SnO$_2$:F thin films were prepared by the spray pyrolysis (SP) technique at substrate temperature in the range 360-520°C using dehydrate stannous chloride (SnCl$_2$.2H$_2$O) and ammonium fluoride (NH$_4$F) as precursors, and mixture of water and methanol as solvent. Optical micro slide glass plates were used as substrates. The X-ray diffraction studies confirmed the tetragonal structure with polycrystalline nature. The preferred directions of crystal growth appeared in the diffractogram of SnO$_2$: F (FTO) films prepared with different substrate temperature were correspond to the reflections from the (110), (200) and (211) planes, respectively. The film thickness and the grain size vary from 305 to 204 nm, from 20.94 to 33.09 nm, respectively. AFM study reveals the surface of FTO to be made of nanocrystalline particles. The electrical study reveals that the films have degenerate and exhibit n-type electrical conductivity. The sprayed FTO films have minimum sheet resistance of 9.03 Ω/cm$^2$, highest figure of merit of 558.1x10$^{-3}$ Ω$^{-1}$ at 800 nm. The average visible transmittance (800 nm) of the deposited films is 80.664 %. In the visible region of the spectrum, the transmission is very high. For films prepared at 520°C, relatively higher transmittance of about 92.78% at 800 nm has been observed. The transmission attained in this study is greater than the values reported for tin oxide films prepared at substrate temperature 520°C, from aqueous solution of SnCl$_2$.2H$_2$O precursor. Resistivity is smaller than the values reported. The obtained results revealed that the structures and properties of the films were greatly affected by substrate temperature.

**Key words**: Spray pyrolysis; SnO$_2$: F; thin films; substrate temperature, the crystal growth orientation.

### 1. INTRODUCTION

The highly transparent and conductive thin films, owing to its high transmittance and conductivity, have been wide device applications [1, 2]. An important application of thin film technology from the point of global energy crunch is solar cell, which converts the energy of the solar radiation into useful electrical energy. The main requirement for thin film solar cells is the window
material, which allows the visible region of solar spectrum to pass through but reflect the IR radiation. Studies on these highly conducting semiconductors have attracted the interest of many researchers because of their wide applications in both industry and research. Such spectrally selective coating have wide applications in solar thermal energy conversion, solar photovoltaic conversion, solar heating, window insulation, and thermal insulation in lamps [3, 4]. In recently years there has been a growing interest in the use of transparent conducting oxide thin films as conducting solar window materials in thin film solar cells [3, 5, 6], heat reflectors for advanced glazing in solar application [7, 8] and as various gas sensors [5-13]. Tin oxide is the first transparent conductor to have received significant commercialization [5, 9, 14]. Among the different transparent conductive oxides, SnO$_2$ films doped with fluorine or antimony seem to be the most appropriate for use in solar cells, owing to its low electrical resistivity and high optical transmittance. SnO$_2$ is chemically inert, mechanically hard, and can resist high temperature [5]. Many excellent reviews of transparent conductive oxides are available [15]. SnO$_2$ either doped or undoped can be synthesized by numerous techniques such as thermal evaporation [3, 9], sputtering [5, 9-12, 16, 17], chemical vapour deposition [3, 18-20], sol-gel dip coating [3, 17, 21], painting [3, 17, 22], spray pyrolysis [3, 5, 7, 13, 20, 23-26], hydrothermal method [27] and pyrosol deposition [3, 20, 28-30]. Among the various deposition techniques, the spray pyrolysis is the well suited for the preparation of doped tin oxide thin films because of its simple and inexpensive experimental arrangement, ease of adding various doping material, reproducibility, high growth rate, and mass production capability for uniform large area coatings, which are desirable for industrial solar cell applications [3, 5, 11, 13, 17, 23, 31, 32]. However, economical large area film production is the essential characteristic of the simple spray pyrolysis technique [16]. Usually, the chemical spray pyrolysis route has been employed to deposit FTOs at optimized substrate temperatures around 723-748 K [20]. Tin oxide is wide band gap (~4eV) and indirect band gap (of about 2.6 eV) nonstoichiometric semiconductor [33, 34]. It has low n-type resistivity ($10^{-3}\Omega \text{ cm}$) and high transparency (90%) in the visible region [35].

