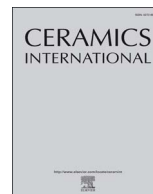




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Enhanced dielectric properties of Ca^{2+} doped Li-Al-Si photoetchable glass

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ABSTRACT

The Li-Al-Si photoetchable glass (PEG) easily forms a complex three-dimensional (3D) structure, which is promising as an interposer in 3D integrated microsystems. However, its dielectric loss is rather large ($\sim 10^{-2}$ @ 1 GHz), which inhibits the corresponding application in radio frequency (RF) microsystems. In this paper, the enhancement of dielectric properties caused by of Ca doping on the microstructure of the Li-Al-Si photoetchable glass system was investigated. The structure and performance were analyzed through X-ray diffraction (XRD), Mid-infrared spectroscopy analysis (MIR), Raman spectroscopy and impedance analysis. The results demonstrated that a significant modification in the dielectric properties were obtained with dielectric loss of 3×10^{-3} . The reason was attributed to the decreased number of the non-oxygen bridge, which makes the structure more stable. Using hydrofluoric (HF) etching, through glass vias with a diameter of 117 μm were obtained.

1. Introduction

With the development of very large scale integration (VLSI) circuits, the silicon interposer fabricated by through silicon via (TSV) technology has been predominant in the integrated circuit packaging field [1]. However, some deficiencies of TSV remain, such as processing difficulty and increased depth-diameter ratio and dielectric loss at high frequency. Through glass via (TGV) is a new three-dimensional (3D) interposer technology [2,3]. However, the cost for utilization of high energy lasers is quite expensive and inefficient. Recently, a novel photoetchable glass (PEG), with which micro-holes by graphic exposure and wet chemical etching method can be easily fabricated, has attracted much attention [5]. J. M. Yook et al. proposed that the photoetchable glass could be utilized as an interposer [4]. However, due to the high dielectric loss, the frequency range of this material in RF microsystems is limited. Consequently, for photoetchable glass, reduction of its dielectric loss is a key issue.

To reduce the dielectric loss in glass, many methods have been developed, such as rare earth doping [5], decreasing the number of non-bridging oxygen bonds [6], the mixed alkali effect [7], and stabilizing the network structure [8–10]. A. Wagh et al. studied the $\text{PbF}_2\text{-TeO}_2\text{-B}_2\text{O}_3\text{-Eu}_2\text{O}_3$ glass system. It was discovered that Eu^{3+} could reduce dielectric loss, whereas with decreased the substitution of Eu_2O_3 for B_2O_3 , the dielectric loss decreased with increasing frequency and increased with increasing temperature [5]. B. Deb discovered that an

increased amount of Mo led to increasing non-bridging oxygen bonds in the Ag-Mo-P glass system, therefore leading to an increased dielectric constant [6]. G.H. Zhang et al. discovered that with a gradual increase in the addition of Na_2O , the electrical conductivity of $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2\text{-Na}_2\text{O}$ melts monotonously increased, while with K_2O addition, the electrical conductivity monotonously decreased [7]. H. Savabieh et al. studied the $\text{Li}_2\text{O-SiO}_2\text{-Al}_2\text{O}_3\text{-TiO}_2\text{-BaO-ZnO}$ glass system and discovered that the dielectric properties depended on the density and phase structure. The density increase would lead to the dielectric constant increase, whereas the dielectric constant increased when the hexagonal phase was formed and decreased when the tetragonal phase was formed. Therefore, the dielectric loss was mainly affected by the structure [10].

In this paper, the effect of Li-Al-Si photoetchable glass doped with various proportions of CaO was studied. The network of the glass was analyzed through infrared and Raman spectra, to explain the varieties of the oxygen-bridge by the deviation and intensity of the corresponding peak. The change of the crystal phase was qualitatively and quantitatively analyzed through XRD. The changes in the dielectric constant and the dielectric loss were measured by an impedance analyzer.

2. Experimental procedure

The PEG was based on the lithium aluminum silicate system. The specific formula was (77-X)%wt. SiO_2 , 10%wt. Li_2O , 5%wt. Na_2O , 5%

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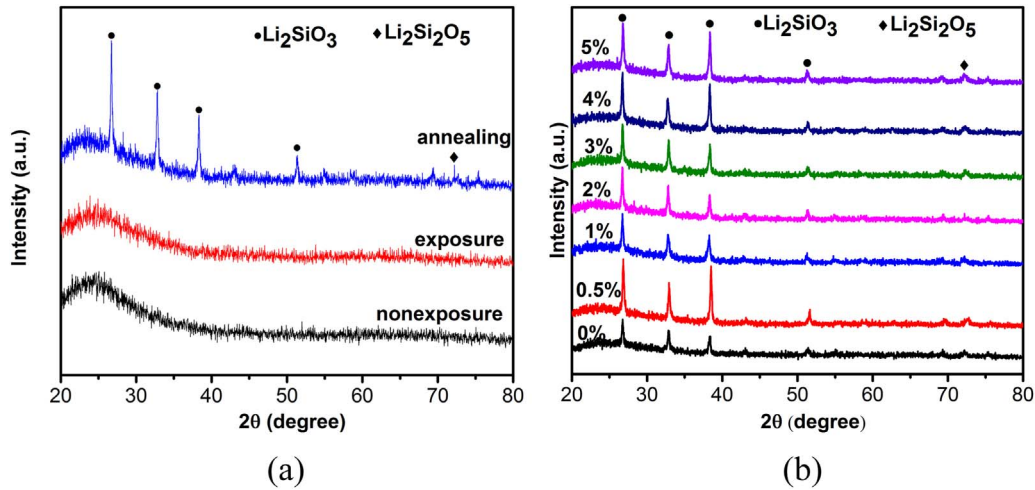


Fig. 1. (a). XRD spectra of nonexposure, exposure, annealing and crystallization of the PEG doped 2% CaO. (b). XRD spectra of the PEG doped from 0% to 5% CaO.

