The Effect of Dy_2O_3 Doping On The Dielectric Constant And Dissipation Factor Of ZnO- Based Varistor

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Abstract:

The effect of Dy_2O_3 doping on the dielectric constant and dissipation factor of ZnO- based varistor were investigated at different sintering temperatures.

XRD test shows that the ZnO based varistor ceramics is a poly crystalline phases where ZnO is the main phase and spinel phase $Zn_7Sb_2O_{12}$ is the secondary phase in all samples.

The electric test explains that the dielectric constant decreases with increasing Dy_2O_3 concentrations at certain sintering temperature, while the dissipation factor was increasesing.

It also appeared that the increasesing of sintering temperature leads to increases the dielectric constant of the samples.

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INTRODUCTION

Varistor ceramics differentiate by superior nonlinear current – voltage behavior and high energy-handling capabilities have been widely used to sense and limit transient voltage surges. Bi_2O_3 base ZnO varistors Played preponderant function in practical applications and physical research since the 1970s [1,2].

The production of ZnO varistors is done by mixing ZnO powder with some certain oxides powders and process the powder mixture by conventional ceramic processing and sintering methods, the sintering process results a polycrystalline ceramic with a singular grain boundary property, these processes produce the nonlinear current-voltage (I-V) characteristics of the device [2,3,4,5]. Microstructurally, the ZnO varistors are composed of semiconducting n-type ZnO grains, surrounded by very thin (1-10^{-3} μm) insulating inter granular layers which known as spinel phase $Zn_7Sb_2O_{12}$ and Bi_2O phase [4, 6, 7].

Bi_2O_3-based zinc oxide varistors exhibit good nonlinear (electrical) properties, especially the nonlinear coefficient, breakdown voltage, and energy absorption capability as a result of that Bi_2O_3 easily reacts with certain metals used in preparing multilayer nonlinear varistors [8, 9].

The dielectric constant of a material under given conditions reflects the extent to which it assembles electrostatic flux lines [10]. Physically, that means the highest polarization value developed by a material in an external applied field of certain strength, the highest dielectric constant will be technically, it is the ratio of the value of the electrical energy stored in the material by an external applied voltage, proportion to that stored in the vacuum [11]. It is also the ratio of the capacitance of a capacitor using a material as a dielectric, comparing with a similar capacitor contains a dielectric of the vacuum or the air [11, 12].

The dielectric constant of samples sintered at various temperatures has been determined from the experimental capacitance values using the following formula:

$$k = \frac{C\, d}{A\, \varepsilon_\circ}$$

Where, k represents the dielectric constant, C=the capacitance, d= the sample thickness , $\varepsilon_\circ$= vacuum permittivity and A($A = \pi r^2$) area of the sample[13, 14].

The dielectric constant is an essential piece of information when designing capacitors and in other circumstances where a material might be expected to introduce capacitance into a circuit, it's determination is a very important property of dielectric materials [15, 16].

In physics, the dissipation factor (DF) defined as a measure of loss-rate of energy of a mode of oscillation (mechanical, electrical, or electromechanical) in a dissipative system. It is the reciprocal of Quality factor (Q) which represents the quality of oscillation. For example, electrical potential energy is dissipated in all dielectric materials, usually in the form of heat [16, 17].

Sample Preparation

Prepared of the samples accomplished by the conventional preparation procedure of ceramic. The amounts of the oxides used in proportions of [(95-X) mol% ZnO, 0.5 mol % Bi_2O_3, 2.5 mol % Sb_2O_3, 0.5 mol % Co_3O_4, 0.5 mol % Cr_2O_3, 0.5 mol % NiO and 0.5 mol % MnO_2, where (X=0.001, 0.005, and 0.01 mol % Dy_2O_3)].

Raw materials were mixed by high-energy using magnetic stirrer with magnetic bar in glass container (dry mixing) for 24 hours.

