Various routes for low temperature RF-magnetron sputtering of Indium Tin Oxide films

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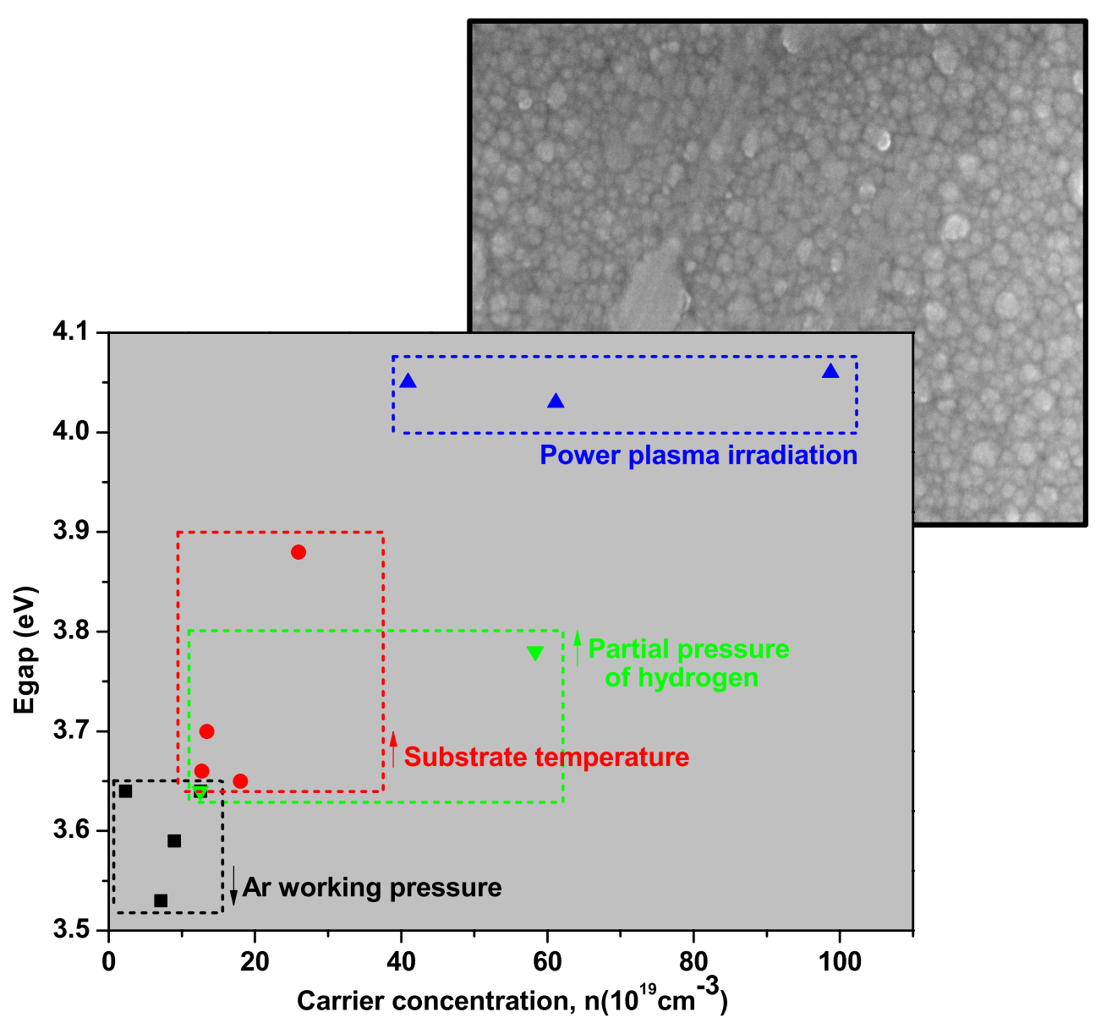
ABSTRACT

In this work we have studied the influence of the Ar working pressure, substrate temperature, low power plasma irradiation and partial pressure of hydrogen in the RF-magnetron sputtering of indium tin oxide (ITO) thin films on glass substrates. This work aims at identifying the best conditions to achieve good quality ITO film at low temperature.

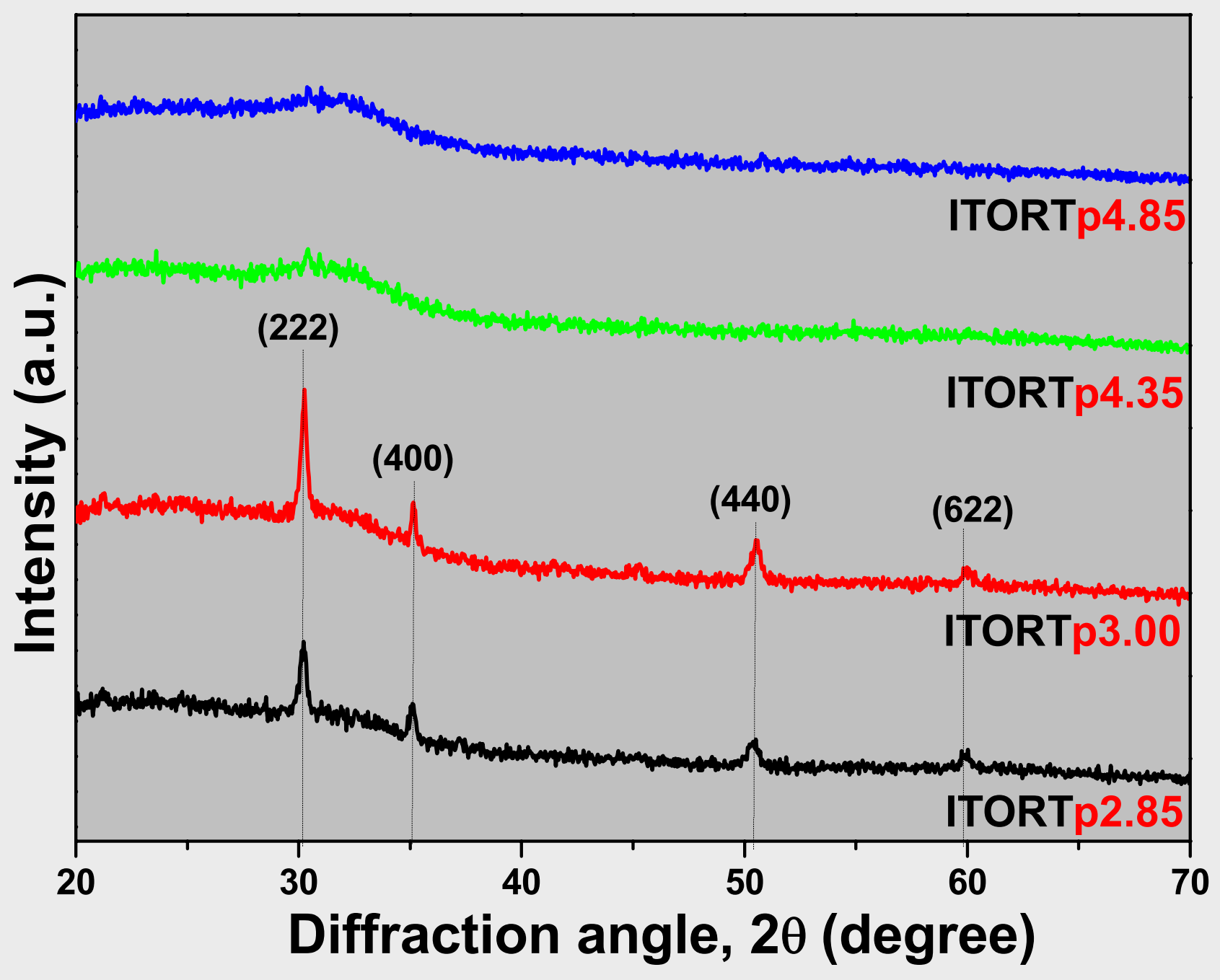
Four sets of samples were prepared which were characterized by scanning electron microscopy, X-ray diffraction (XRD), Van der Pauw, transmittance and absorbance measurements.