In the present work, SnO$_2$:F (20 wt.% F levels) thin films have been prepared by the spray pyrolysis (SP) technique at substrate temperature in the range 360-520°C using dehydrate stannous chloride (SnCl$_2$.2H$_2$O) and ammonium fluoride (NH$_4$F) as precursors. The aim of this work is to study effect of substrate temperature on the crystal growth orientation and some physical properties of SnO$_2$: F thin films deposited by spray pyrolysis technique, such as the electrical, structural and optical properties. The results obtained has been compared and discussed with the specified results by several researchers.
2. EXPERIMENTAL

Thin films of FTO were deposited on optical micro slide glass plates by homemade spray pyrolysis experimental instruments. As a precursor for tin used dehydrate stannous chloride (SnCl₂·2H₂O). 10g of SnCl₂·2H₂O dissolved in 5 ml of concentrated hydrochloric acid (HCl) was heated at 90 °C for 10 min. The addition of HCl was required in order to break down the polymer molecules that were formed when diluting with methanol. This mixture was diluted by adding methanol served as starting solution and the diluted solution was made up to 25 ml. As formed the fluorine doped tin oxide solution, the fluorine doping was achieved by adding ammonium fluoride (NH₄F) to the starting solution. For fluorine doping, 2g of ammonium fluoride (NH₄F with 98%, Sigma-Aldrich) dissolved in 25 ml of doubly distilled water was added with the starting solution. The weight percentage of [NH₄F] / [SnCl₂·2H₂O] ratios in the spray solution used in this study was taken as 20 (20 wt. % F levels). In each case, the amount of spray solutions prepared was 50 ml. All the spray solutions were magnetically stirred for 1h and finally these solutions were filtered by syringe filter with 0.2 µm pore size before spraying on substrate. The optical glasses with 75x25x1 mm³ dimensions were used as substrates. The substrates were washed with water, then boiled in concentrated chromic acid and kept in distilled water for 48 h [4]; finally substrates were cleaned with organic solvents and helping ultrasonic cleaner. The substrates were pre-heated to the required temperature. After deposition, all the films were allowed to cool down naturally to room temperature on hot plate after deposition. The flow rate (2 ml/min.), total spraying quantity (50 ml) and plate rotation speed (20 rpm/min.) were all kept fixed. Filtered compressed air was used as carrier gas. The total deposition time was maintained at 30 minutes for each film, including waiting times. To avoid excess cooling of the substrates 10 minutes waiting time was allowed between spraying applications. The substrate temperature (working temperature) was varied from 360°C to 520°C. In all, more ten samples were produced simultaneously at each substrate temperature. Process was repeated several times for each temperature. It was realized that the crystals have similar properties and then passed to other processes.

The structural characterization of the films was carried out by X-ray diffraction (XRD) measurements using a Rigaku D/Max-IIIC diffractometer with CuKα radiation (λ=1.5418 Å), at 30 kV, 10 mA. Film thickness was measured by cross-sectional scanning electron microscopy (SEM-Nova NanoSEM 430) and was confirmed with the Swanepoel method. Surface morphology of the resulting films was examined by SEM and atomic force microscopy (AFM), which was produced by Nanomagnetics-Instrument. The electrical measurements were carried out by
Hall measurements in Van der Pauw configuration at room temperature. Optical transmittance measurements of the FTO films were measured using UV-Vis spectrophotometer (Perkin Elmer, Lambda 35) in the wavelength ranging from 350 to 1100 nm.

3. RESULTS AND DISCUSSION

3.1. STRUCTURAL PROPERTIES

The surface morphology of the films was studied also by AFM. From the AFM images, it was observed that the grain size become larger and the crystallinity was improved with the increase in the substrate temperature. AFM surface 3D (three-dimensional) images of FTO film prepared at various substrate temperatures are shown Fig.1 [(a) and (b)]. When the substrate temperature is increased 520°C, the distribution of grains is uniformly on the substrate surface. The root mean square (RMS) values of surface roughness are found to be 0.2-6.4 nm in the films doped 20wt. % F. The surface roughness was observed to be improved because the radicals’ mobility at the sample surface enhanced with substrate temperature. These results agree with the results of Lee et al. [13].