The mixture was calcined at $500\ ^{\circ}C$ in air for 2 hours with heating rate of $5^{\circ}C/min$ to remove the gases and the humidity in the powders, then the mixture crashed and remiled, after 3 wt % polyvinyl alcohol (PVA) binder addition, the powder was uniaxially pressed into pellets of 15 mm in diameter at a pressure$20\ MPa$. The pellets were sintered in air (to transforms individual ceramic particles into a compact polycrystalline body, and this process is widely used to fabricate bulk ceramic components) at sintering temperature values (S.T) of $(1050, 1100, 1150)\ ^{\circ}C$ with heating rate equals to $5^{\circ}C/min$ for 2 hours for all samples. The following table explains the samples details opposite the sintering temperature values and Dy_2O_3 concentrations.

Table (1).The details of the samples including the samples names, sintering temperature values, and Dy_2O_3 concentrations.

Sample	S.T °C	Dy_2O_3 concentration $*10^{-3}$	Sample	S.T °C	Dy_2O_3 concentration $*10^{-3}$	Sample	S.T °C	Dy_2O_3 concentration $*10^{-3}$
D1	1050	1	D4	1100	1	D7	1150	1
D2	1050	5	D5	1100	5	D8	1150	5
D3	1050	10	D6	1100	10	D9	1150	10
B1	1050	0.0	B2	1100	0.0	B3	1150	0.0

The dielectric constant and the dissipation factor were measured in the range of $20\ Hz - 3\ MHz$ (at room temperature) by using high frequency (GwINSTEK Company) LCR Meters (LCR-8105G model).

Results and Discussion

Fig (1) shows the phase composition (X-Ray diffraction) of the samples at doping concentration $10*10^{-3}$. We can note that ZnO is the main phase and spinel phase $Zn_7Sb_2O_{12}$ is the secondary phase in all samples.

Fig (2, 3, and 4) explains the variation of dielectric constant against frequency at different doping concentrations at sintering temperature $(1050, 1100, 1150)$ ℃ respectively, where the frequency range changed from 20 Hz to 3 MHz .

While Fig (5, 6, and 7) explains the dissipation factor behavior at different doping concentrations at sintering temperature $(1050, 1100, 1150)$ ℃ respectively, where the frequency range changed from 20 Hz to 3 MHz .

The inability of polarization process in the molecules dipoles to follow the rapid changes of the external electric field oscillating leads to dielectric loss. The amount of dielectric constant at a given temperature increases with the proportion of doping concentrations, and then decreases with increasing of doping concentrations, and this applies to all sintering temperature values [18, 19].

That means the dielectric constant of the samples (B1< D1< D2 < D3, B2< D4< D5 < D6, and B3< D7< D8< D9), where the increment of doping concentrations leads to increase the number of dipoles and the boundary thickness (insulating layer) between ZnO grains because that the radius of (Dy^{3+} 0.89) is larger than the radius of Zn^{2+} (0.74nm) [20].

The maximum value of dielectric constant obtained at doping concentrations of $5*10^{-3}$, at sintering temperature of (1150 ℃).

In the other side (On the contrary of the dielectric constant) for all samples, the dissipation factor (logically increasing with increasing of frequency), it decreases with increasing of doping concentrations, where the dissipation factor of the samples (B1>D1> D2 > D3, B2>D4> D5 >D6, and B3> D7> D8 > D9) [18, 19].

