Elaboration of ZnO Based Varistors and the Effect of the Rare-Earths on their Electrical Behaviour

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Summary:

In this work we suggest a technological participation to improve the electrical behaviour and the reliability of the polycrystalline non-linear electronic devices, ZnO, based varistor, to be used to protect the electrical and electronic systems against the sudden increasing of high voltage on Electrical loads. This work includes the effect of Rare-Earth Metals (Er, Ce, Pr, Y, Dy) on the reliability of the varistor, ZnO, for different temperature firing.

The nonlinearity coefficient, $\alpha = \frac{1}{d \ln (I)}$, the leakage current, $I$, the threshold voltage $V_s$, the grains size, $d$, which separate the two grains, are all responsible of the electrical behaviour of this material. On adding the impurities such as: Cerium (Ce), Yttrium (Y), Erbium (Er), Praseodymium (Pr), and Dysprosium (Dy) as a rear-metal earth, it is concluded that each of them is positively affect on the performance of ZnO, which lead to stability of the devices and improve electrical and electronic system's behaviour and reliability.

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Keywords: varistor; Rare-Earth Metals; threshold voltage; leakage current; 

1. Introduction

Electronic Poly crystalline device, ZnO, possess, non linear I-V characteristics, which have three zones: linear zone, nonlinear zone and the saturation zone and given by the following empirical formula [5]:

$$I = KV \alpha$$

(1)

Where $K$ is constant depend on $V$ and $I$. Their resistance is nonlinearly variable with the applied voltage in the non linear zone [1, 2]. They are semiconductor type n, have a granular structure, every two grains are separated by a junction, where a Schottky barrier between these two grains is formed [4-10]. This is due to ions immigration into both junction's sides which a depletion region is formed, this element is used to protect the electrical and electronic systems from the sudden increasing of the electrical voltages which are applied on its both sides [4-16].

The most important scientific premonition for the industrial is to obtain a protection electronic samples which support the high energy to provide an efficacy protection for the electrical and Electronic Systems from the high voltage which may damage the electrical systems.
In this work we suggest a new scientific participation including a new technology which aims to provide the modern requirements for the industrial applications to have an electronic systems with good stability and high performance.

In this paper, we show, that, the Zinc oxide ZnO will be used for good protection to the electrical systems and may provide relatively a high non-linearity factor, and a small leakage current [7-17]. Our participation in this paper is to use the oxides of rare–metal earth, as impurities to improve the electrical properties of ZnO based varistor, that mean to stabilize the electrical behaviour of the non-linear elements using for protection, and then it increase the reliability of electrical devices.

The aim of this work is to suggest a new scientific technique which may improve the performance and the reliability of the electrical and electronic devices, ZnO based varistor, which may be used to protect electrical system against sudden increasing of the tension

For this aim, some physical parameters like: non-linearity coefficient, threshold voltage, Vs, size grain, d, homogeneity factor, β, and the leakage current, IL., We will present our participation in the following work.

2. **Experiment proceeding**

The lots of samples were prepared as the following:

2.1. **lot1-the classical mixture**

It consists of the following percentage:

\[95.3\% \text{ZnO} + 1\% \text{Bi}_2\text{O}_3 + 0.2\% \text{Nb}_2\text{O}_5 + 0.5\% \text{MnO}_2 + 0.5\% \text{Cr}_2\text{O}_3 + 1\% \text{Co}_3\text{O}_4 + 0.5\% \text{NiO} + 0.6\% \text{La}_2 \text{O}_3 + 0.4\% \text{Ce}_2\text{O}_3 ] \text{mol}

This composition is the classical which gives the best value of α, in our case .It is used to perform the performance of the non-linear varistor, ZnO, and its ratios are different from each producer to another.

2.2. **lot2-Rare earth oxides**

2.2.1. **lot2-a- The Ce (Cerium) effect**

We added to the previous composition (lot1) a different percentage of Ce (cerium) by making the quantity of (ZnO+CeO3) constant, saving the same percentage of the other additives, as following:

\[ \text{ZnO} (1-x) \% + \text{Ce}_2\text{O}_3 x\% \ (x=0, 0.1, 0.15, 0.3) + \text{percentage of the lot1} \].

