Studying Effect of Eu Doping on the Structural Properties and Infrared Spectroscopy of Aluminum Oxide powders by Solid State Reaction Method

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Abstract
Eu doped Aluminum oxide transparent conducting powder were prepared by solid state reaction method. Structural properties of the samples were investigated as a function of various Eu-doping levels (x=0.00-0.0012-0.0016-0.002-0.003). The results of x-ray diffraction have shown that the samples are polycrystalline structure in tetragonal phase with preferential orientations along the (400) for all samples The relative intensities, distance between crystalline planes (d), crystallite size (D) and lattice parameters (a), (c) were determined. Infrared Spectroscopy have been studied by Infrared Spectrometer Device.

Keywords: powder, Eu doped Aluminum Oxide, solid state reaction, Structural properties, Infrared Spectroscopy.
DOI: 10.7176/CMR/12-4-02
Publication date: April 30th 2020

1. Introduction
Transparent conducting oxides (TCOs) are semiconductors that are produced from a combination of metal and oxygen such as: ZnO, In2O3, SnO2. The studying of TCOs is very important because of their special properties that is used in technology applications [1].

Aluminum oxide (Al2O3) is considered as one of the most important member of the TCOs for its unique electrical and optical properties because it has low electrical resistivity, high optical transparency in visible region, high optical reflectance in infrared region and chemical inertness. So, Al2O3 is used in solar cells, sensors, display devices and in other important applications [2].

Al2O3 is an p-type semiconductor with wide band gap energy (Eg = 3.5-4 eV) [3]. Al2O3 has tetragonal structure belonging to the P42/mnm space group. The lattice parameters are a = b = 2.184 and c = 3.184 A [4]. Its unit cell contains two Aluminum and three oxygen atoms as is shown in figure 1. The Aluminum atom is at the center of six oxygen atoms placed at the corners of a regular octahedron. Every oxygen atom is surrounded by four Aluminum atoms at the corners of an equilateral triangle [5,6].

![Fig. 1: Unit cell of the crystal structure of Al2O3. Large circles indicate oxygen atoms and the small circles indicate tin atoms.](image)

2. Experimental Method
Al1-xEuO3 powders (x = 0.00, 0.012, 0.016, 0.002, 0.003) were prepared by solid state reaction method. were accurately weighed in required proportions and were mixed and ground thoroughly using an Agate mortar and pestle to convert to very fine powders.

The grinding of the mixtures was carried out for 3 hours for all the powder samples. The ground powder samples were firing at 700°C for 3 hours.
3. Results and discussions
3.1 Structural properties
The X-ray diffraction patterns of undoped and Au doped \( \text{Al}_2\text{O}_3 \) powders prepared with various Au concentration 0 wt\%, 0.12 wt\%, 0.16 wt\%, 0.2 wt\% and 0.3 wt\% are shown in Fig. 2.

The XRD reveals that all samples are having polycrystalline nature with tetragonal structure and peaks correspond to (105), (305), (400), (440), (4.0.12), (113), (314), (116), planes. The preferred orientation is (400) for all samples. We noticed disappearance of these orientations (501), (518) in all doped samples.
Fig. 2: XRD results of pure $\text{Al}_2\text{O}_3$, 0.12 wt% Eu doped $\text{Al}_2\text{O}_3$, 0.16 wt% Eu doped $\text{Al}_2\text{O}_3$, 0.2 wt% Eu doped $\text{Al}_2\text{O}_3$, 0.3 wt% Eu doped $\text{Al}_2\text{O}_3$.

Table (1) shows results of structural values of undoped $\text{Al}_2\text{O}_3$ sample.

| عينات المدروسة | $2\theta$ (deg) | (hkl) | $d$ (Å) | Rel. int. [%] | $\beta$ (deg) | $D$ (nm) | $D$ (nm) | ثوابت الشبكة |
|---------------|-----------------|-------|---------|---------------|--------------|----------|----------|---------------|
| عينات المدروسة |                 |       |         |               |              |          |          | $a$(Å) | $c$(Å) |
| (نقي)            | 23.93          | (114) | 3.717   | 8             | 1.12         | 7.577    | 1.184    | 2.184 | 3.184 |
|                   | 38.52          | (305) | 2.336   | 72            | 1.17         | 7.516    |          |       |       |
|                   | 44.71          | (400) | 2.026   | 100           | 1.25         | 7.180    |          |       |       |
|                   | 73.12          | (501) | 1.294   | 9             | 1.25         | 8.266    |          |       |       |
|                   | 76.63          | (518) | 1.243   | 10            | 1.50         | 7.052    |          |       |       |

Table (2) shows results of structural values of Au doped $\text{Al}_2\text{O}_3$ samples ($x=0.012$).