Samples	Thickness t (nm)	Sheet resistance $R_\square$ (Ω)	Resistivity ρ (Ω.cm)	Hall mobility μ_{Hall} ($cm^2/V.s$)	Carrier concentration n (cm^{-3})	Band gap Egap (eV)
ITORTp2.85	293	63	0.0018	28.2948	$1.2560e^{20}$	3.64
ITORTp3.00	290	68	0.0021	23.3063	$2.2939e^{19}$	3.64
ITORTp4.35	348	190	0.0054	12.9685	$8.9677e^{19}$	3.59
ITORTp4.85	303	830	0.0261	4.2135	$7.1224e^{19}$	3.53
ITORTp2.85	349	35	0.0012	26.88	$1.7990e^{20}$	3.65
ITOT100p2.85	362	74	0.0026	17.1743	$1.2744e^{20}$	3.66
ITOT150p2.85	298	71	0.0022	21.7491	$1.3436e^{20}$	3.70
ITOT250p2.85	285	34	0.0010	23.6770	$2.5974e^{20}$	3.88
ITORTp2.85P10W	274	31	$6.3416e^{-4}$	16.9438	$6.1144e^{20}$	4.03
ITORTp2.85P20W	248	23	$4.4118e^{-4}$	15.9821	$9.8734e^{20}$	4.06
ITORTp2.85P40W	192	59	0.0011	10.7705	$4.0936e^{20}$	4.05
ITORTp2.85P0WH$_2$	248	23	$4.7653e^{-4}$	22.9603	$5.8343e^{20}$	3.78