2.2.2. **lot2-b- The Erbium (Er) and Praseodymium (Pr) effect.**

This lot is composed of the following ratios:

\[ \text{ZnO}(1-x)\%+ \text{Er}_2\text{O}_3 x\% \ (x=0,0.1,0.15,0.3) + 0.5\% \text{Pr} + \text{percentage of the lot1} \] .

2.2.3. **lot2-c- The Y (Yttrium) effect**

This mixture contain the following percentage: 

\[ \text{ZnO}(1-x)\%+ \text{Y}_2\text{O}_3 x\% \ (x=0,0.1,0.3,0.5) + \text{percentage of the additives shown in the lot1} \] .

2.2.4. **lot2-d- The DY (Dysprostium) effect**

It consist of: 

\[ \text{ZnO} (1-x)\% + \text{Dy}_2\text{O}_3 x\% \ (x=0,0.4,0.7,1) + \text{percentage of additives of the classical mixture (lot1)} \] .

3. **The equipments and electrical measurements**

The powder was measured by balance type "Denver Instrument Company-AA-200" with accuracy of 10-6 gr., 5 gr for each sample, then they are mixed by using planetary mixer with possibility of speed
changing starting with 0 till 360 Cycle/minute, then the mixed powder was put in a plastic container which turn around with a speed of 45 Cycle/min, and the powder is put in cylindering block with diameter of 1cm.

The samples were pressed by half automatic pressure with strength of 500 kg/cm², then they were smoothed by using glass paper of different smoothness levels, then chemical smoothing were done, and the samples were painted by using serigraphy ink consisting of Ag & Pt solution which was dried in 270°C temperature for 10 minutes.

Samples were fired at temperature 1150 C° by using a temperature firing Furnace of type "CARBOLITE", which is programmable with eight stages. The DC measurements of I-V characteristic was done by MP1500 Model CJ1001 device. Then the current pulses was generated by a device of model SEFELEC-SCT1000 and the samples of 1cm diameter and 3.2mm thickness were used.

The chemical, and the analyzing structure study was done by using: Electronic microscope Numeric scanning devise model EDAX S-4500 (Hitachi, Japan) For Qualitative analysis.

4. Results

4.1. The Erbium (Er) effect

Figure (1) shows the Erbium (Er) effect on the I-V characteristic of ZnO varistor. We add also the Praseodymium (Pr) by 0.5% ratio which was studied by the Choo-Woo Nahm[14] who showed that, the addition of (Pr) to these powder forming the device increases both of the threshold voltage. This figure shows also, that leakage current increase with increasing of the Erbium. The table1, explore that, the bulk density of the material is also relatively acceptable and, the grain size decreases with increasing of the Erbium.

Then we studied the effect of temperature firing duration on the results for 1 hour, then 2 hours, where we reformed the samples for in each temperature firing case, then we draw the I-V characteristic for each case (figure 1&2).

We observed that there is no more decreasing on the samples dimensions by increasing the temperature firing duration.

The results show in each of the two cases, there is an increasing of the values of the bulk density, the non-literary factor $\alpha$, and the threshold voltage $V_t$, and a decreasing at the grain size, $d$, while, all these values decrease when we increase the temperature firing duration to 2 hours according to the following table:

<table>
<thead>
<tr>
<th>Temperature firing</th>
<th>Erbium ratio %</th>
<th>Nonlinearity Factor, $\alpha$</th>
<th>Grain size $d($μm$)$</th>
<th>Bulk density gr/cm³</th>
<th>Bulk density pc %</th>
<th>Threshold voltage Volts/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tf=1h</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>20</td>
<td>9</td>
<td>5.53</td>
<td>96.34</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>0.10</td>
<td>39</td>
<td>8.1</td>
<td>5.56</td>
<td>96.86</td>
<td>315</td>
<td></td>
</tr>
<tr>
<td>0.15</td>
<td>52</td>
<td>7.3</td>
<td>5.62</td>
<td>97.73</td>
<td>385</td>
<td></td>
</tr>
<tr>
<td>0.30</td>
<td>40</td>
<td>6.5</td>
<td>5.51</td>
<td>96.5</td>
<td>415</td>
<td></td>
</tr>
<tr>
<td>Tf=2h</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>16</td>
<td>8.5</td>
<td>5.54</td>
<td>96.65</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>0.10</td>
<td>26</td>
<td>7.6</td>
<td>5.55</td>
<td>96.68</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>0.15</td>
<td>32</td>
<td>6.1</td>
<td>5.61</td>
<td>97.73</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>0.30</td>
<td>26</td>
<td>5.9</td>
<td>5.28</td>
<td>91.2</td>
<td>390</td>
<td></td>
</tr>
</tbody>
</table>