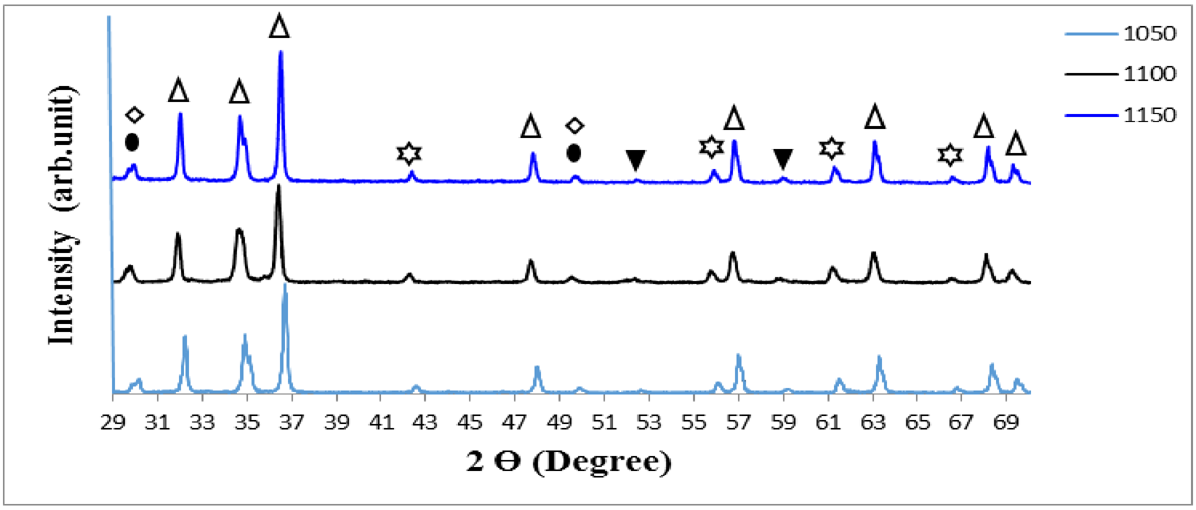

Fig (1). XRD data of the samples sintered at 1150 ℃ , where ● Bi_2O_3, ◇ Sb_2O_3, ✡ $Zn_7Sb_2O_{12}$, Δ ZnO, and ▼ Dy_2O_3.

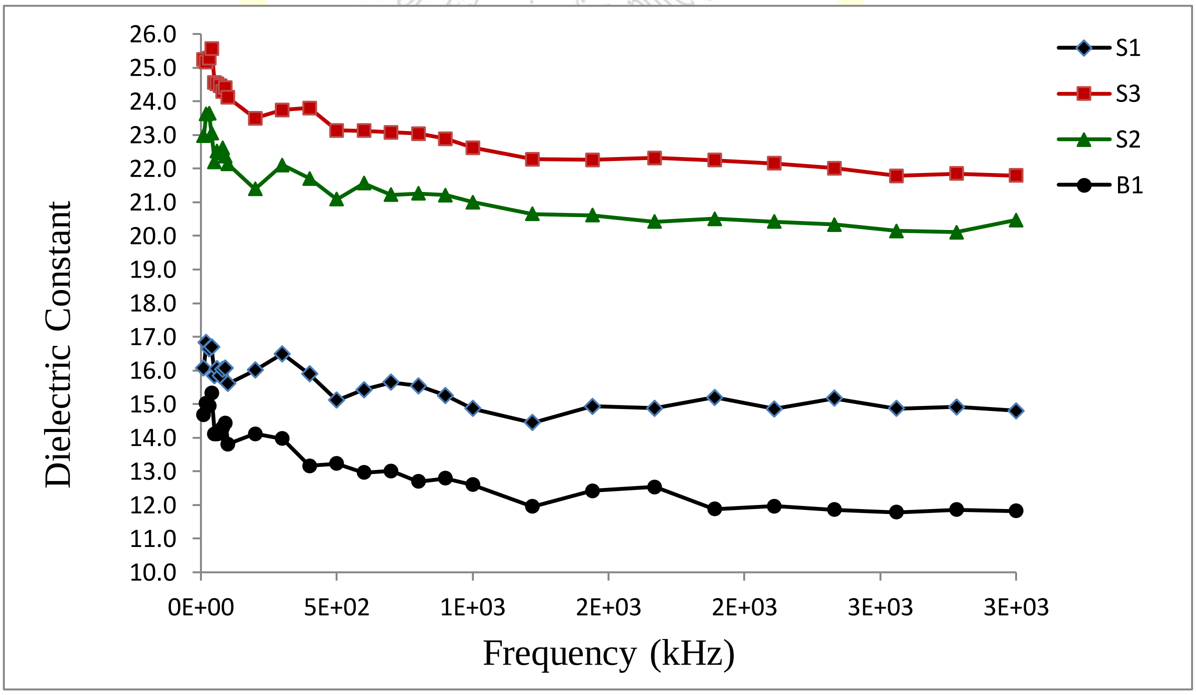

Fig. 2. The dielectric constant against frequency at different Dy_2O_3 concentrations, at sintering temperature1050℃.