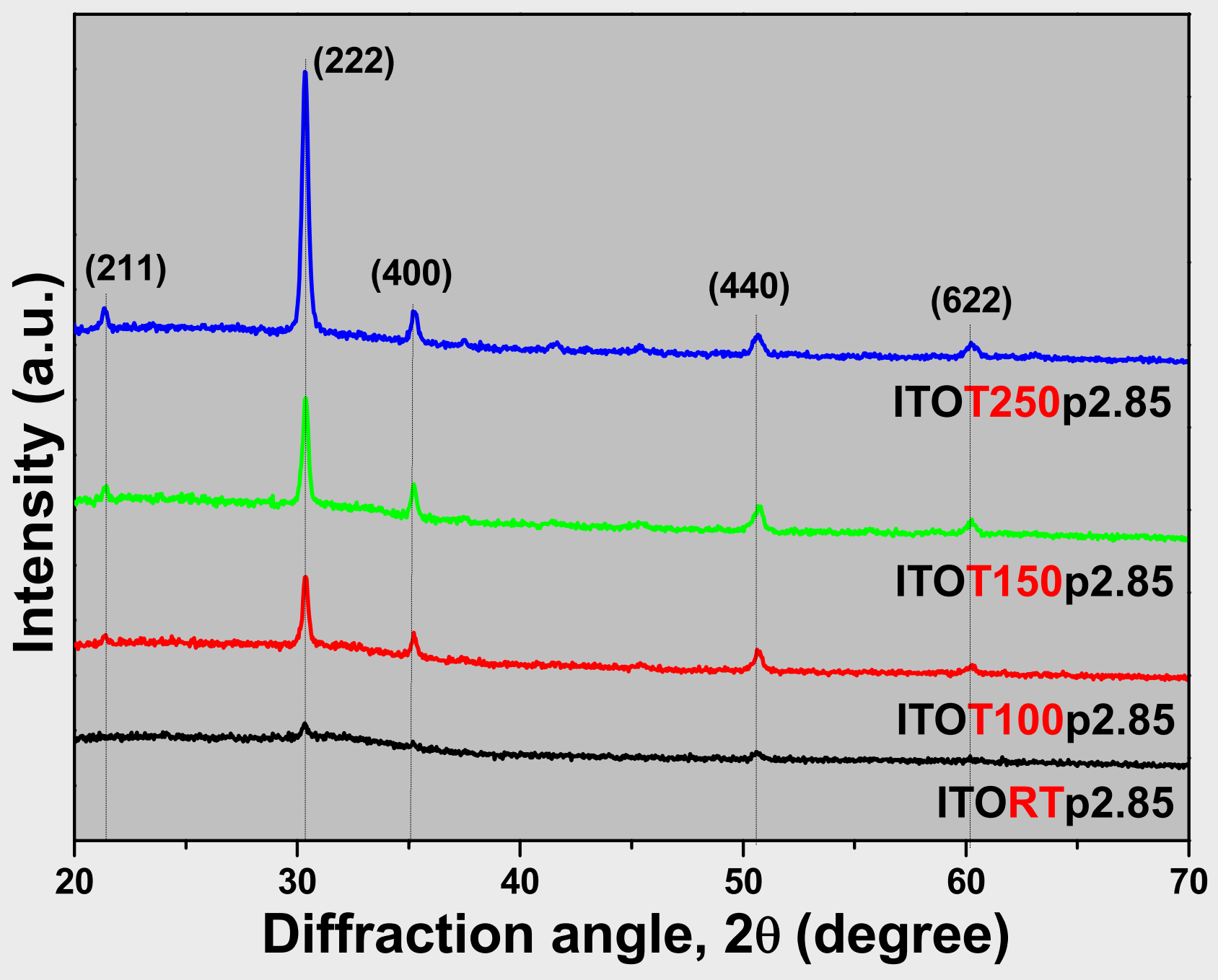


Structural properties

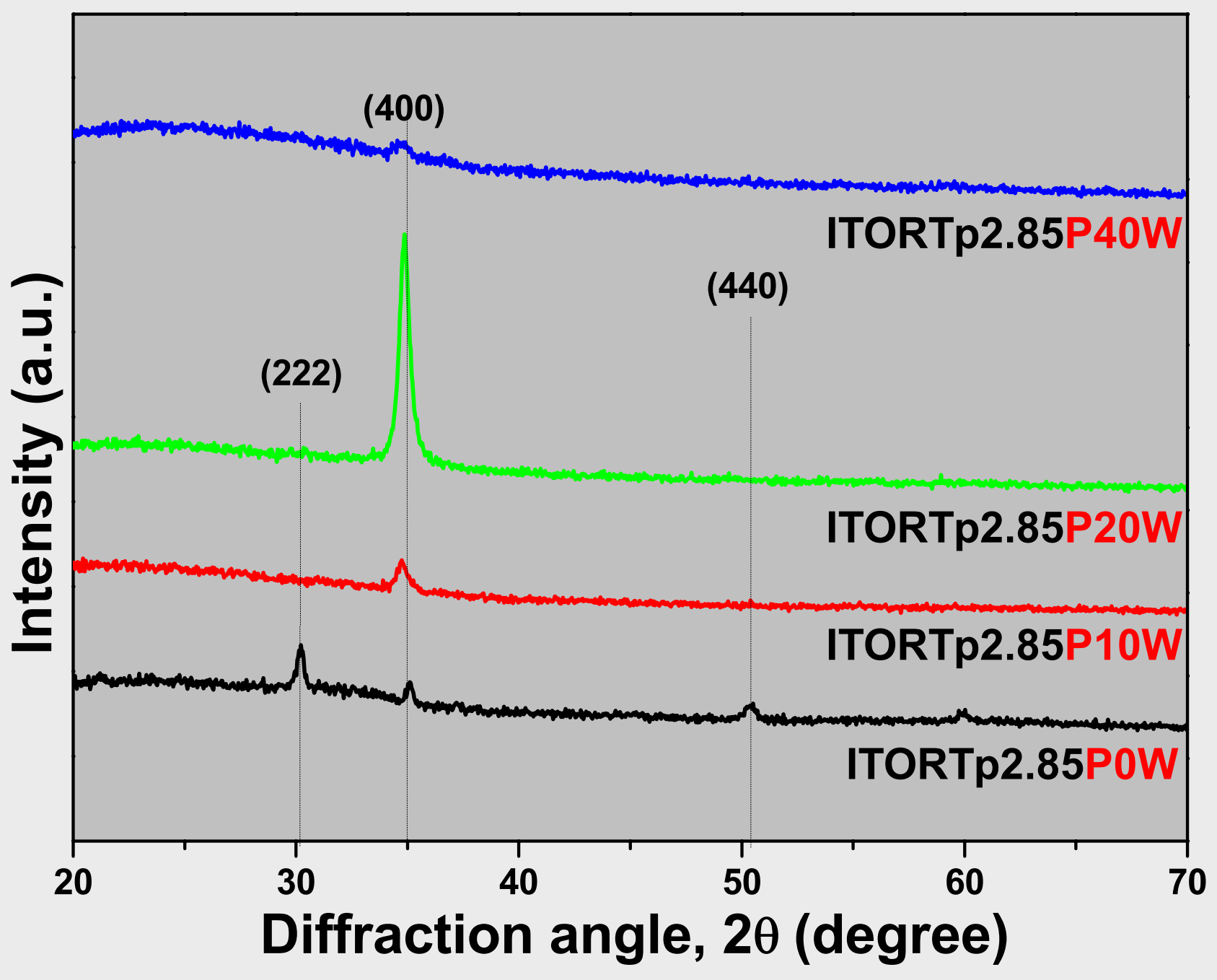
Argon working pressure



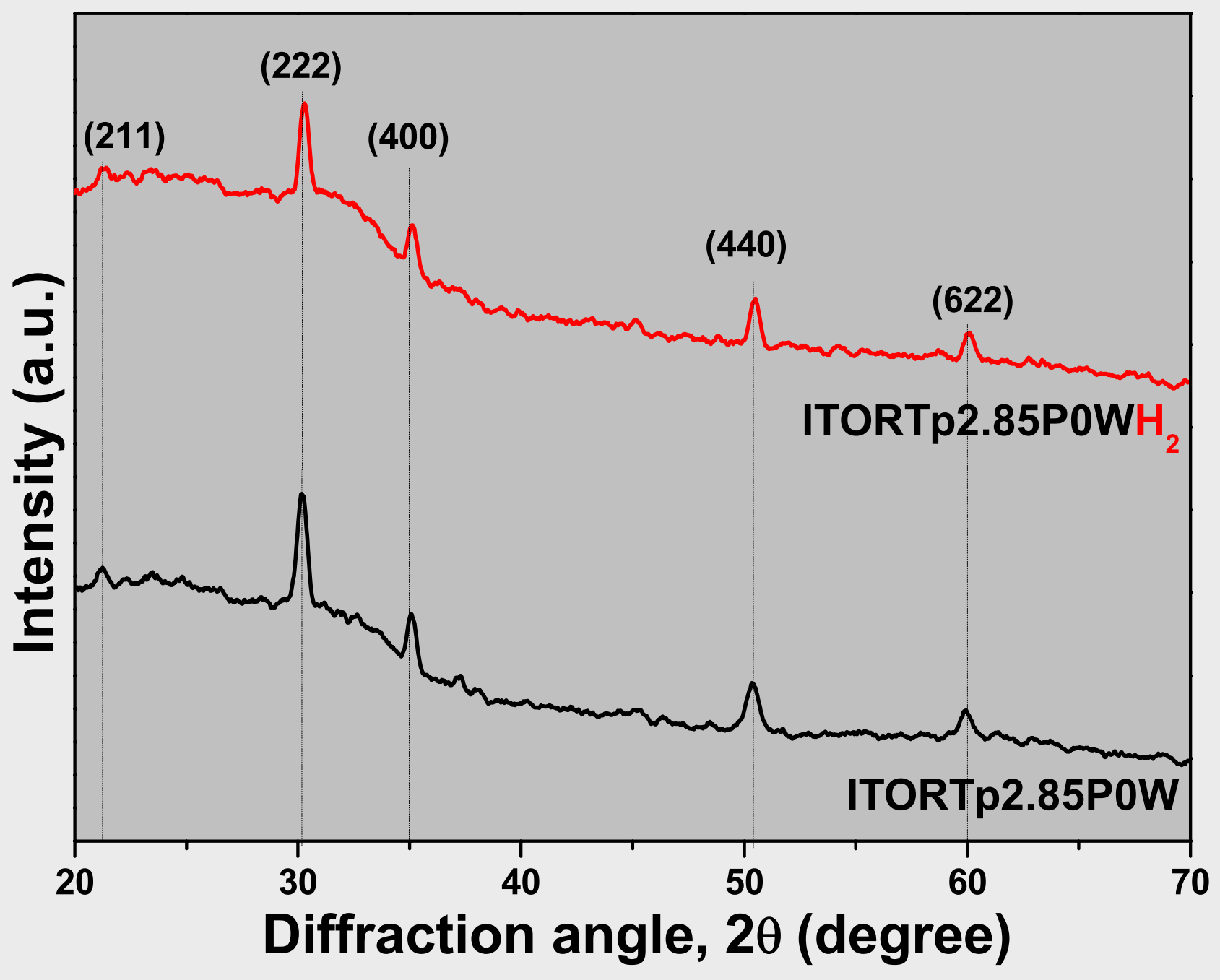
Substrate temperature



Power plasma irradiation



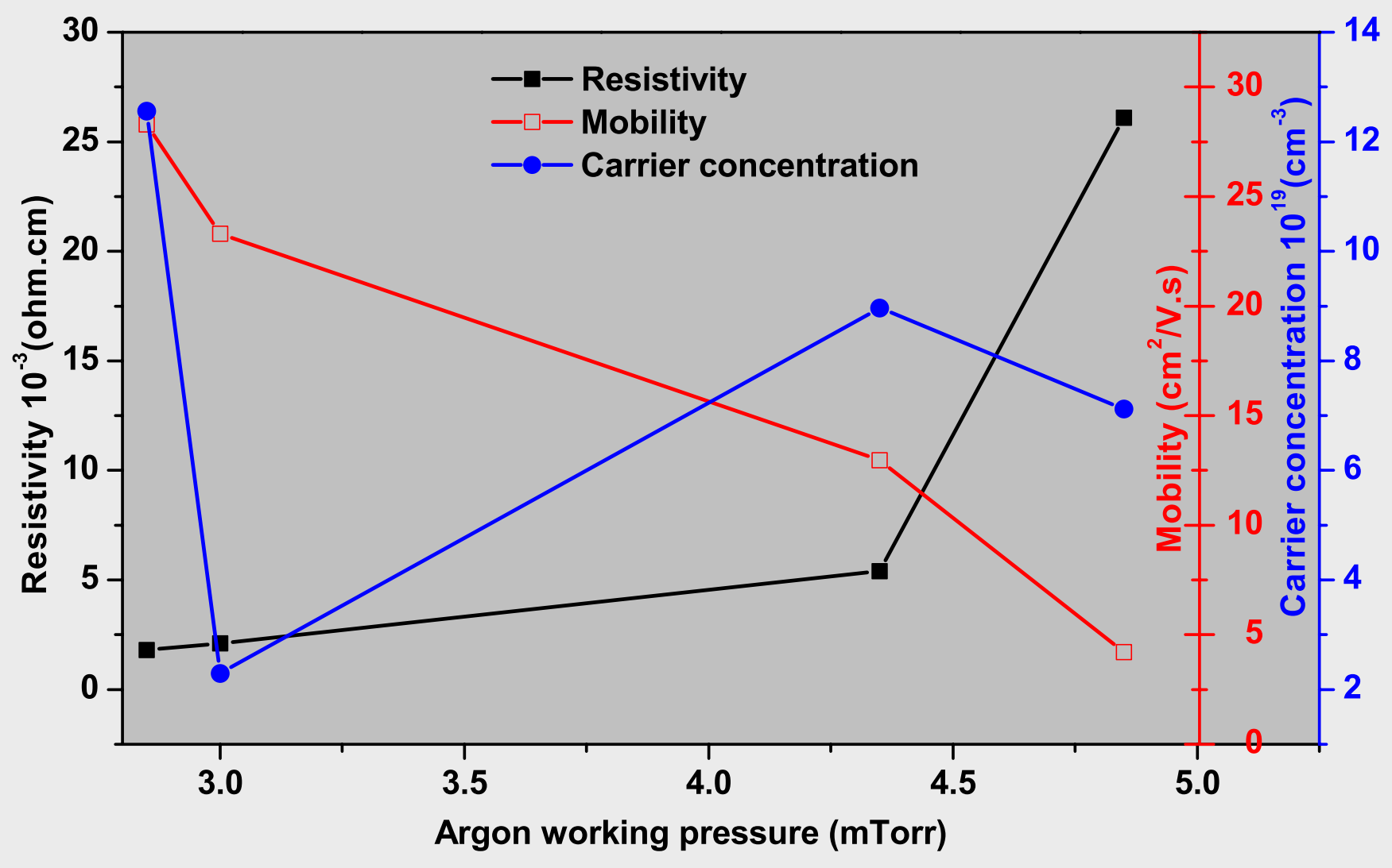
Partial pressure of hydrogen

