

# The Role of $\text{Fe}_2\text{O}_3$ and Light Induced on Dielectric Properties of Borosilicate Glass

Markus Diantoro<sup>1,\*</sup>, Norma Dian Prastiwi<sup>1</sup>, Ahmad Taufiq<sup>1</sup>, Nurul Hidayat<sup>1</sup>, Nandang Mufti<sup>1</sup>, Arif Hidayat<sup>1</sup>

<sup>1</sup>Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang (State University of Malang), Jl. Semarang 5 Malang 65145, Indonesia

\*email: markus.diantoro.fmipa@um.ac.id

**Abstract.** Functionally glass materials have been widely applied in various technological applications remarkably due to their optoelectric properties. In this present study, the glass was prepared from leaching product of local silica sands.  $\text{Bi}_2\text{O}_3$  and  $\text{Na}_2\text{CO}_3$  were added to reduce the melting point of silica sand to form silica glass and  $\text{Fe}_2\text{O}_3/\text{B}_2\text{O}_3$  was incorporated to examine its effect on the crystal structure, morphology, and light-induced dielectric properties of the borosilicate-based functional glass. The characterizations were conducted by means of Differential Thermal Analyses (DTA), X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), and capacitance meter under the influence of light intensity. The XRD pattern shows the absence of any sharp diffraction peak indicates the amorphous state of the borosilicate glass. While the SEM image shows that the borosilicate glass exhibited amorphous characteristic. Furthermore, the increasing of  $\text{Fe}_2\text{O}_3$  tends to reduce the dielectric constant. On the other hand, the increase of light intensity increase the dielectric constant with a step like properties.

## 1. Introduction

The demand for the development of functionally glass material for many optoelectronic technological applications increases from time to time [1]. For instance, functional glass can be applied in kitchenware, glass roof, screen, and solar smart glass. Unfortunately, many functional glass materials are fabricated from commercially high cost materials. In general, the main material of glass is silica which has melting temperature of 1715 °C [2]. In Indonesia, silica can be easily found from natural resources such as from silica sand [3]. In this study, the possibility of develop functionally glass material, borosilicate glass, from natural material be investigated.

## 2. Experimental Method

As alternative of the use commercial material for glass fabrication, silica sand as a natural resource from Tuban, Indonesia was chosen as the starting material. The silica sand was immersed in 2M HCl for 12 h, washed, and dried to obtain higher purity of  $\text{SiO}_2$  powder. The powder was then characterized by X-ray fluorescence (XRF) to clarify the increasing of Si content which corresponds to  $\text{SiO}_2$ . Functional glass  $\text{B}_2\text{O}_3\text{-Fe}_2\text{O}_3/\text{Bi}_2\text{O}_3\text{-Na}_2\text{CO}_3\text{-SiO}_2$  was prepared by mixing and melting  $\text{B}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{Na}_2\text{CO}_3$ , and  $\text{SiO}_2$ . The compositions of each samples are shown in Table 1.



The mixtures were then annealed at 420 °C for 1 h. After processing, the samples were then characterized by using XRD, SEM, FTIR, and capacitance meter.

**Table 1. Raw Material Compositions for Borosilicate Glass**

Sample	Compositions (wt%)				
	Fe <sub>2</sub> O <sub>3</sub>	B <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Na <sub>2</sub> CO <sub>3</sub>	Bi <sub>2</sub> O <sub>3</sub>
Glass 1	0	18	12	10	60
Glass 2	1	17	12	10	60
Glass 3	2	16	12	10	60
Glass 4	3	15	12	10	60
Glass 5	4	14	12	10	60

### 3. Results and Discussion

The XRF data for the silica sand before and after leaching treatments is given in Table 2.

**Table 2. Main Elemental Contents of Silica Sand**

Element	Conc. (%)	Conc. (%)
	Before Leaching	After Leaching
Si	80.7(3)	86.8(4)
K	6.22(3)	5.24(9)
Ca	4.40(3)	2.2(3)
Ti	1.40(3)	0.87(4)
Fe	4.23(07)	1.16(02)
Ni	1.96(03)	2.68(04)

From Table 2, it can be seen that leaching increases the Si content from 80.7(3)% to 86.8(4)% and reduce some elemental impurities. It means that the leaching process was effective to increase the Si content by reducing impurities. It is because Si cannot be dissolved in the HCl but impurities can.

Figure 1 shows the diffraction patterns of B<sub>2</sub>O<sub>3</sub>-Fe<sub>2</sub>O<sub>3</sub>/Bi<sub>2</sub>O<sub>3</sub>-Na<sub>2</sub>CO<sub>3</sub>-SiO<sub>2</sub> with 0%, 2%, and 4% of Fe<sub>2</sub>O<sub>3</sub> recorded from XRD measurement. It can be clearly seen that the absence of any sharp diffraction peak indicates the amorphous state of the borosilicate glass found in this experiments.