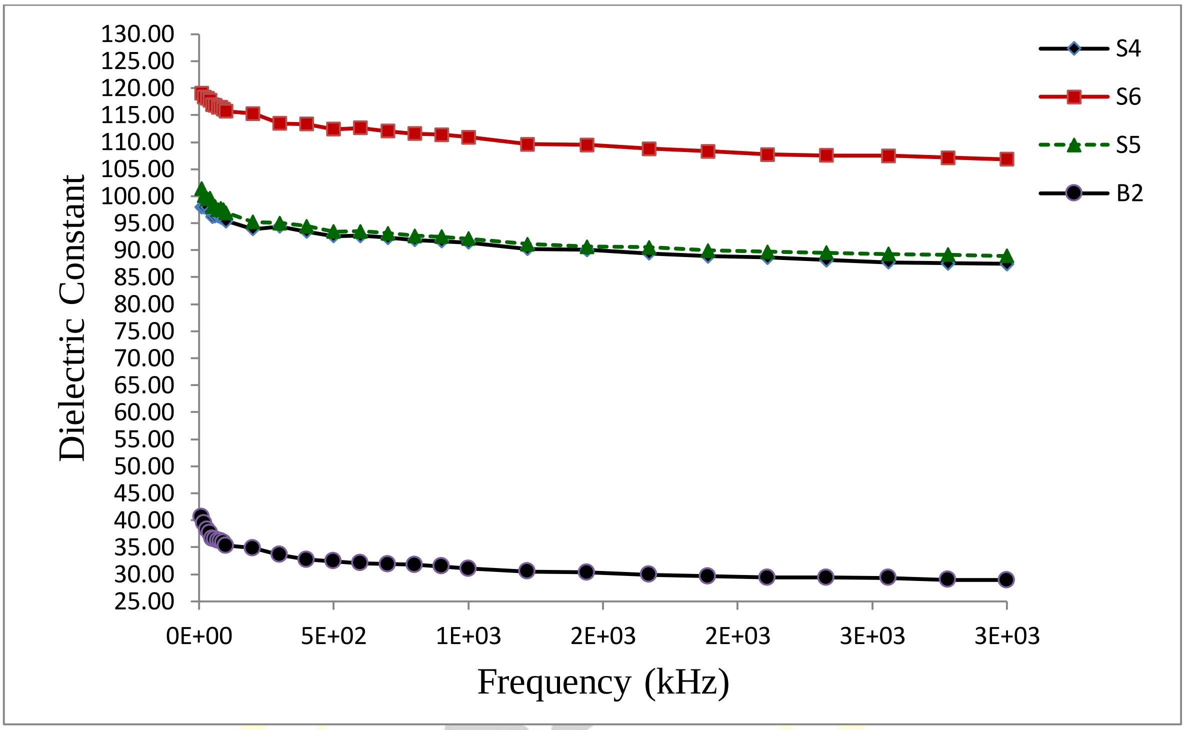

Fig (3). The dielectric constant against frequency at different Dy_2O_3 concentrations, at sintering temperature 1100℃.