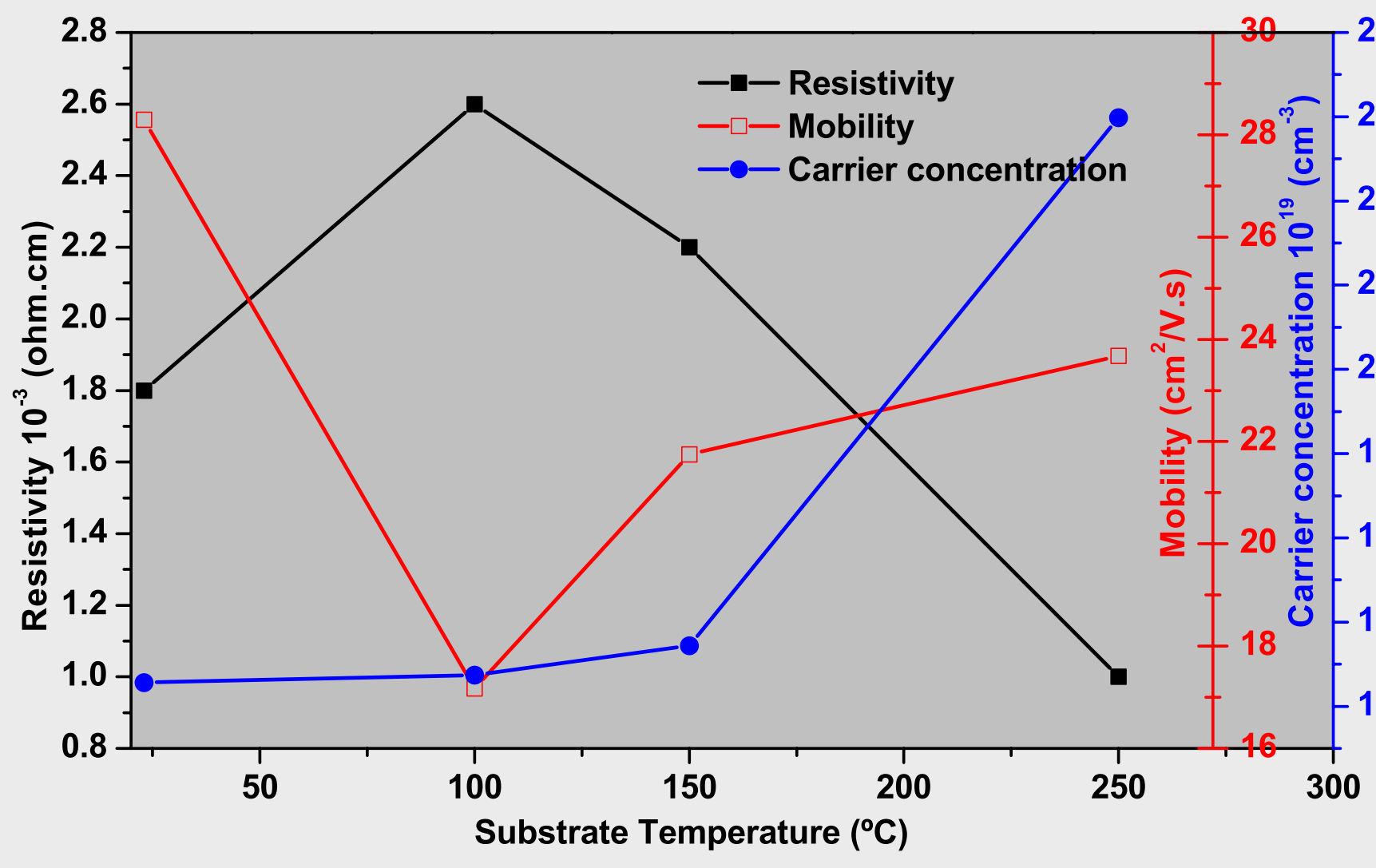


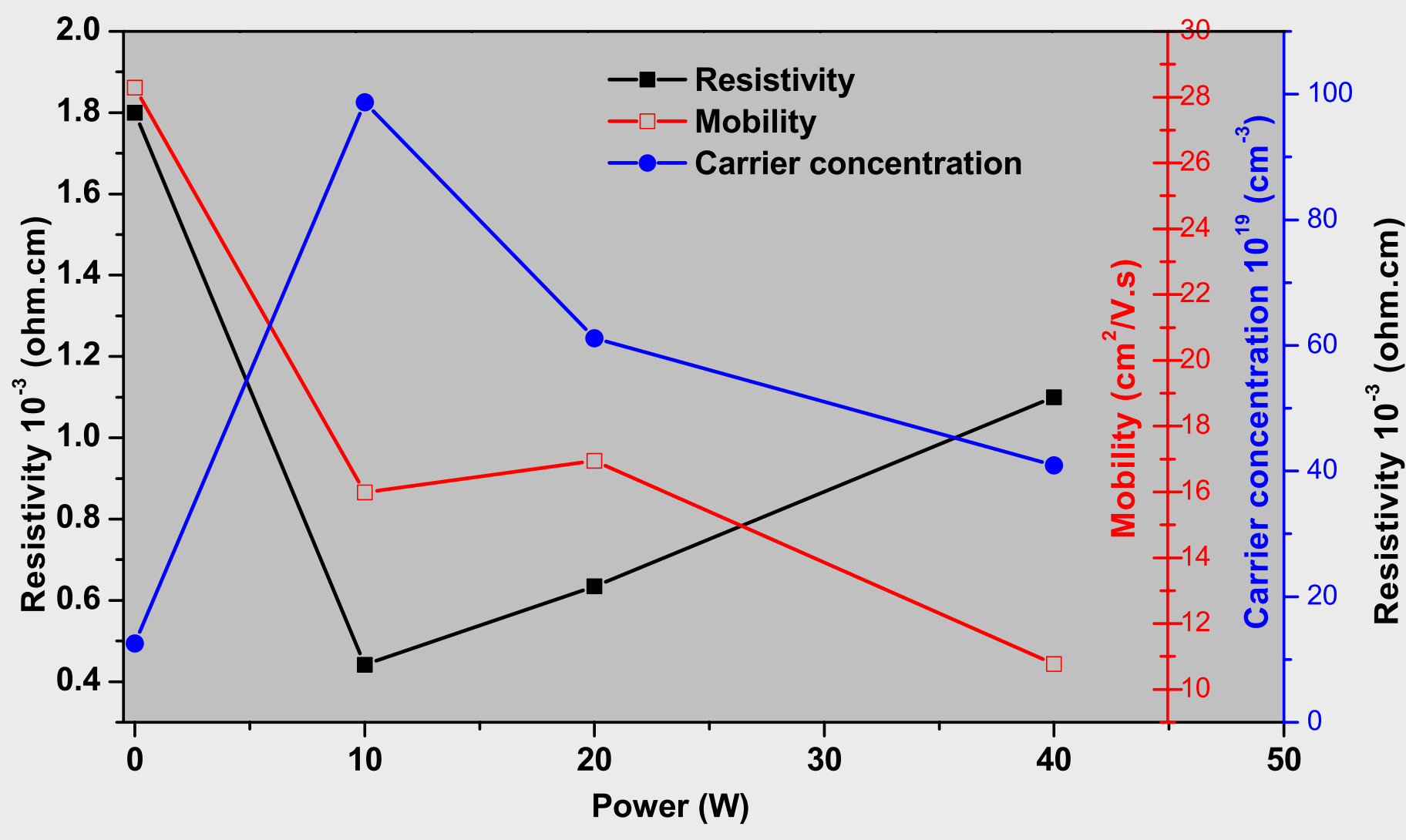
The XRD results show that **decreasing the working pressure** leads to a shift from an **amorphous structure to one with a high degree of crystallinity** and the **increase in the substrate temperature** or **a low power plasma irradiation** of the growing films **improves the crystallinity.** The latter also promotes the growth of films preferentially oriented along the [222] crystal direction. The **addition of 5% of hydrogen** to the working gas **does not substantially change the crystallinity** of the films.