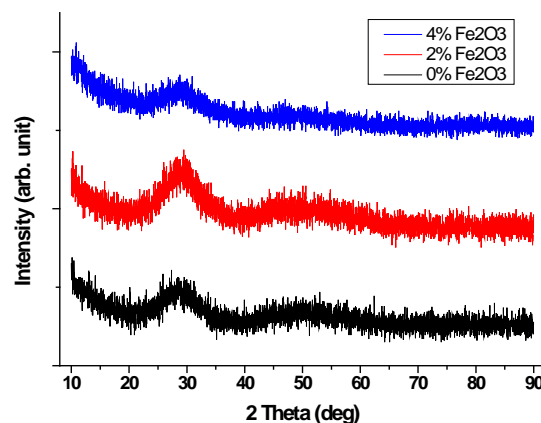


Figure 1. XRD Profiles of B<sub>2</sub>O<sub>3</sub>-Fe<sub>2</sub>O<sub>3</sub>/Bi<sub>2</sub>O<sub>3</sub>-Na<sub>2</sub>CO<sub>3</sub>-SiO<sub>2</sub>

The SEM images of the surface of the samples show that the borosilicate glass found in this research have small grains with homogenous size and morphology. The SEM image is also show that borosilicate glass in amorphous phase as found in XRD result.

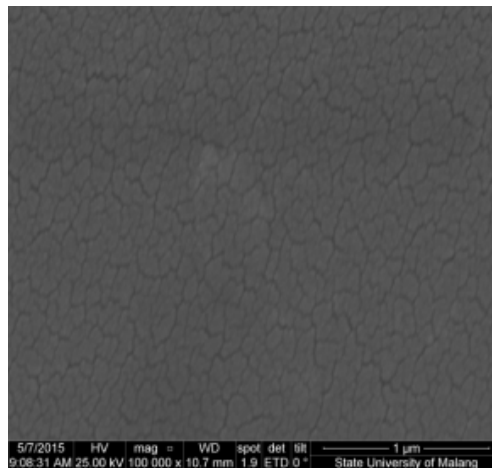


Figure 2. SEM Images for Borosilicate Glass with 1%  $\text{Fe}_2\text{O}_3$  Incorporation.

The thermal response analyses was performed by using TGA-DSC . The result is shown in Fig. 3. There is clearly show that the linear mass change from room temperature up to 400 °C continued by relative constant mass with some small change at limited temperature. The mass change increase in higher temperatures. That can be associated to the chemical reactions. Those reaction is related to the exothermic decomposition or melting of  $\text{NaCO}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ .

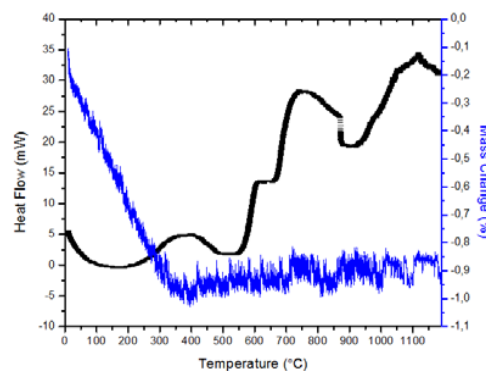


Figure 3. DTA-TG of  $\text{Fe}_3\text{O}_4$  doped borosilicate glass.