Table1: a table shows the variation of the non-linearity factor, the grain size, the bulk density, and the threshold voltage, as the Erbium ratio change.
We observe from table 1, and from the two mentioned figures of the I-V characteristics, that the samples which were fired for one hour have the biggest of non-literary factor and less leakage current and bulk density.

4.2. The Cerium (Ce) effect

Table 2 shows the variations of Cerium effect on the thickness of the sample due to the temperature firing as the Cerium ratio changes in the range(0 -0.3) %.

We conclude that, when the temperature firing increases, the sample dimensions decrease, and we obtain a bulk density of 5.43 gr/cm³ (the theoretical value equal 5.74 gr/cm³) at the temperature firing 1150°C which agree with the ratio (5.43/5.74) and equals to 94.59% which it is an acceptable value but not an ideal value. That means, an existing of porosities inside the volume, this leads to passage of the current leakage through it, the sample, then, may be degraded [17], which is not good for the industrial applications.

So, our results show, if we add the Cerium to the composition forming the sample, the grain size decreases and make the bulk density of the sample becomes bigger, which in our case reached to 5.67 gr/cm³, this is good agreement with the ratio 98.78%, which improves the bulk density of the samples (table 2).

Table 2: variation of the sample thickness due to temperature firing and effect of Cerium.

<table>
<thead>
<tr>
<th>Cerium ratio %</th>
<th>The sample thickness before firing</th>
<th>The sample thickness after firing (mm) and temperature firing (the last line of the table is evaluated by °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.2</td>
<td>2.97  2.89  2.88  2.74  2.71</td>
</tr>
<tr>
<td>0.1</td>
<td>3.2</td>
<td>2.97  2.91  2.91  2.81  2.74</td>
</tr>
<tr>
<td>0.15</td>
<td>3.2</td>
<td>2.96  2.97  2.93  2.86  2.77</td>
</tr>
<tr>
<td>0.3</td>
<td>3.2</td>
<td>2.97  2.97  2.93  2.87  2.89</td>
</tr>
<tr>
<td>800 °C</td>
<td>900 °C</td>
<td>1000 °C  1100 °C  1250 °C</td>
</tr>
</tbody>
</table>
This table shows that, the sample thickness decreases with increasing the firing temperature (from 800 °C to 1250 °C). The sample variation depend on the percentage of cerium. To assure this case we took photos for the microscope structure by an electronic scanning camera in ability of 900 thousand times amplification, so we got a microscope structure of grains which their volume size changes from 5 μm till 2 μm as shown in figure (4). We conclude that, the doping of ZnO by the cerium this lead to an increasing of threshold voltage and to a decreasing of leakage current happened, and this is shown on the I-V characteristic (figure 5).

We explain the increasing of the threshold voltage by the addition of cerium as following: because the volume of sample is granular (high number of grains) [4-10], cerium will minimize the volume of sample (figure 4) which may lead to increasing their numbers, and to minimize the size of the grains, and because the threshold voltage of the grain is constant (about 3 volts/grain) in a certain thickness [5], so, the threshold voltage of the whole sample increase, and here we got agreement between the results of the
microscope pictures (fig.4) and those of I-V characteristic, which explain that, the threshold voltage increment with the increasing of cerium ratio according to figure 6.