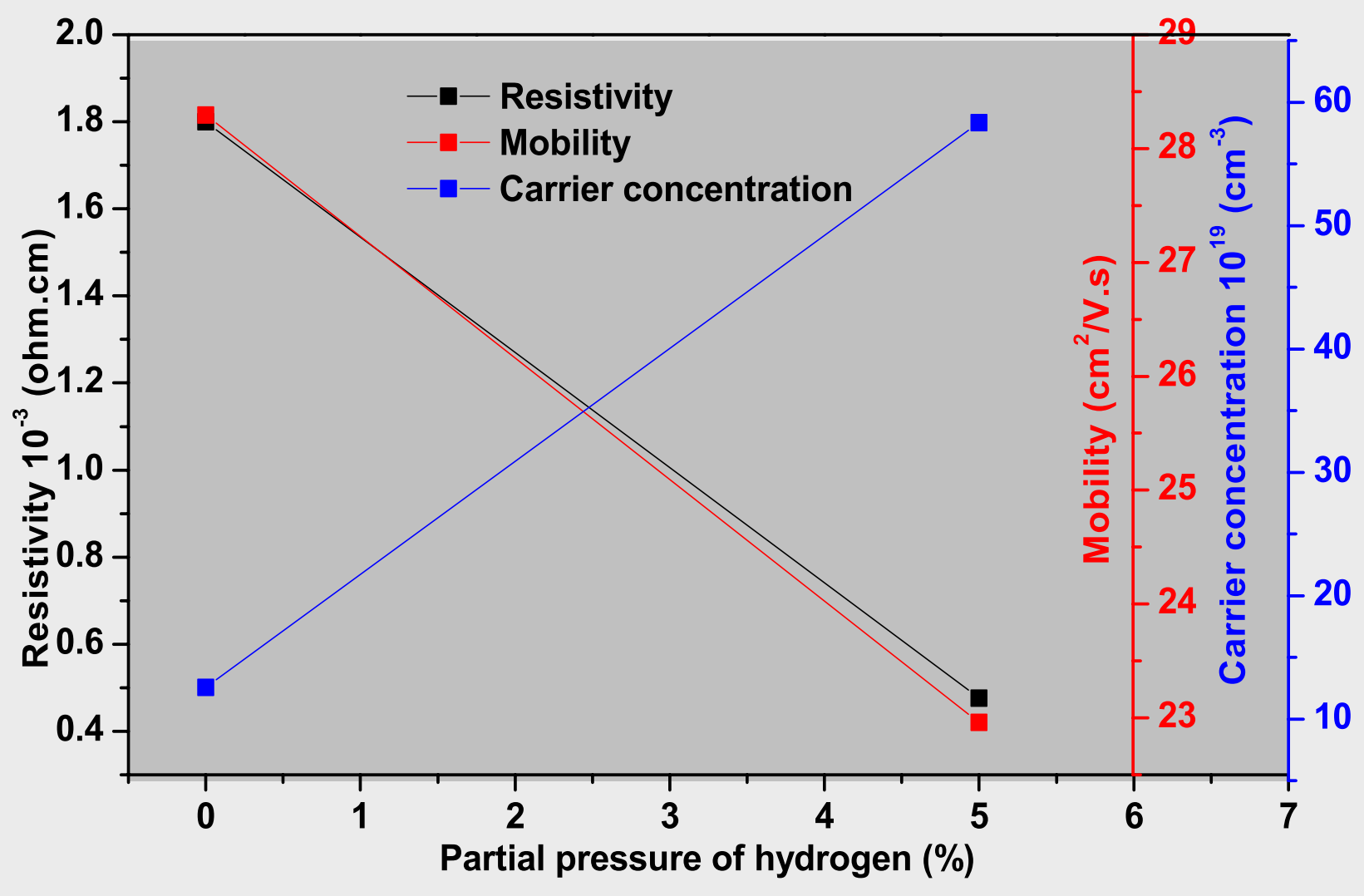
XRD X´Pert MPD Philips PW 3710 system equipped with a CuK source

Electrical properties









These results show that the **resistivity gradually increased** with **increasing argon working pressure** below 4.35 mTorr and then it increased dramatically. This is correlated with a decrease in the carrier concentration and subsequently a decrease in the mobility.

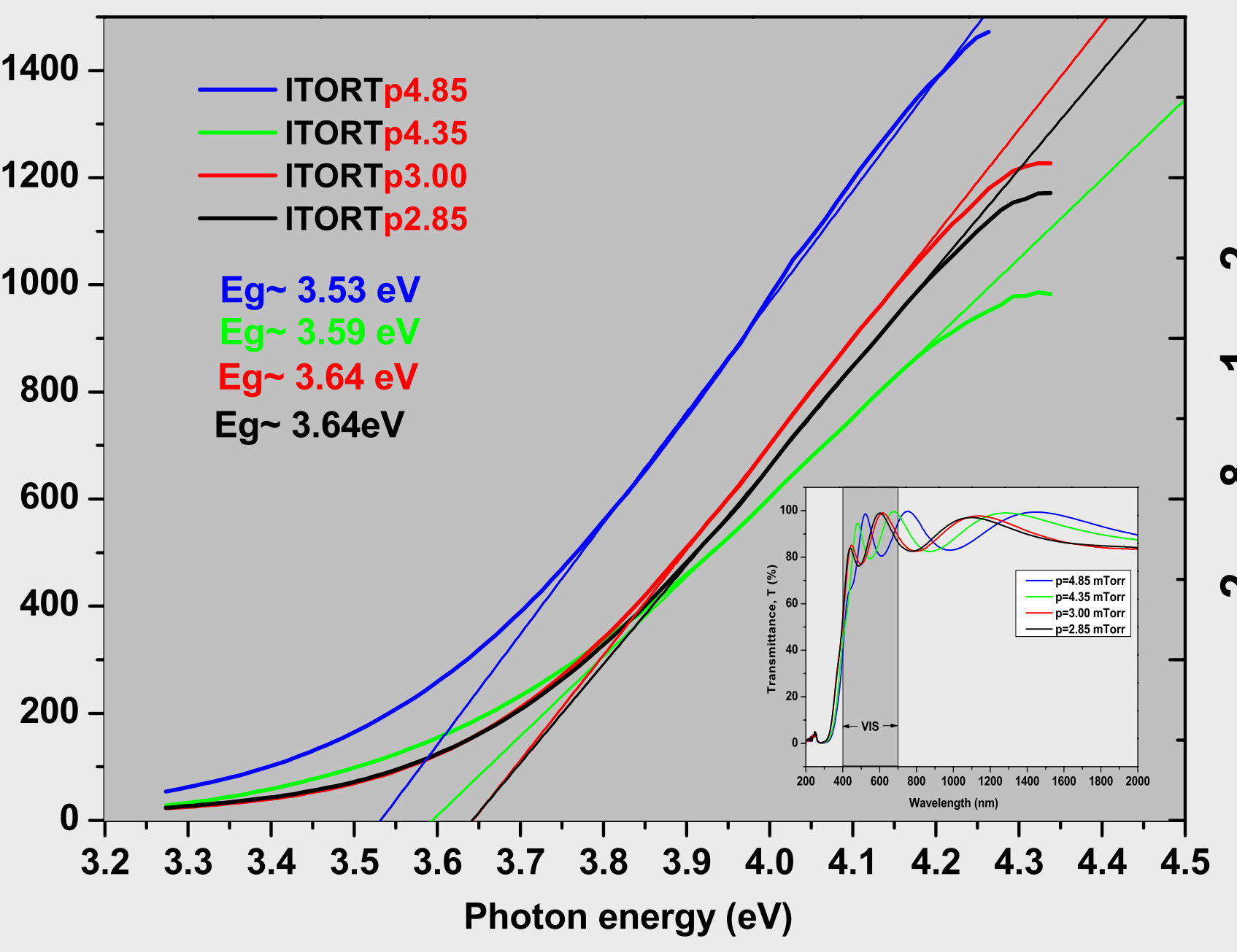
Considering an **increase in the substrate temperature** the resistivity **decreases for temperatures above 100 ºC** due to a increase in the hall mobility and carrier concentration which means that the electron concentration in the film, increase as the substrate temperature is increased.