![AFM surface 3D images](attachment:image1)

**Fig. 1** – The AFM surface 3D images of FTO films as a function of substrate temperature: (a) 360°C, (b) 520°C respectively.

Fig. 2 shows dependence of the surface roughness variation on the substrate temperature. As the substrate temperature increased from 360 to 520°C, the roughness (RMS) of the films decreased from 6.4 to 0.2 nm (Fig. 2, Table 1).
The structural properties of FTO thin films at various substrate temperature
FWHM-Full width at half maximum; D- Crystallite size; RMS- Root mean square roughness

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>plane</th>
<th>FWHM</th>
<th>D (nm)</th>
<th>RMS Roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>360</td>
<td>110</td>
<td>0.407</td>
<td>20.94</td>
<td>6.4</td>
</tr>
<tr>
<td>400</td>
<td>110</td>
<td>0.363</td>
<td>24.19</td>
<td>5.1</td>
</tr>
<tr>
<td>440</td>
<td>110</td>
<td>0.242</td>
<td>27.44</td>
<td>0.9</td>
</tr>
<tr>
<td>480</td>
<td>211</td>
<td>0.235</td>
<td>28.19</td>
<td>0.3</td>
</tr>
<tr>
<td>520</td>
<td>200</td>
<td>0.305</td>
<td>33.09</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Fig. 2 – The surface roughness variation of FTO films as a function of substrate temperature.

The XRD patterns recorded for SnO$_2$: F thin films deposited by the spray pyrolysis technique as a function the substrate temperatures (360, 400, 440, 480 and 520°C) are shown in Fig. 3.

Films deposited at 360°C and above 360°C caused the crystallization of the films as mentioned by other researchers [37-39]. The films deposited at 360°C showed five peaks namely (110), (200), (211), (220) and (310) whereas the films deposited at higher temperatures showed as many as eight [(110), (101), (200), (211), (220), (310), (301), (321), (400)] peaks. Since all the peaks are sharp it is evident that the films deposited at 360, 400, 440, 480 and 520 °C are polycrystalline in nature and are of cassiterite tetragonal structure. In all films the half width of the Bragg peaks decreases and the intensity of the peaks increases with increasing deposition temperature. Especially, the peaks (110), (200) and (211) dominantly increased with increasing temperature [5, 13, 20, 24, 30-33, 36-43]. It has been reported that the preferred orientation of SnO$_2$:F film on glass substrate
Fig. 3 – XRD spectra of the FTO films deposited on optical glass at different substrate temperature.

is affected by source compounds, solvent and growth parameters such as solution concentration, solution feed rate, deposition temperature and spraying gas pressure [1, 26, 44]. The most conspicuous feature from the XRD analysis is that the films in the present study are oriented along the (211) plane at 480°C and along the (200) plane at 520°C. A similar tendency for (200), (110) and (101) texture was found in SnO$_2$: F films when a starting solution of SnCl$_2$ in HCl was employed [5, 14, 33, 45]. This means (in our opinion) that the preferential orientations of crystal growth are strongly dependent on substrate temperature. These results agree with the results of Miao et al. [1], Yavada et al. [4], Ikhmayies et al. [33] and Serin et al. [37]. Smith et al. [28] have analyzed the relation between solution chemistry and morphology of SnO$_2$ films prepared with and without the addition of HCl in
SnCl$_2$.2H$_2$O solution. It was reported that if HCl was added with the starting solution the films were highly oriented along (200) plane. This can be ascribed to the different formation of intermediate molecules in the starting solution. Though SnCl$_2$.2H$_2$O can partly ionize into Sn$^{2+}$ and Cl$^-$, it could also form tin-based polymer molecules [36, 46]. The initially obtained cloudy starting solution, in the present study, that turned highly transparent on addition of HCl may be due to the breakdown of these polymer molecules. The effect of association between SnCl$_2$.2H$_2$O and Cl$^-$ or H$^+$ has to be considered for further explanation [47]. The thicknesses of the films FTO was measured to be 204-704 nm by SEM and were confirmed with the Swanepoel method [48]. Optical quantities of interest can be obtained from the transmittance data, $t$, given by [37,48]:

$$t = \frac{2(n(\lambda_1)/\lambda_1-n(\lambda_2)/\lambda_2)}{1+2\frac{8n_{\text{sub}}.C(\lambda)+(n_{\text{sub}}+1)^2}{[8n_{\text{sub}}.C(\lambda)+(n_{\text{sub}}-1)^2]^{1/2}}},$$

where $n_{\text{film}}$ is the refractive index of film, $n_{\text{sub}}$ is the refractive index of substrate, $T^+(\lambda)$ is the maximum transmittance and $T^-(\lambda)$ is the minimum transmittance in the $\lambda$ values. To determine these values, the similar calculations have been done for ZnO thin films by Bazavan et al. [49]. For a sample the interference envelopes passing through the extreme points in the spectrum are shown in Figure 4.

![Fig. 4 – Transmission curve of interference envelope functions $T^+(\lambda)$ and $T^-(\lambda)$.

Fig. 5 (a) and (b) shows typical cross-sectional SEM micrographs of highly conducting SnO$_2$: F films and the variation of the film thickness of SnO$_2$: F thin films with respect to substrate temperature, respectively. The spray rate was kept constant at 2 ml/min. relatively higher thickness increasing found to be 704 nm for film deposited at 400$^\circ$C. It is seen that the film thickness increased with increasing
substrate temperature from 360°C to 400°C, attains terminal value at 400°C (704 nm), beyond which it decreases. Yadava et al. [4] as stated, this can be explained as follows: initially, at lower substrate temperatures, e.g. 360°C, the temperature may not be sufficient to decompose the sprayed droplets of Sn²⁺ and F⁻ ions from the solution and this therefore, results in a low thickness. At a particular substrate temperature of 400°C, decomposition occurs at the optimum rate resulting in the terminal thickness being attained. A noticeable decrease of the film thickness with increasing the substrate temperature is observed after substrate temperature 400°C. This decrease may be attributed to re-evaporation of film material after deposition or to thermal convection of the sprayed droplet during the deposition process or both [4]. The SEM micrographs displaying the surface morphology of FTO films are shown in Fig.6 [(a), (b), (c)] for the different working temperatures in this study. The FTO films are characterized by uniform-size grains with cubical shape at the deposition temperature below 400°C, which are on the average smaller than the grains in the high temperature region [50]. Then the grain size of FTO films are rapidly increasing as working temperature increasing.

![SEM micrographs of FTO films](image)

**Fig. 5** – (a) Typical cross-sectional SEM micrographs of highly conducting SnO₂:F film; (b) variation of the film thickness of FTO thin films with respect to substrate temperature.

The grain size of SnO₂:F films deposited at 360, 400, 440, 480 and 520°C is calculated using Scherrer’s Formula [4, 20, 26, 31], \( D = \frac{0.9 \lambda}{\beta \cos \theta} \) where \( D \) is the size of crystallite, \( \beta \) is the broadening of diffraction line measured at half its maximum intensity in radians and \( \lambda \) is wavelength of X-rays (\( \lambda = 1.5418 \) Å). The full width at half maximum (FWHM) values, grain size and RMS are given in Table 1.
9 Effect of substrate temperature on the crystal growth

Table 2

Electrical parameters of FTO thin films at various substrate temperatures t- film thickness; Rs- sheet resistance; ρ- bulk resistivity; n- carrier concentration; μ- carrier mobility

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>t (nm)</th>
<th>Rs (Ω cm⁻²)</th>
<th>ρ (x 10⁻⁴ Ω cm)</th>
<th>n (x 10²⁰ cm⁻³)</th>
<th>μ (cm² / V s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>360 °C</td>
<td>305</td>
<td>386.62</td>
<td>117.92</td>
<td>0.12</td>
<td>43.8</td>
</tr>
<tr>
<td>400 °C</td>
<td>704</td>
<td>86.42</td>
<td>60.84</td>
<td>0.69</td>
<td>14.9</td>
</tr>
<tr>
<td>440 °C</td>
<td>423</td>
<td>43.41</td>
<td>18.36</td>
<td>0.43</td>
<td>79.7</td>
</tr>
<tr>
<td>480 °C</td>
<td>312</td>
<td>16.52</td>
<td>5.15</td>
<td>0.93</td>
<td>113.5</td>
</tr>
<tr>
<td>520 °C</td>
<td>204</td>
<td>9.03</td>
<td>1.84</td>
<td>1.71</td>
<td>198.9</td>
</tr>
</tbody>
</table>

Fig. 6 – Micrographs of FTO films (fluorine concentration at 20 %) obtained for different deposition temperature at (a) 360°C, (b) 440°C and (c) 520°C respectively; (d) Grain size of various working temperature in FTO films.
Such a discrepancy in grain size values has been reported by several researchers [43, 51]. Grain size variation of FTO films calculated from the Scherrer’s equation as a function of the substrate temperature shown in Fig. 6 (d). This indicates that the grain size become larger with the substrate temperature.