We are focusing here on the variations of the non-linear coefficient and on the leakage current, which lead us to conclude that, the non-linearity factor \( \alpha \) at nonlinear zone of I-V characteristic shown on figure 5 [10-15] after applying the following equation:

\[ \alpha = \frac{d\ln J}{d\ln V} \]  

We find that the value of each of: \( \alpha \), Vs, grain size \( d \), and the bulk density are all varying with the cerium as is shown in table 3:

<table>
<thead>
<tr>
<th>Temperature firing</th>
<th>Cerium ratio %</th>
<th>Non-linearity factor ( \alpha ) ( \pm 1 )</th>
<th>Grain size ( d(\mu m) )</th>
<th>Bulk density pc (theoretical value=5.74 gr/cm(^3))</th>
<th>Threshold voltage Volts/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tf=1h</td>
<td>0.00</td>
<td>43</td>
<td>12</td>
<td>5.51</td>
<td>95.99</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>48</td>
<td>10.2</td>
<td>5.54</td>
<td>96.51</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>81</td>
<td>9.7</td>
<td>5.67</td>
<td>98.78</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>44</td>
<td>8.6</td>
<td>5.52</td>
<td>96.16</td>
</tr>
</tbody>
</table>

from figure (5) we observe that, the leakage current decreases about 13 times for 0.3%Ce ratio and about 8 times for 0.1%Ce ratio, which indicate that addition of Cerium improve the studied sample performance.

### 4.3 The effect of Yttrium

We add the Yttrium (from 0 to 0.5%) to the classical composition (lot2), then, we have observed an instability at the threshold voltage. We add on the mixture a percentage of 0.5‰ Lithium which lead to the increasing of threshold voltage, as shown on the I-V characteristics shown at (fig.7):

From this I-V characteristic we can measure, \( \alpha \) (eq.1) and, Vs.

From the results of microscopic structure, the grain size, \( d \), and the bulk density may be varying as shown in following table 4:
Table 4: variation of non-linearity factor, grain size, bulk density, and the threshold voltage when Yttrium ratio varying.

<table>
<thead>
<tr>
<th>Temperature firing</th>
<th>Yttrium ratio %</th>
<th>Non-linearity factor $\alpha \pm 1$</th>
<th>Grain size $d(\mu m)$</th>
<th>Bulk density pc (theoretical value=5.74 gr/cm$^3$)</th>
<th>Threshold voltage Volts/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tf=1h</td>
<td>0.00</td>
<td>22</td>
<td>8.4</td>
<td>5.51</td>
<td>95.99</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>60</td>
<td>1.7</td>
<td>5.61</td>
<td>97.8</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>75</td>
<td>1.3</td>
<td>5.67</td>
<td>98.8</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>59</td>
<td>1.2</td>
<td>5.72</td>
<td>96.16</td>
</tr>
</tbody>
</table>

The values of $\alpha$ which shown in table 4 are relatively high which refers that the elaborated samples have a high response, we also conclude that $\alpha$ increase with the increasing of Yttrium ratio till the value 0.3% Mol of $Y$, then the value of $\alpha$ begins to decrease. We emphasizes that: All the previous samples including rare-earth oxides (Ce, Dy, Pr) have a similar effect on the electrical behavior for ZnO varistor. We can also conclude from this I-V characteristic, that, the threshold voltage increases with Yttrium ratio increment (fig. 8).

From the equation $V=d.V_b$ (where $d,V_b$ represent the grain size and threshold voltage of the junction respectively), we conclude that the increasing of the global threshold voltage value for the sample is associated with a decreasing of the grain size. To emphasize this suggestion we took photography (fig. 9) of the smooth surface of the studied sample by an electronic analyzer, so we find out from figure 9 that the grain size decreases with the increasing of Yttrium ratio which is in good agreement with the result obtained and shown on figure 9. We can also conclude from figure 7 that the leakage current decreases. We will explain that at paragraph VI. We conclude that the bulk density of the samples is increased from 5.53gr/cm$^3$ till the value 5.57gr/cm$^3$ which explains the increasing of density of material and decreasing the current passage through the grains. So, the leakage current decreases which is exactly in good agreement with the results shown on figure 7.