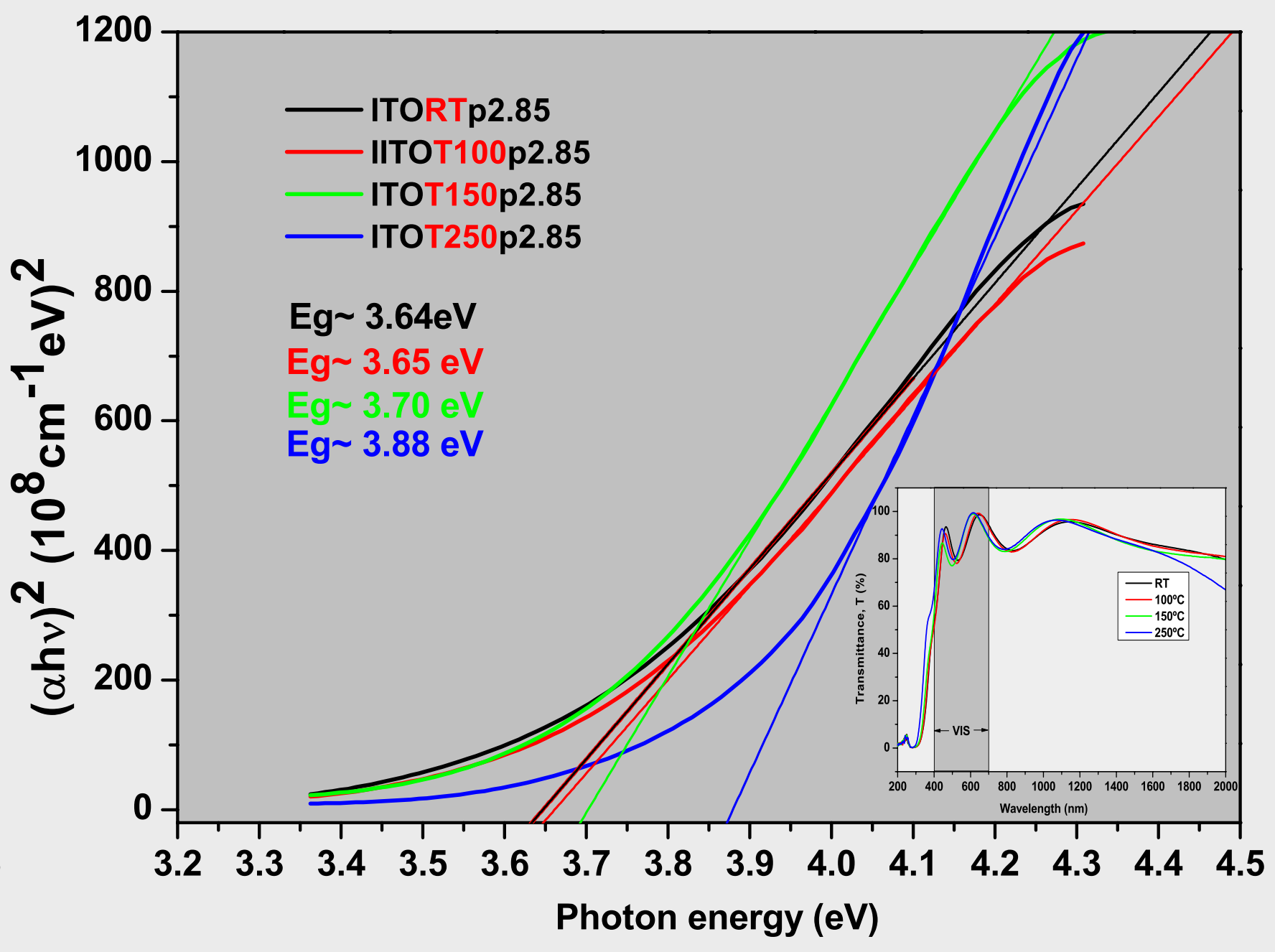
As a function **of power plasma irradiation**, the results suggest that below 10 W, the **resistivity decreases** and **increases substantially** due to a **decrease** in the carrier concentration.

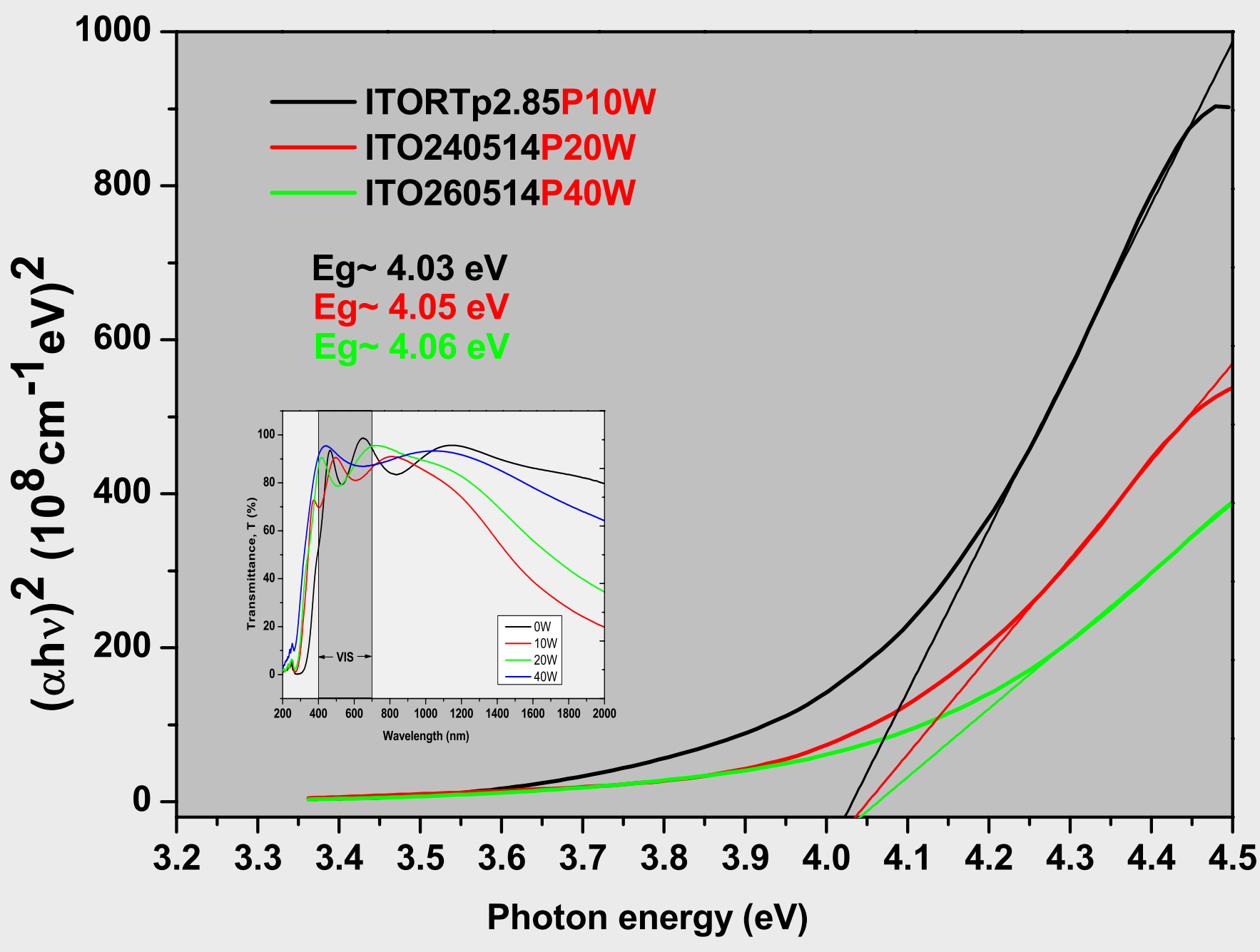
These results show that the **resistivity decrease** with **increasing hydrogen partial pressure**. The hall mobility also decreased. On the contrary, the carrier concentration increased with increasing the hydrogen partial pressure.