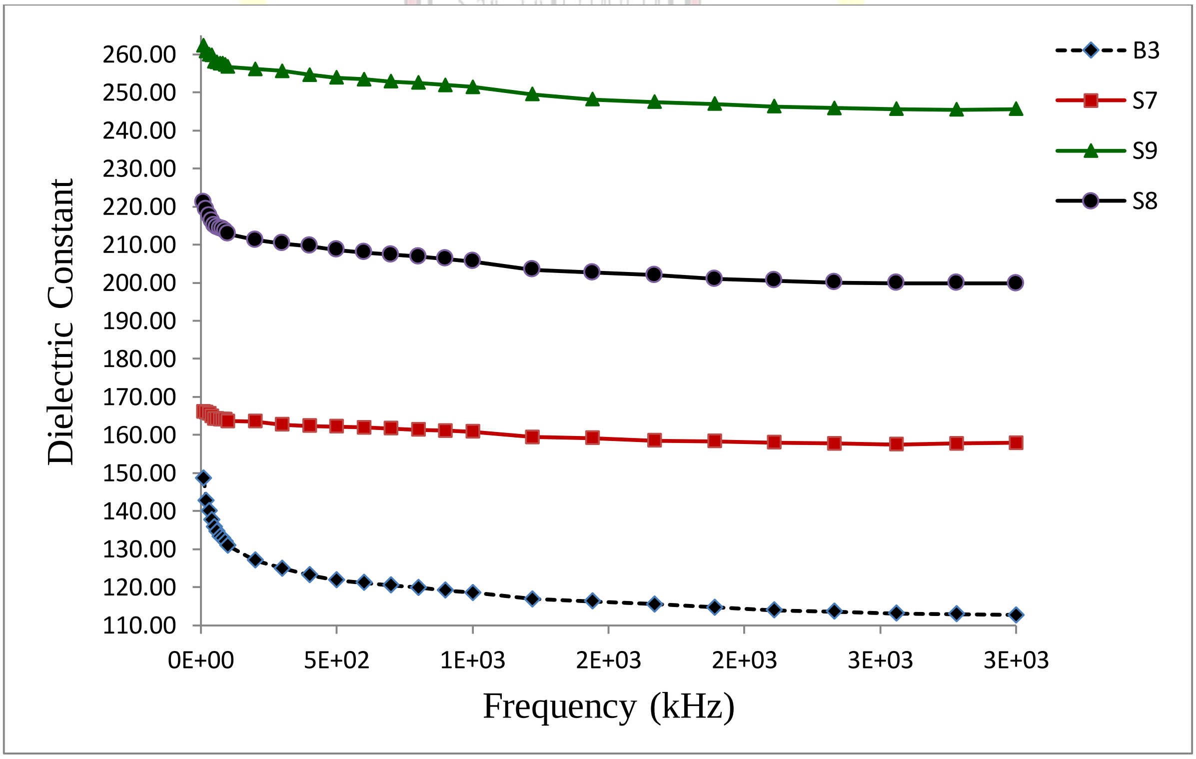

Fig .4. The dielectric constant against frequency at different Dy_2O_3 concentrations, at sintering temperature 1150℃.

