



# Investigation in Nano III-V ternary $\text{In}_x\text{Ga}_{1-x}\text{P}$ semiconductor materials by chemical vapor deposition

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## Abstract

Phosphides of group III have generated important applications in optoelectronic devices. Principally  $\text{In}_x\text{Ga}_{1-x}\text{P}$  is a novel alloy for the development of solid-state lighting and photovoltaic systems, since it is possible to control its band gap from 2.26 eV to 1.27 eV by simply varying the indium concentration. However during the growth of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  inherent defects are obtained in the material, degrading its optical properties. In this work, the effect of the indium concentration is studied. The results of the optical and structural characterization of a series of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films ( $0 < x < 0.3$ ) deposited by chemical vapor deposition (CVD) are reported.

**Keywords:**  $\text{In}_x\text{Ga}_{1-x}\text{P}$ , Semiconductor; Luminescence and Optoelectronics.

## 1. Introduction

In the development field of new materials, the compound semiconductors continue being an area of great interest and rapid expansion [1]. The ternary semiconductor  $\text{In}_x\text{Ga}_{1-x}\text{P}$  is an important alloy for the development of lighting emitting devices, photovoltaic systems and power electronic, due to the capacity to control the band gap ( $E_g$ ), which varies according to the indium concentration in a range of energies from 2.26 eV to 1.27 eV [2]. Recently some attempts to grow high-quality low-cost  $\text{In}_x\text{Ga}_{1-x}\text{P}$  have been done. One of the techniques that more likely fulfill the requirements is the chemical vapor deposition (CVD). This technique has reduced the cost of the synthesis maintaining an acceptable level in the optoelectronic properties of  $\text{In}_x\text{Ga}_{1-x}\text{P}$ . However, the inherent mismatch between the lattice parameters of the sub-strate (sapphire, SiC, AsGa, Si, LiGaO) [3], [4] and the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  phase, plus the indium incorporation ( $0 < x < 1$ ) limits the growth of the material and degrade the optical and electronic  $\text{In}_x\text{Ga}_{1-x}\text{P}$  properties. [5], [6], [8] in this work spectroscopy UV-VIS and photoluminescence (PL) have been used to study the optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films grown by CVD [9]. Scanning electron microscopy and X-ray diffraction were used to characterize the morphology and structure of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films.

## 2. Experimental

The synthesis of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  multilayer films with an indium composition of  $0 < x < 0.3$  deposited on sapphire at temperature of  $900^\circ\text{C}$  were grown by CVD. These films use the layers of Indium Phosphide and gallium Phosphide (GaP) as buffer and nucleation layer, respectively.

The absorption measurements were made by two different techniques: transmission and diffuse reflectance. The absorption spectra were obtained with an AVANTES spectrometer (AvaSpec 256) in the wavelength range from 180 nm to 1100 nm. The diffuse reflectance was carried out in a UV-visible spectrometer Cary 300. All measurements of absorption were realized at room temperature. The PL measurements were obtained using two different light sources.

The luminescence of the sample is collimated through a spectrometer (SPECTRAPRO 500i) where Signal is quantified. In the second PL measurement, a UV-visible spectrometer, Hitachi Digilab F4500, with xenon lamp as excitation source was utilized. The XRD characterization was carried out in a powder diffractometer (Philips X'pert). The surface of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films was studied in a SEM Jeol 5300.

### 3. Results and discussion

The absorption results obtained by diffuse reflectance were very different in comparison with the transmission measurements. The attenuation zone (including tails) varies in a region of energies from  $\approx 2$  eV to  $\approx 3.3$  eV (620 nm to 375 nm), which are near to the values of energies band gap expected in the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films according to the Vegard's law. The origin of these absorption tails are attributed to the deformation of the crystalline lattice and to the existence of defects such as oxygen impurities and gallium/nitrogen vacancies [10].

