. The proposed absorber uses Pyrex glass as a dielectric layer for higher absorption in a terahertz range and is wafer-level fabricated by thermo-compression bonding technique using gold films as intermediate layers. In addition, an array of comb-shaped hexagonal pattern is introduced as a multi-band LC resonator and symmetric geometry is used for polarization insensitivity. The fabricated absorber shows two absorption peaks at 0.98 THz and 1.55 THz with the absorptivity of 93% and 74%, respectively, and almost identical responses to the different polarization angles.

1. Introduction

A terahertz (THz) frequency, whose wavelength lies between the microwaves and infrareds, can be used for various potential areas such as biological science, medical imaging, security, and ICT (information and communication technology) applications because it has microwave characteristics and optical properties [1]. Especially, there is a strong need for THz absorbers with high absorptivity in THz detection applications, like thermal sensors, since highly sensitive, low-cost terahertz imaging systems can be realized by combining these detectors with appropriate THz sources [2,3]. However, it is hard to find naturally existing materials with strong absorption coefficients in the THz regime.

Electromagnetic metamaterials (MMs) are one possible solution to achieve strong absorption in the THz regime. MMs are a class of artificial medium composed of periodic arrays of subwavelength unit cells made by conductive patterns, exhibiting several exotic electromagnetic properties not available in nature. These MM concepts have been used to demonstrate THz absorbers, and various resonant-type THz MM absorbers with high absorptivity and insensitivity to polarization have been reported. For instance, Tao et al. experimentally demonstrated a MM-based absorber with an absorptivity of 70% at 1.3 THz [4]. The top layer is realized by electrical ring resonator and with a cut wire on the bottom layer. Two layers are separated by an 8-μm-thick polyimide spacer. This study has been extended to a polarization insensitive design with a demonstrated absorptivity of 65% at 1.15 GHz [5]. Tao et al. reported a flexible metamaterial absorber fabricated on a metallic ground plane showing an absorptivity of 97% at 1.6 THz [6]. This flexible MM absorber is realized on a highly flexible polyimide substrate, which enables its use in nonplanar applications. In addition, the absorber can operate over a very wide range of incident angles for both TE and TM configurations.

In the beginning, most investigators have focused on the design and fabrication of single-band absorbers. Since their narrow bandwidth limits their potential applications in many functional devices, multiple band MM absorbers have been studied [7,8]. Multiple resonance was achieved by vertically stacking multiple metallic layers where each layer generates each resonance and absorption frequency. In addition, tunable metamaterial absorbers have attracted extensive attention due to their great flexibility in practical applications. For instance, Wang et al. demonstrate a mechanically tunable absorber in the terahertz region [9]. The absorption frequency can be tuned continuously by shifting the position of the movable part along the surface of the fixed part. In addition, Shrekenhamer et al. have tried to realize the active frequency tunable absorber by changing the dielectric constant with liquid crystal [10]. The resonant frequency is controlled by changing the orientation of the liquid crystal molecules.

In these MM absorber designs, the effective electrical permittivity and magnetic permeability are manipulated to match the impedance with that of free space, thereby minimizing the reflectance. With this limit, the transmission is dependent on the imaginary part of the refractive index, which is related to the dielectric loss of the substrate and should be optimized as high as possible. In

* Corresponding author. Tel.: +82 2 820 5741; fax: +82 2 822 8467.
E-mail address: cwbaek@cau.ac.kr (C.-W. Baek).

http://dx.doi.org/10.1016/j.mee.2015.04.010
0167-9317/

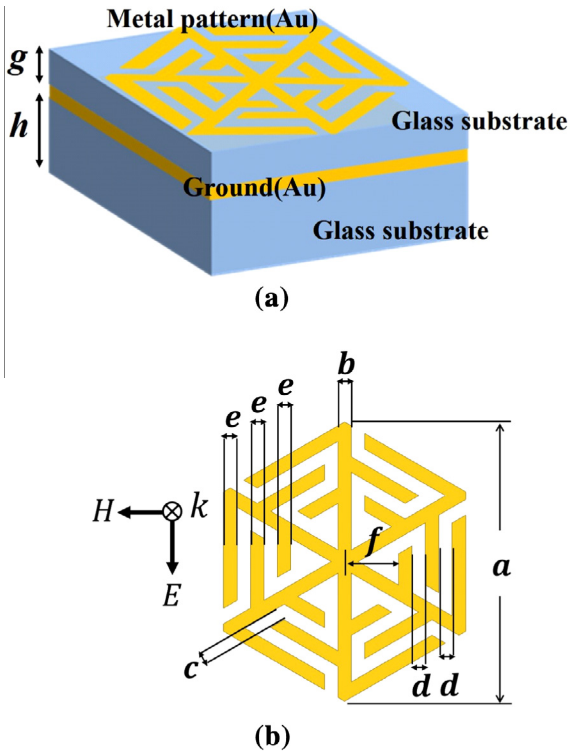

Fig. 1. (a) Schematic drawing of the proposed metamaterial absorber structure. The thicknesses of the top glass dielectric layer and the bottom substrate are $g = 100$ μm and $h = 400$ μm. (b) Unit cell of the comb-shaped hexagonal resonator structure. The dimensions are $a = 42$ μm, $b = c = d = e = 2$ μm, and $f = 8$ μm.