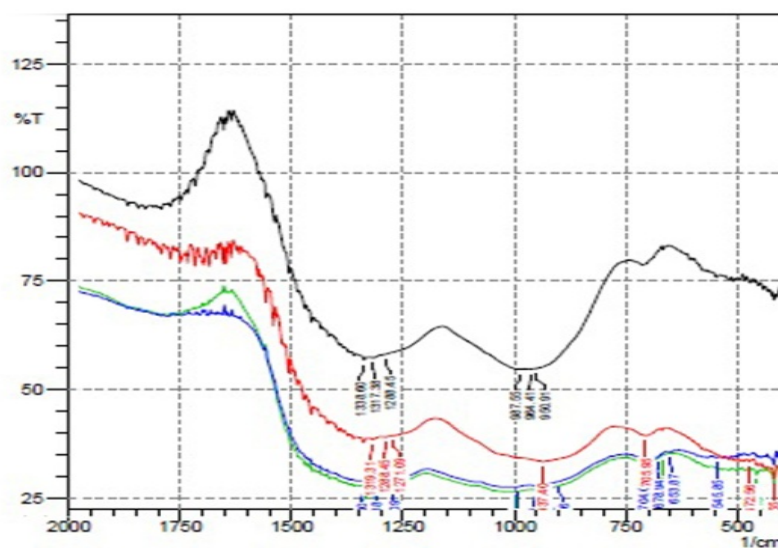


Figure 4. FTIR Spectra of Borosilicate Glass

The FTIR spectra of borosilicate glass as shown in Fig. 4. The figure reveals that the chemical bonding within the samples. Absorbance peak at 464-465  $1/\text{cm}$  correspond to Fe-O formation in  $\text{FeO}_6$  structural unit. Two absorbance peaks at 475 – 479  $1/\text{cm}$  show that the vibration band of Si-O-Si and Bi-O. Absorbance peak at 702 - 705  $1/\text{cm}$  represent B-O-B bonding in group  $\text{BO}_3$ . Absorbance peak at 935 - 937  $1/\text{cm}$  is in a good agreement with stretching mode of  $\text{BO}_4$  tetrahedral unit. Absorbance peak at 1330  $1/\text{cm}$  goes to stretching of B-O bonding. This spectra is also similar to the spectra that reported by Gu et al 2014 observing at 479  $1/\text{cm}$ , 703  $1/\text{cm}$ , 1022  $1/\text{cm}$ , and 1384  $1/\text{cm}$ .

Based on the Figure 5, it can be seen that the increasing of  $\text{Fe}_2\text{O}_3$  content tends to reduce the dielectric constant. Furthermore, the change of light intensity also reduces the dielectric constant. The light is quantized as photon which corresponds to light intensity. In this work, the change of dielectric constant due to the change of light intensity is similar to the photoelectric effect occurring on the metal surface.

Measurement of dielectric constant of samples is shown in Figure 5. It can be seen that the increasing of  $\text{Fe}_2\text{O}_3$  content result in the decrease of their dielectric constant. Furthermore, the change of light intensity also reduces the dielectric constant. The light is quantized as photon which corresponds to light intensity. In this work, the change of dielectric constant due to the change of light intensity is similar to the photoelectric effect occurring on the metal surface. The figure also shows that the higher the  $\text{Fe}_2\text{O}_3$  concentration. It agree with the previous result reported by Shapaan *et al.* [4]. Furthermore, Yadav *et al.* also reported that the  $\text{Fe}_2\text{O}_3$  leads to reduce the dielectric constant [5].

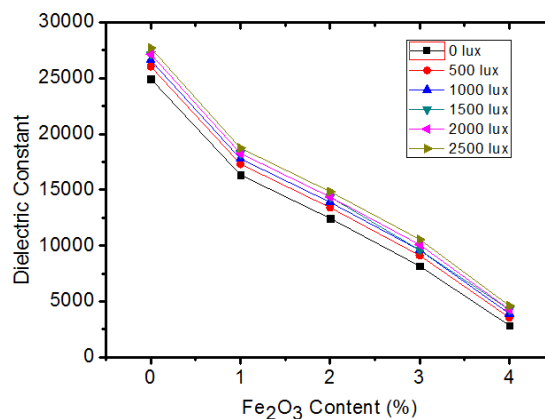


Figure 5. Dielectric Properties of Borosilicate Glass

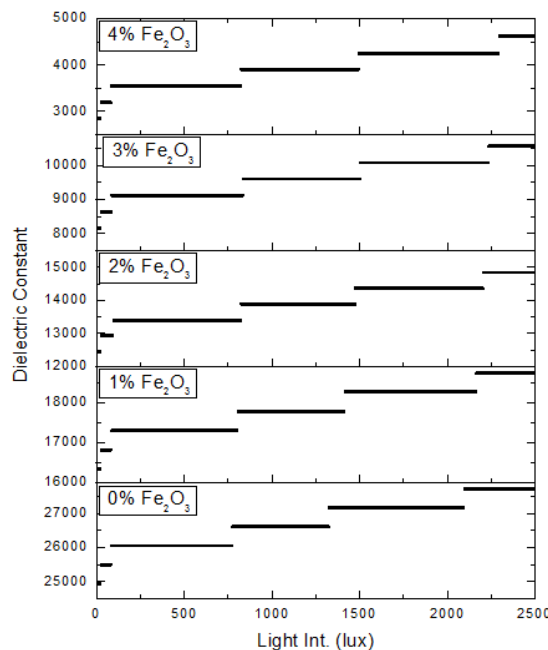


Figure 6. A typical dielectric constant as a function of light intensity.

The reduce of dielectric constant as increase of  $\text{Fe}_2\text{O}_3$  concentration is not in line with the increase of applied light intensity. The  $\text{Fe}_2\text{O}_3$  incorporating glass show different nature as shown in Fig. 6. The light induced on the  $\text{Fe}_2\text{O}_3$  doped glass is significantly increase by increase of the intensity. Similar phenomena is also shown by  $\text{Al}_2\text{O}_3$  doped lead silica glass [6].

#### 4. Conclusion

This study concludes that the silica sand can be used as the raw material for the development of borosilicate functional glass. The crystalline state of the produced samples are amorphous. The addition of  $\text{Fe}_2\text{O}_3$  and light inducement decrease the dielectric properties of borosilicate glass.

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