Fig. 9: A microscopic photo for surface of ZnO doped by the Yttrium which shows a decreasing the grain size comparing with figure 4.

Fig.10 :A Microscopic picture which shows a decreasing of the grain size of the ZnO varistor, by the effect of Dysprosium.
4.4. The Dysprosium effect on the electric behaviour of polycrystalline devices

The Dysprosium Dy was added to the classical composition (Section-II), then we have observed, an increasing of the threshold voltage as shown on the I-V characteristics (fig.11) and an increasing of each the non-linearity factor \( \alpha \) (equation1), and the bulk density for(Dy>0.7%), then after this value, they (\( \alpha \) and bulk density) begin to decrease monotonously as functions of the variation of Dysprosium ratios as shown on table 5.

We conclude that, the Dysprosium Dy, has the same behavior of rest of other rear-metal earth. This work prove the Choon-Woo Nahim's work[14], who conclude that, the addition of Dy, leads to the increasing of the non-linearity factor, \( \alpha \), and threshold voltage, but he didn’t study the effect of Dy's ratio variation on these two physical factors, while we studied the effect of these changes as we see previously. So, this work emphasizes the results obtained by Choon-Woo Nahims [14].

We can also remark that by adding Dy, the threshold voltage increases less than that obtained by the other rear-earth oxides which we got before.

The relatively small threshold voltage is due to increasing of grain size comparing with the previous samples, where we have grains size with \( 8\pm2\mu m \) as average for 100 samples (fig.10).

![I-V characteristic with Dy effect](image_url)

Figure 11: I-V characteristic for ZnO varistor doped by Dysprosium

Table 5: the variation of non-linear factor, the grain volume, the bulk density, and the threshold voltage as the Dysprosium ratio varies

<table>
<thead>
<tr>
<th>Temperature firing</th>
<th>Dyrosium ratio %</th>
<th>Non-linearity factor ( \alpha ) ±1</th>
<th>Grain size ( d(\mu m) )</th>
<th>Bulk density pc (theoretical value=5.74 gr/cm(^3))</th>
<th>Threshold voltage Volts/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tf=1h</td>
<td>0.00</td>
<td>21</td>
<td>8.1</td>
<td>5.51</td>
<td>95.99</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>44</td>
<td>7.2</td>
<td>5.61</td>
<td>97.8</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>52</td>
<td>6.4</td>
<td>5.67</td>
<td>98.8</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>31</td>
<td>6.1</td>
<td>5.72</td>
<td>96.16</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>24</td>
<td>5.8</td>
<td>5.4</td>
<td>94</td>
</tr>
</tbody>
</table>
5. discussion of the results

Our results show that the rare earth impurities (Dy, Y, Pr, Ce, Er) have the same effect on the electrical behavior, they all, increase the threshold voltage and the non-linearity factor in a specific range of their quantity ratio, subsequently these impurities will be an important factor to improve stability of leakage current and non-linearity factor. Consequently, our results give varistors which support a high capacity of the energy. This lead to prevent the effect of the high voltage and current on the electrical systems. Which assure a good protection against the sudden high voltage increasing.

In addition, the rare earths used as impurities lead to decrease the grain size and to increase their Number, N, in a specific thickness (3.2mm in our case) and also they increase the total threshold voltage, Vs, as the following equation:

\[ V_s = N \cdot V_b \]

Where, \( V_b \) is the threshold voltage for one junction which equal 3 volts according to the work of Dorlanne.O, [5], and this is confirmed by the two photos shown on figure 4. This figure shows the structure of ZnO, before and after addition of the rare–metal earths, but the decreasing of leakage current during impurities with rare–metal earth is explained as following: the sample has granular structure, each two grains are separated by a junction, where, a Schottky barrier is formed on this junction. So, all the grains are connected together and allow current to pass through the sample. However, the grain number increases, the leakage current decreases, the porosity of sample decreases and then the bulk density of sample increases [14](see table1) which all, are considered as criteria to the leakage current decrement. This is considered as symbol of the performance of our samples[5].