order to realize high absorptive absorbers, therefore, it is a better choice to use a lossy dielectric substrate. Most of the reported THz MM absorbers have been usually fabricated by additional coating of thin film dielectric materials onto the base substrate based on the microfabrication processes: spin coating of polymers such as polyimide and benzocyclobutene (BCB), or chemical vapor deposition (CVD) of silicon dioxide on the silicon or GaAs substrates.

In this paper, a polarization-insensitive, multi-resonant MM absorber is fabricated based on the wafer boding approach and its performances are measured. Compared to previous works where a thin film dielectric layer is additionally deposited onto the base substrate, Pyrex glass wafer itself is directly used as a dielectric material as well as a base substrate here. Pyrex glass, which has a loss tangent ($\tan\delta$) of 0.052 at 0.8 THz, shows higher absorption characteristics in the THz region compared to other materials such as quartz ($\tan\delta \approx 0.004$ at 1 THz), doped silicon ($\tan\delta \approx 0.01$ at 1 THz), polyimide ($\tan\delta \approx 0.015$ at 0.8 THz) and many other organic materials [11,12]. However, it is difficult to make Pyrex glass into the form of a thin film with a desired thickness by conventional deposition techniques. A broadband THz absorber using self-assembly of multilayer glass microspheres and spin-coating of polydimethylsiloxane (PDMS) onto a glass substrate was demonstrated [13], but it needs complex and specific fluid-based fabrication processes and is not adequate for resonant-type absorbers since further resonator patterning on the structure is not easy. In our method, two Pyrex glass wafers metallized with gold are thermo-compression bonded using gold as an intermediate adhesive layer. Both dielectric layer and base substrate made of glass with an in-between metallic ground plane are simply fabricated using this two-step process. The glass dielectric layer can then be easily transformed into the form of a thin film by using a chemical mechanical polishing (CMP) process, which enables wide-range control of the layer thickness with good precisions from its original wafer thickness (hundreds of micrometers) to a few micrometers. In addition, symmetric comb-shaped hexagonal resonator structures are adapted to achieve polarization-insensitive and multi-resonant properties of the absorber.

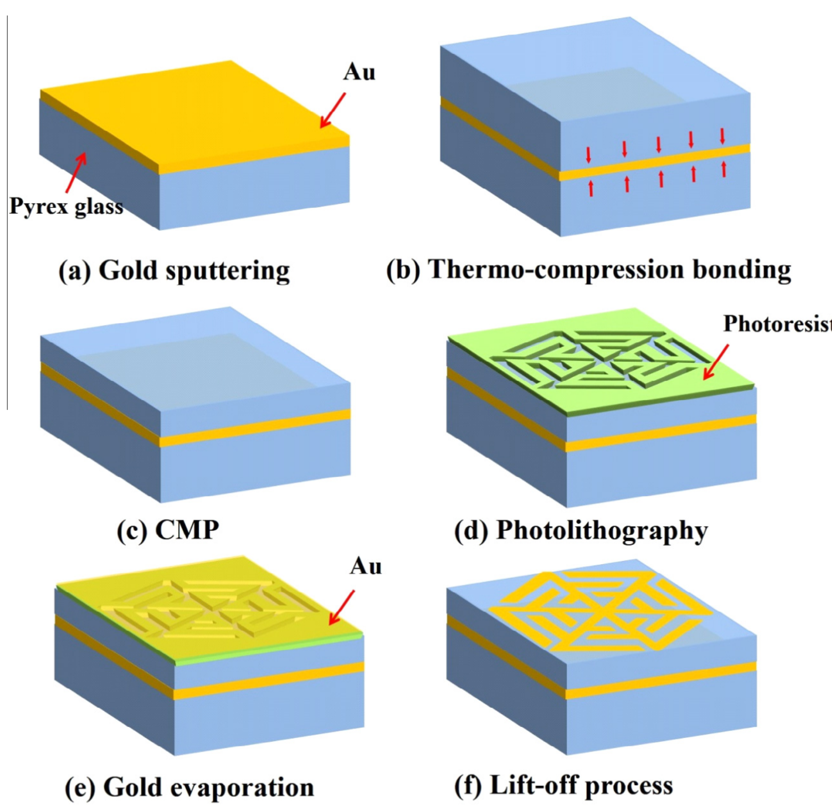

Fig. 2. Fabrication process of the proposed metamaterial absorber.