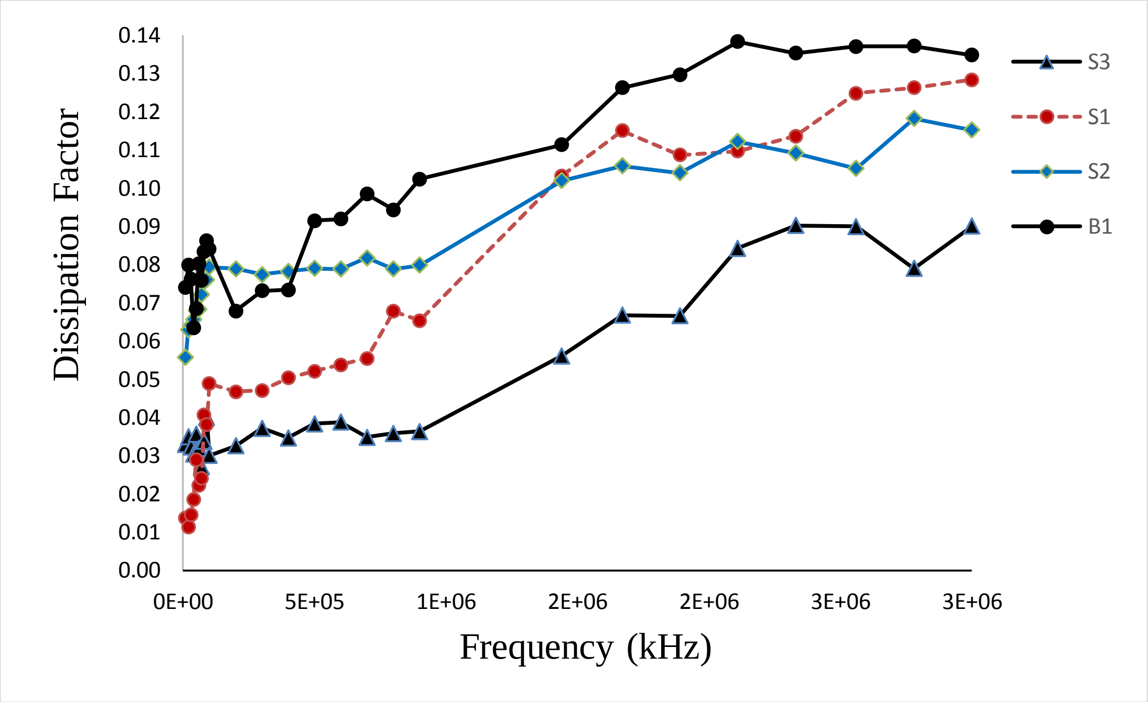

Fig (4). The dissipation factor against frequency at different Dy_2O_3 concentrations, at sintering temperature1050℃.

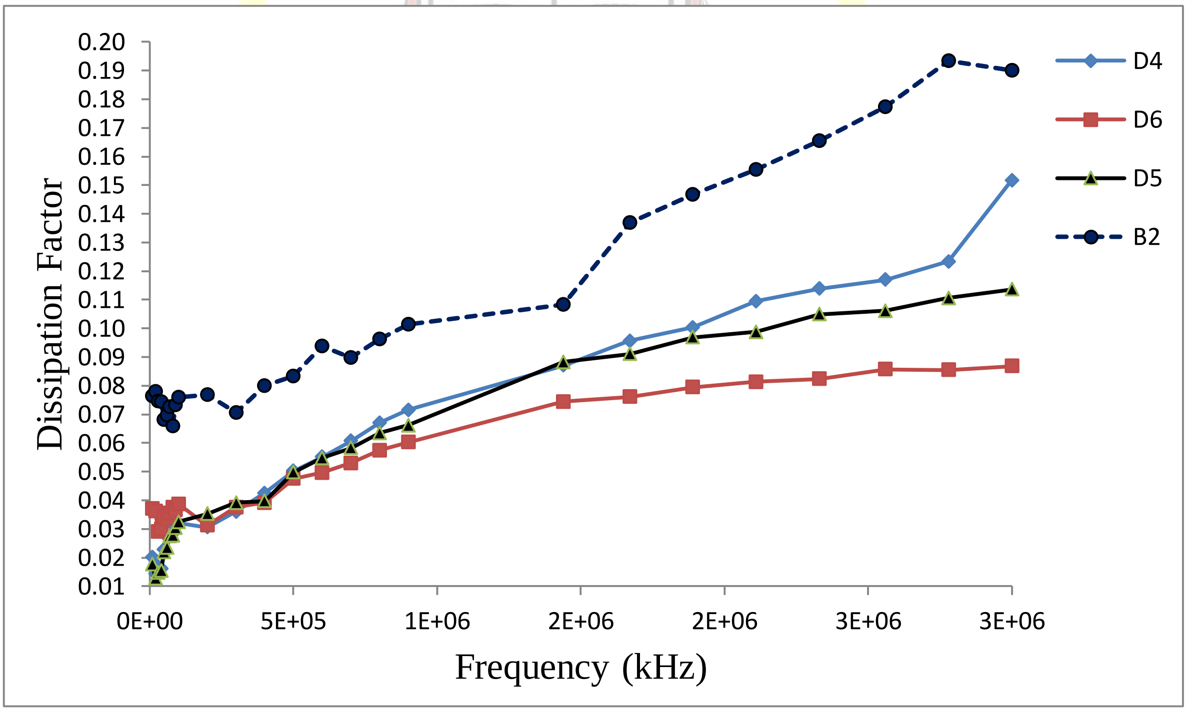

Fig. 5. The dissipation factor against frequency at different Dy_2O_3 concentrations, at sintering temperature1100℃.