The samples with indium composition smaller than 20 atomic percent ( $x < 0.20$ ) showed peaks with a FWHM of  $\approx 500$  meV whereas samples with higher indium composition ( $x > 0.20$ ) presented a broader peaks with a FWHM of  $\approx 1$  eV. Therefore, as well as the composition is increased in the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  phase the band gap energy is modified, showing a red-shift of the PL peak and also broader luminescence in the high indium samples. This behavior has its origin in the deformation of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  lattice (stress due indium incorporation and the formation of a wide range of different  $\text{In}_x\text{Ga}_{1-x}\text{P}$  crystals) and the existence of defects (oxygen impurities and gallium/nitrogen vacancies). Furthermore, in some parts of the spectra some modulations were observed due to the interference effect (Fabry-Perot) caused by internal reflections within the multilayer in  $\text{In}_x\text{Ga}_{1-x}\text{P}$  [11].

Figure 5 shows the XRD results of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films. These diffractograms showed a hexagonal crystalline phase (wurzite) for the films.  $\text{In}_x\text{Ga}_{1-x}\text{P}$  (0002) and GaP (0002) planes are marked. The  $\text{In}_x\text{Ga}_{1-x}\text{P}$  crystalline phase was correlated with GaP phase located in the  $2\mu$  ( $34.56^\circ$ ) position for the crystallographic plane (0002) according to the ICDD crystallographic letters [12]. In Fig. 4b is shown traces of Structural and optical characterization of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  nano-structured grown by chemical

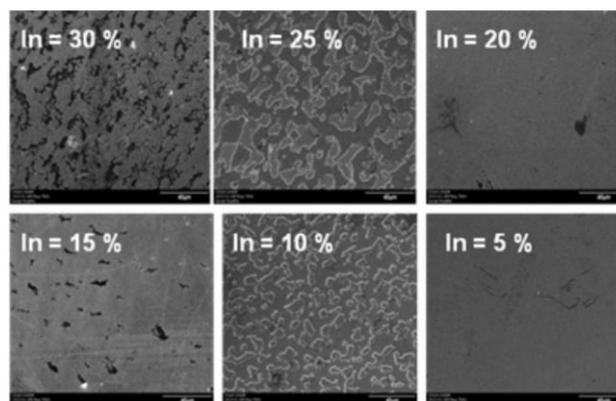


Figure 5 Images of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films surface obtained in the sem. amplification of 750 x and a scale of 40  $\mu\text{m}$ . some impurities that appear in the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films, indium oxide ( $\text{In}_2\text{O}_3$ ), indium phosphide (inp) and indium metallic (clusters). The indium oxide can be related with the emission in the 550 nm region (emission by an indirect transition of 2.09 eV reported by novkovski) [7].

Figure 5 shows SEM images of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films. The surface morphology of the films does not follow a pattern of growth that has a relation with the indium composition. The growth mode of the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films appears to be the Volmer-Weber type. This growth mode is characterized by island formation due to nucleation crystals in diverse crystallographic directions. In this case, the crystals are the structures of columnar type which self-ensemble to form  $\text{In}_x\text{Ga}_{1-x}\text{P}$  islands.

### 4. Conclusions

A series of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films deposited by CVD were characterized. It was found that the  $\text{In}_x\text{Ga}_{1-x}\text{P}$  films with indium composition,  $x < 0.20$  present absorption and emission spectra that follow the Vegard's law.  $\text{In}_x\text{Ga}_{1-x}\text{P}$  with higher content of indium ( $x > 0.20$ ) showed a broad PL emission (FWHM  $\approx 1$  eV) and large tails of absorption. In addition an extrinsic emission in the region of  $\approx 570$  nm ( $\approx 2.17$  eV) was observed in this films. XRD showed the presence (traces) of undesirable phases such as  $\text{In}_2\text{O}_3$ , InN and metallic indium in the films. SEM analysis found the formation of  $\text{In}_x\text{Ga}_{1-x}\text{P}$  islands that affect the smoothness of the film surface.

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