At the same time during the temperature firing at 1240°C, a so-called spinal phase is formed[14-17] consisting of rare–metal earth material and the substrate ZnO, and positioning at the grain boundaries [14], contribute to barrier height \( \Psi \) formed at the junction which is expressed by the following equation [5]:

\[ \Psi = \frac{q N_s}{2 \epsilon_r \epsilon_0 N_d} \]

Where q is the electron charge, \( N_s \) (cm-2) is the density of the surface state at the junction, \( N_d \) (cm-3) is the density of charge carriers which could be ions or electrons which are responsible of the current density which pass through the sample.

Also \( \epsilon_r \), (8.654x10-12 F/m) and \( \epsilon_0 \): are the relative and absolute permittivity constant for the ZnO and the air respectively.

We suggest that a Spinal phase is formed which cover the grain an prevents grain growth. This phase is not affected by temperature and could be active at a specific ratio of rare–metal earth according to the range we use in this work. This phenomena will be an important factor for the stability and reliability of our samples and improve its performance.

We can explore then, that the samples which were fired for two hours, have a leakage current higher than the current at the samples which was fired for one hour, and it could be explained by the following: as barrier height formed between two sides of the junction, which is consisting of ions and captions which all, may immigrate during the temperature firing process, from both of junction sides towards grain depth, and its number becomes in two hours more than what happen in one hour[5], which decreases the height of the barrier and facilitate of charges movement which is responsible of current.

We conclude that the firing time has an important role at the stability and the performance of studied materials.

The current increase and expressed by the following equation [5]:

\[ J = j_0 \exp(- \frac{\Psi}{kT}) \]

Where K: is Boltzmann constant, T: the temperature in Kelvin, this relation express the electrical transport mechanism of the studied materials [4,5].
6. Chemical analysis

To confirm the content of our samples, we have achieved a chemical analyze by the microscopic analyzer with precision of 900 thousand times. This analysis was made on some points on the surface of the each sample, we obtain the figure 14. We have observed the absence of the Niobium, Nb, the cerium (Ce), Erbium (Er), and the Dysprosium (Dy). When we have repeated the analysis in other point on the surface, we have obtained the figure 12 which shows the existence of the Niobium (Nb). In addition, we have repeated the analysis for the third times, we obtain the figure 16 which shows the appearance of the Nicl (Ni). and no appearance of the other elements (Er, Dy, Pr). But the I-V characteristics Explore the existence of these elements, because their influence on the value of $\alpha$, $Vs$ and $If$, consequently the distribution of chemical composition is inhomogeneous. On other hand, the power of the analyzer is insufficient to appear the other elements, that means we have need to power more than of 11 Kev. which is difficult for the analyzer.

![Fig.12: Chemical Analysis Shows the composition of the classical composition, without Nb, Ni, Er, Dy and Pr](image1)

![Fig.13: Chemical Analysis Shows the composition of the classical composition, without, Ni, Er, Dy and Pr](image2)
7. Conclusion

We used the rare–metal earths as impurities in the following classical composition consisting of:

\[ \text{[95.3\%ZnO} + 1\%\text{Bi}_2\text{O}_3 + 0.2\%\text{Nb}_2\text{O}_5 + 0.5\%\text{Mn}_2\text{O}_3 + 0.5\%\text{Cr}_2\text{O}_3 + 1\%\text{Co}_3\text{O}_4 + 0.5\%\text{Ni}_2\text{O}_3 + 0.6\%\text{La}_2\text{O}_3 + 0.4\%\text{Ce}_2\text{O}_3] \text{mol} \]

The percentages vary according to the variation of \( x \) value which represent the ratio of the rare-metal earth in the classical composition as the following: Cerium Ce and Erbium, Er, in the range (0\% - 0.3\%), the Yttrium, Y, range through the range (0\% - 0.5\%) and Dysprosium, Dy range in the range (0\% - 1\%), then we conclude through this work an increasing of each of the threshold voltage, \( V_s \), and non-linearity factor \( \alpha \), and bulk density \( \rho_v \) for the studied material, At the other hand, they decrease the leakage current \( I_L \).

According to the previous discussion we suggest to exploit the results of this work at the industrial applications.

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