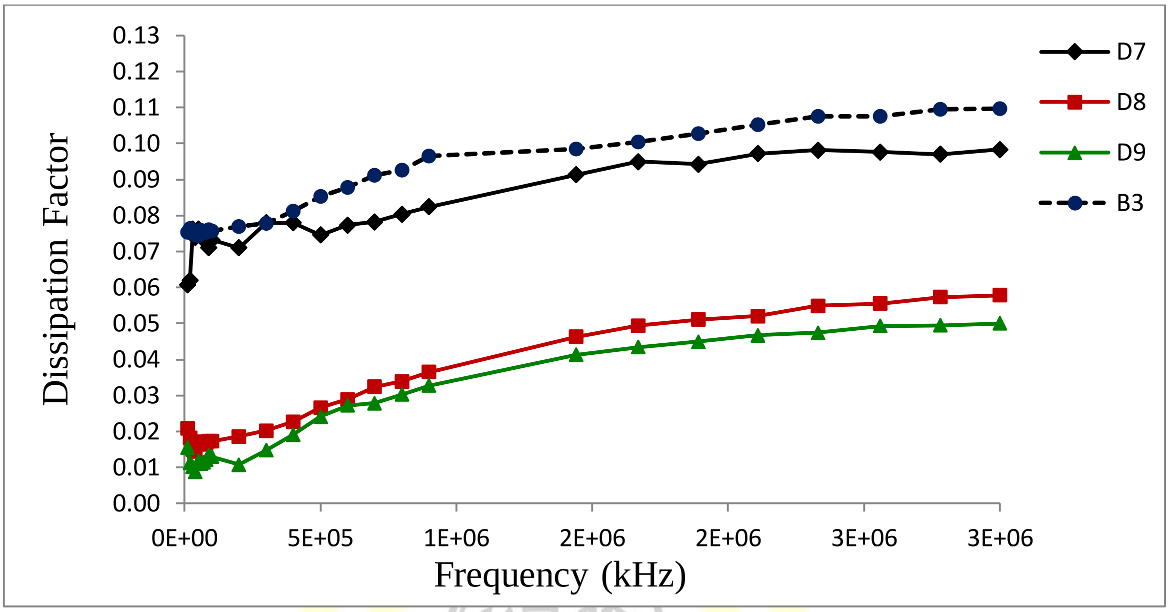

Fig. 6. The dissipation factor against frequency at different Dy_2O_3 concentrations, at sintering temperature 150℃ .

Conclusion

1- The addition of Dy_2O_3 to produce ZnO varistor generate a depletion layer around ZnO grains which represents an insulating layer and then changes the amount of the dielectric constant and dissipation factor.
2- The changing of Dy_2O_3 doping at a certain temperature decrease the dielectric constant values (To some extent and then return to increase) as a results of increasing the number of dipoles.
3- The changing of Dy_2O_3 doping at a certain temperature increases the dissipation factor values (To some extent and then return to decreases) as a results of the inability of polarization process in the molecules to follow the rapid changes in the external field.
4- The increasing of sintering temperature in turn leads to increasing the directionality of the molecular dipoles which increases the thermal energy of these dipoles which in turn leads to increases the dielectric constant of the samples.

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تأثير التطعيم بأوكسيد الديسبروسيوم (Dy_2O_3) على ثابت العزل ومعامل التبديد لمقاوم أوكسيد الخارصين (ZnO) المتغير

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الخلاصة

تم دراسة تأثير إضافة أوكسيد الديسبروسيوم Dy_2O_3 لمقاوم أوكسيد الخارصين السيراميكي المتغير المحضر على ثابت العزل وعامل التبديد وعند درجات حرارة تلبيد مختلفة.

أوضحت نتائج حيود الاشعة السينية أنّ مقاوم أوكسد الخارصين السيراميكي المتغير عبارة عن تركيب متعدد التبلور, وأن اوكسيد الخارصين ZnO يمثل الطور الاساسي و spinel phase $Zn_7Sb_2O_{12}$ هو من الاطوار الثانوية وقد ظهر في جميع العينات.

ومن نتائج الاختبار الكهربائي تبيّن أنّ مقدار ثابت العزل يقل بزيادة تركيز اوكسيد الديسبروسيوم Dy_2O_3 عندرجة حرارة تلبيد محددة بينما يزداد عامل التبديد بازدياد التركيز.

وتبين كذلك أنّ الزيادة الحاصلة بدرجة حرارة التلبيد قد تؤدي الى زيادة ثابت العزل للعينات المحضرة.