3.2. ELECTRICAL PROPERTIES

The electrical measurements were carried out by Hall measurements in Vander Pauw configuration at room temperature. The negative sign of Hall coefficient confirmed the n-type conductivity of the films. Resistivity ($\rho$), mobility ($\mu$) and carrier concentration ($n$) of FTO films were given in Table 2 and Figure 7 as a function of the substrate temperature. As seen in the table, there is a rapid decrease of the resistivity with the substrate temperature. This result was consistent with other measurements mentioned previously. That is, the crystalline was enhanced with substrate temperature for film deposition. As the substrate temperature increased from 360 to 480°C, mobility and carrier concentration of the films varies as the reciprocal increased-decrease, then, increased at the same trend up to 520°C. These values are comparable with the values found in literature [5, 13, 31, 33, 37]. It is well known from many previous that the substrate temperature governs the stoichiometric variation of SnO$_2$ film. With increasing substrate temperature the film become non-stoichiometric, which indicates that the surface mobility of sputtered ions at the sample surface was enhanced with substrate temperature and thus the grain size become larger.

![Fig. 7 – Resistivity, mobility and carrier concentration of FTO films as a function of substrate temperature.](image)
This resulted in carrier scattering due to reduced grain boundaries and enhanced mobility [13, 31, 52, 53]. As the substrate temperature increased from 360 to 520°C, resistivity and sheet resistance (R_{sh}) of the films deposited on a glass substrate decreased from 117.92x10^{-4} to 1.84x10^{-4} Ωcm and from 386.62 to 9.03 Ω/cm², respectively. That is, both the sheet resistance (R_{sh}) and resistivity (ρ) are found to decrease with increasing substrate temperature (Figure 8). The resistivity 1.84x10^{-4} Ωcm achieved for fluorine doping 20 wt% was found to be the lowest among the values reported to date for SnO_2:F films prepared using SnCl_2.2H_2O as the precursor. The resistivity and the sheet resistance of the FTO films follows the same trend as a function of the substrate temperature (Table 2). This result was consistent with other measurements mentioned previously [31]. Especially, sheet resistance (R_{sh}) is a useful parameter in comparing thin films, particularly, those of the same material deposited under similar conditions [1, 43]. As the substrate temperature increased from 360 to 400°C mobility decrease from 43.8 to 14.9 cm² V^{-1} s^{-1} while after 400°C it again increase, which is to the reported one [13]. As the substrate temperature increased from 360 to 400°C, carrier concentration also increase from 0.12x10^{20} to 0.69x10^{20} cm^{-3}, when decreased from 400 to 440°C, while after 440°C it again increase.

![Fig. 8 – Variation of sheet resistance and resistivity of FTO films with substrate temperature.](image-url)
3.3. OPTICAL PROPERTIES

Fig. 9 shows the variation of transmittance (T) with respect to wavelength of FTO thin films deposited at various substrate temperatures. Average visible transmittance (AVT) is calculated as 80.664 %, in the wavelength 800 nm. The transmission in the visible region has been found to be ranging from 68.14% to 92.78% depending upon the substrate temperature. An increase in transmission is observed with increase in temperature. These values are comparable with the values found in literature [13, 37, 54]. At lower temperatures, at 400°C and under, relatively lower transmission is due to the formation of milky films and that is because of incomplete decomposition of the sprayed droplets. In general, in the visible region of the spectrum, the transmission is very high. It is due to the fact that the reflectivity is low and there is no absorption due to transfer of electrons from the valence band to the conduction band owing to optical interference effect, it is possible to maximize the transmission of thin film at particular region of wavelengths [54]. The optical transmission spectrum of the films has been determined on the basis of UV-vis transmission measurements (Figure 9).