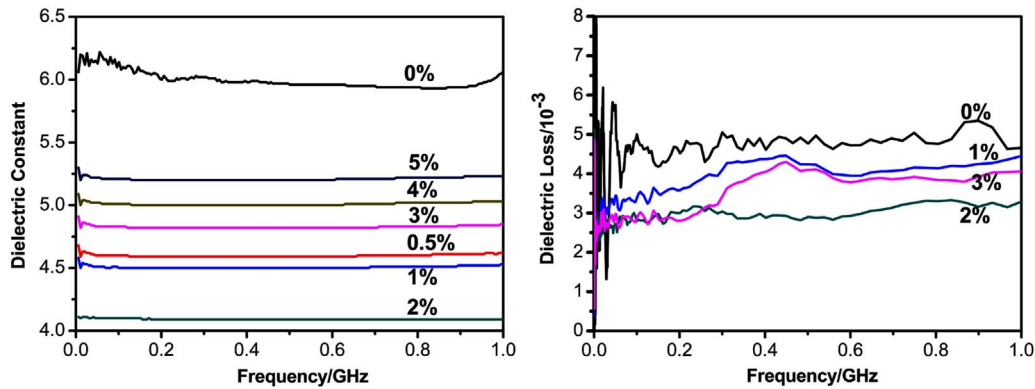


Fig. 2. Dielectric properties of PEG with 0–5% of CaO.

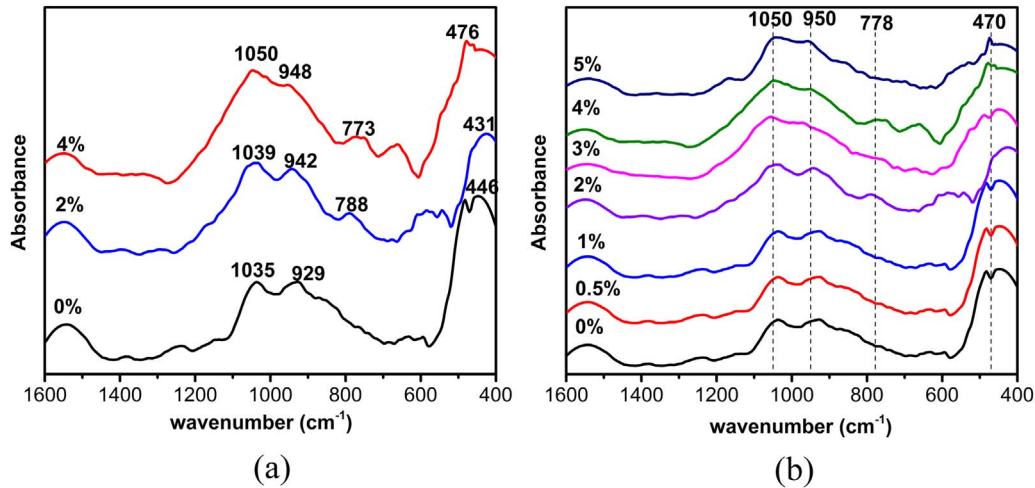


Fig. 3. (a). MIR spectra of PEG with 0%, 2%, 4% of CaO. (b) MIR spectra of the PEG doped from 0% to 5% CaO.

wt. K_2O , 1%wt. Al_2O_3 , 2%wt. ZnO , X%wt. CaO (where the X was 0, 0.5, 1, 2, 3, 4, 5), 0.2%wt. Sb_2O_3 and 0.04%wt. Ce_2O_3 . The raw materials were mixed and melted to obtain the original glass sample. The sample size of $10\text{ mm} \times 15\text{ mm} \times 0.5\text{ mm}$ was obtained by cutter bar and polished by grinding miller. Samples were exposed to UV of 310 nm in wavelength and 10 J/cm^2 in dose and annealed at 600°C . Samples were etched with HF after graphic exposure and annealing.

The glass materials were analyzed by XRD (Cu $\text{K}\alpha$ radiation, Rigaku, Japan, with a scanning angle from 20° to 80° with a step of 0.02°), MIR

(Tensor, Bruker Vertex70v spectrometer, with a scanning wavenumber from 400 cm^{-1} to 1600 cm^{-1} with a step of 2 cm^{-1}), Raman Spectroscopy (Renishaw in Via, 532 nm, with a scanning Raman shift from 200 cm^{-1} to 1600 cm^{-1} with a step of 1 cm^{-1}), and Impedance Analyzer (E4991B, Agilent, from 0 GHz to 1 GHz.). The XRD analysis could be utilized for qualitative and quantitative analysis of crystalline phases, which significantly affect the dielectric properties of PEG materials. The XRD results of the unexposed, exposed, annealed and crystallized samples are presented in Fig. 1. The MIR was used to

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