| عينات المدروسة | $2\theta$ (deg) | (hkl) | $d$ (Å) | Rel. int. [%] | $\beta$ (deg) | $D$ (nm) | $D$ (nm) | ثوابت الشبكة |
|---------------|-----------------|-------|---------|---------------|--------------|----------|----------|---------------|
| عينات المدروسة |                 |       |         |               |              |          |          | $a$(Å) | $c$(Å) |
| (0.12wt%)     | 22.36           | (113) | 3.975   | 6             | 0.34         | 24.888   | 18.65    | 4.748 | 3.184 |
|                | 38.47           | (314) | 2.339   | 18            | 0.23         | 38.226   |          |       |       |
|                | 44.60           | (400) | 2.031   | 100           | 0.20         | 44.860   |          |       |       |
|                | 65.09           | (440) | 1.433   | 8             | 0.28         | 35.165   |          |       |       |
|                | 67.52           | (40.12)| 1.387   | 10            | 0.23         | 43.406   |          |       |       |

Table (3) shows results of structural values of Au doped $\text{Al}_2\text{O}_3$ samples ($x=0.016$).
Table (3)

| المدخلة | 2θ (deg) | (Å) | Rel. int. [%] | β (deg) | D (nm) | متواسط ثبات الشبكة |
|---------|----------|-----|---------------|---------|--------|------------------|
| (0.16wt%) | 23.14 | 3.843 | 6 | 1.12 | 7.566 | 3.68 |
| | 38.87 | 2.316 | 28 | 1.17 | 7.524 | |
| | 44.73 | 2.025 | 100 | 1.25 | 7.181 | |
| | 66.31 | 1.409 | 7 | 1.25 | 7.931 | |
| | 67.07 | 1.395 | 10 | 1.50 | 6.638 | |

Table (4) shows results of structural values of Au doped \( Al_{2}O_{3} \) powders (x=0.002).

Table (4)

| المدخلة | 2θ (deg) | (Å) | Rel. int. [%] | β (deg) | D (nm) | متواسط ثبات الشبكة |
|---------|----------|-----|---------------|---------|--------|------------------|
| (0.2wt%) | 25.27 | 3.523 | 4 | 1.12 | 7.596 | 3.68 |
| | 38.52 | 2.336 | 16 | 1.17 | 7.516 | |
| | 44.72 | 2.026 | 100 | 1.25 | 7.181 | |
| | 65.07 | 1.433 | 8 | 1.25 | 7.876 | |
| | 67.45 | 1.388 | 6 | 1.50 | 6.653 | |

Table (5) shows results of structural values of Au doped \( Al_{2}O_{3} \) powders (x=0.003).

Table (5)

| المدخلة | 2θ (deg) | (Å) | Rel. int. [%] | β (deg) | D (nm) | متواسط ثبات الشبكة |
|---------|----------|-----|---------------|---------|--------|------------------|
| (0.3wt%) | 28.05 | 3.180 | 8 | 1.12 | 7.640 | 3.68 |
| | 38.51 | 2.337 | 84 | 1.17 | 7.515 | |
| | 44.74 | 2.025 | 100 | 1.25 | 7.181 | |
| | 64.99 | 1.434 | 10 | 1.25 | 7.873 | |
| | 67.13 | 1.394 | 14 | 1.50 | 6.641 | |

The relative intensities of undoped and Au doped \( Al_{2}O_{3} \) powders are calculated. The distance between crystalline planes values (d) are calculated by using following relation:

\[ 2d \sin \theta = n \lambda \]  

Where \( d \) is distance between crystalline planes (Å), \( \theta \) is the Bragg angle, \( \lambda \)is the wavelength of X-rays (\( \lambda=1.54056 \) Å).

The crystallite size is calculated from Scherrer’s equation [7]:

\[ D = \frac{0.94 \lambda}{B_{1/2} \sin \theta} \]  

Where, D is the crystallite size, \( \lambda \) is the wavelength of X-ray, \( \beta \) is full width at half maximum (FWHM) intensity in radians and \( \theta \) is Bragg’s angle.

The lattice constants a and c for tetragonal phase structure are determined by the relation [8]:

\[ \frac{1}{a^2} = \frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2} \]  

Where \( d \) and (hkl) are distance between crystalline planes and Miller indices, respectively. The calculated lattice constants a, c values are given in table 1,2,3. It was seen that a, c and c/a match well with JCPDS data (\( a=b=2.184 \) Å and \( c=3.184 \) Å).

The change in peak intensities is basically due to the replacement of \( Al^{3+} \) ions with \( Au^{2+} \) ions in the lattice of the \( Al_{2}O_{3} \). This process leads to the movement of \( Al^{3+} \) ions in interstitial sites.

5. Conclusion

This paper presents a study of structural properties of Au doped \( Al_{2}O_{3} \) powders prepared by solid state reaction method. X-ray diffraction patterns confirm that the samples have polycrystalline nature with tetragonal structure and show presence (105), (305), (400), (440), (4.0.12), (113), (314), (116) planes in pure tin oxide sample. The all samples have preferred orientation along (400) plane. The average of crystallite size is within the range \([11.877-7.004 \text{ nm}] \) for all samples. It was defined that the lattice constants a, c for all the samples, were almost
identical with JCPDS values, and the ratio c/a remained constant with increasing Fe dopant concentration. FTIR analysis revealed that the Fe doping manifests itself by a shift in $\text{Al}_2\text{O}_3$ absorption peaks positions.

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