![Optical transmission spectra of FTO thin films as a function of substrate temperature.](image)

The figure of merit is an important parameter for evaluating TCO thin films for use in solar cells [31]. Conductivity and transmittance are inversely proportional to each other and should be as possible for effective usage. In order to compare the performance of various transparent conductors the most widely used figure of merit as defined by Haacke is $\Phi_M = T^{10}/R_{sh}$ [3, 26, 31, 44, 55], where $T$ is the transmittance at 800 nm and $R_{sh}$ is sheet resistance. This Formula gives more
weight to the transparency and thus is better adapted to solar cell technology [31]. The calculated AVT and figure of merit values are given in Table 3. The variations of figure of merit and sheet resistance with substrate temperature are shown in Figure 10. It is seen that the figure of merit decrease with the increase in the substrate temperature. This may be attributed to the improvement in transparency and reduction in sheet resistance with the increase in the substrate temperature [20]. The value obtained for FTO the films doped at 360°C is the highest value obtained (55.81x10^{-2} \ \Omega^{-1}) in present study.

**Table 3**

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>T(%) (λ= 800 nm)</th>
<th>Rs(Ωcm^{-2})</th>
<th>ΦM (x10^{-3}Ω^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>360 °C</td>
<td>68.14</td>
<td>386.62</td>
<td>558.1</td>
</tr>
<tr>
<td>400 °C</td>
<td>74.84</td>
<td>86.42</td>
<td>63.8</td>
</tr>
<tr>
<td>440 °C</td>
<td>77.52</td>
<td>43.41</td>
<td>1.8</td>
</tr>
<tr>
<td>480 °C</td>
<td>90.04</td>
<td>16.52</td>
<td>21.2</td>
</tr>
<tr>
<td>520 °C</td>
<td>92.78</td>
<td>9.03</td>
<td>52.3</td>
</tr>
</tbody>
</table>

Fig. 10 – Plot of sheet resistance and figure of merit as a function of substrate temperature.

The obtained values are in good agreement with the earlier reports [31, 36, 52, 56]. Our value is comparable to the values of Φ for FTO films prepared by spray pyrolysis technique reported by others [57].
4. CONCLUSIONS

Polycrystalline SnO$_2$: F thin films were prepared using a homemade spray pyrolysis apparatus at various substrate temperatures in the range 360-520°C deposited onto amorphous glasses. The effects of substrate temperature on SnO$_2$: F films structural, electrical and optical properties were experimentally investigated. X-ray diffraction studies reveal that the material in the thin form is polycrystalline with tetragonal structure. The hall measurements show that the conductivity of the films is of n-type. The electrical conductivity characteristics, atomic force microscope (AFM) and SEM images, UV-vis spectra and X-ray diffraction patterns confirmed that the crystallinity is affected by substrate temperature. The FTO films are very smooth. The film thickness was range 204-704 nm. X-ray diffraction pattern reveals the presence of cassiterite structure with (200) and (211) preferential orientation for FTO films. The lowest sheet resistance for the SnO$_2$: F films were 9.03 Ω/cm$^2$. The average visible transmittance (800 nm) of the deposited films is 80.664 %. A high value of figure of merit in the FTO films was 55.81x10$^{-2}$ Ω$^{-1}$. All the films are degenerate with carrier concentrations in the range of 0.12x10$^{20}$-1.71x10$^{20}$ cm$^{-3}$. The resistivity of the samples is of the order of 117.92x10$^{-4}$-1.84x10$^{-4}$ Ωcm. The obtained results are suggesting that the deposited films could be used as transparent electrodes in solar cells applications.

With this method, similar studies were made previously by many researchers, emphasized the similarities and differences between the results obtained. In the present work, for films prepared at 520°C, relatively higher transmittance of about 92.78% at 800 nm has been observed. The transmission attained in this study is greater than the values reported for FTO films prepared at substrate temperature 520°C, from aqueous solution of SnCl$_2$.2H$_2$O precursor. The resistivity found as 1.84x10$^{-4}$ Ωcm for FTO films doping 20 wt% F is the lowest. In addition to other differences and similarities, these are the most important results obtained from the study.

REFERENCES