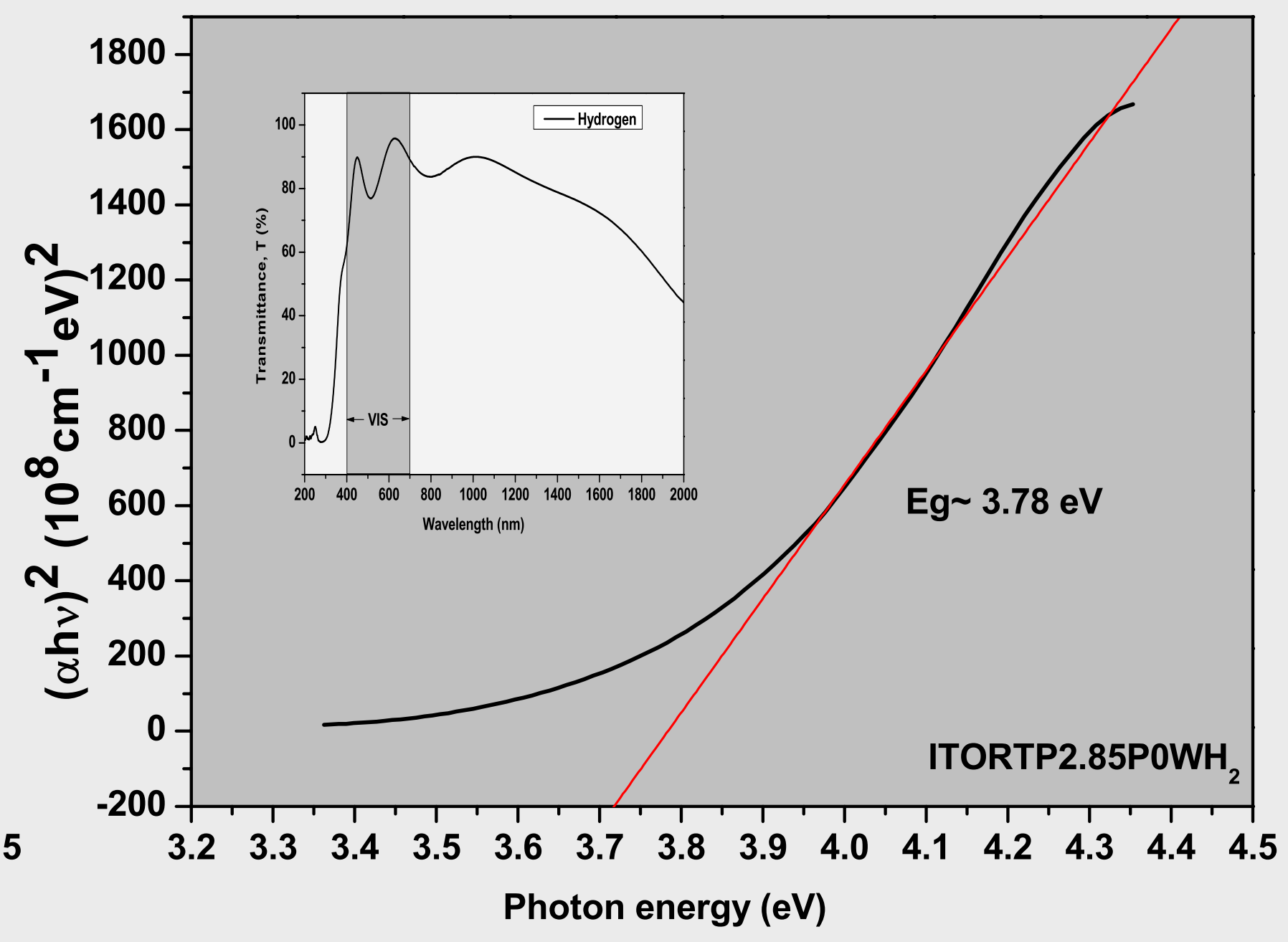
Van der Pauw measurements

Optical properties









Optical measurements were performed, from which the band gap energies were estimated. The absorption edge analysis of the ITO films shows that **increasing the working pressure** leads to a decrease in the band gap and the **increase in the substrate temperature** or **addition of 5% of hydrogen** to the working gas leads to an increase in the band gap. Increasing the **power plasma irradiation** of the growing films the values obtained for the band gap does not change substantially. With increasing the substrate temperature to 250 ºC and decreasing the power plasma irradiation from 40 W to 10 W, the transmittance at wavelengths above 1000 nm decreases. This is because of the free carrier absorption which increases as the carrier concentration increases. Since the majority carriers in ITO are electrons that means that the electron concentration in the film, increase as the substrate temperature is increased.

BAND GAP Shimadzu UV3600 spectrophotometer

CONCLUSIONS

It was found that it is possible to produce ITO films with a thickness of 300 nm and displaying a sheet resistance of 63 Ohms and average transmittance, in the visible range, of about 90% by performing the deposition at low pressure and at room temperature. However, improvements in the sheet resistance up to a factor of 3 were obtained either by increasing the substrate temperature or applying a low power plasma irradiation or adding a partial pressure of hydrogen to the working gas.

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