Impact of Chamber Pressure on Indium Doped β-Gallium Oxide

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Abstract

Indium doped β-Ga_2O_3 have been a major research interest for the last few decades due to their importance in bandgap engineering to fabricate high-power electronics, deep UV photonic devices, and nuclear detectors. In this work, we deposited two types of $(In_xGa_{1-x})_2O_3$ alloy with x=25%, samples at 620 °C substrate temperature while varying the partial oxygen chamber pressure from $1×10^{-3}$ to $5×10^{-2}$ torr. The electron mobility analysis of the samples demonstrated significant conductivity for the high oxygen pressure grown Indium doped β-Ga_2O_3 (IGO) compared to the poor carrier mobility of low O_2 pressure grown IGO. Further crystal analysis exhibited polycrystalline behavior for the conductive samples and monoclinic, near single-crystalline behavior for the non-conductive samples. The conductive sample has a mobility of 7.02 cm^2Vs^{-1}, resistivity of 0.05118 Ω-cm, and a carrier concentration of $1.737×10^{19}$ cm^{-3}. According to the bonding analysis, such superior mobility can be attributed to the generation of free electrons due to the reduction of trap sites caused by a higher number of metal-oxygen lattices in the IGO thin film.

Introduction

Importance of Ga_2O_3:

- Ultra-large bandgap
- High breakdown field
- High thermal stability

β-Ga_2O_3 substrates with well-controlled doping enable its applications in optoelectronic devices and high-power electronics [1].

Current challenges:

- Doping difficulty
- High density of unintended electron carriers
- Defects/impurities

Pulsed laser deposition (PLD):

- Substrate temperature
- Deposition rate
- Wide range of materials deposition
- Doping

Optimized properties for the experiment:

- Substrate temperature
- Laser repetition rate
- Growth pressure
- Height between the substrate and target

Characterization:

- X-ray diffraction (XRD)
- X-ray photoelectron spectroscopy (XPS)
- Ellipsometry
- Hall measurements

Experimental setup

Substrate: 2-inch diameter conventional c-plane sapphire.

Target Composition: 25% Indium doped β- Ga_2O_3 $In_{0.25}$ $Ga_{0.75}O$.

Growth Conditions:

- KrF excimer laser (248nm)
- 5000 pulses at a 5Hz repetition rate
- Laser energy : 250mJ
- Target to substrate height: 1.5 inch

Absorption of laser pulse in material:

$Q_{ab} = (1-R)I_0e^{-\alpha L}$

R = Reflection co-efficient

α = Attenuation co-efficient

L= Source to target distance

I_0 = Intensity of laser power

D = Diffusivity of the material

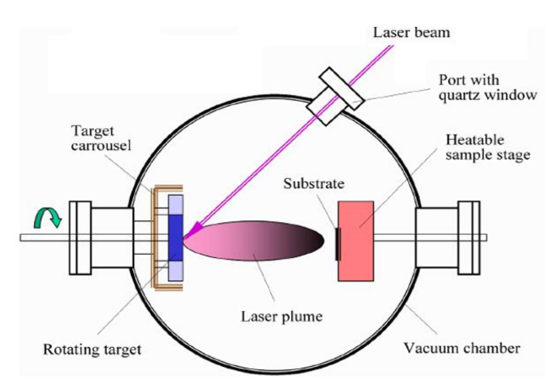

Fig 1. Working principal of pulsed laser deposition (PLD).

Results and Discussions

XRD data analysis

Wavelength λ = 1.540562 Å

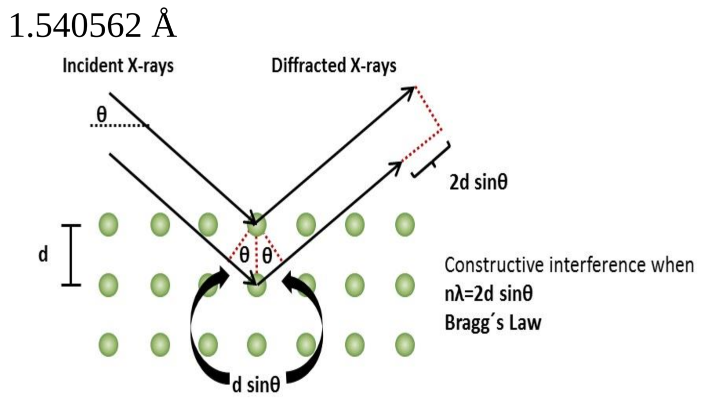

Fig 2. Working principal of X-Ray diffraction.

- ❑ IGO thin film exhibits monoclinic peaks at 18.88°, 38.16°, 58.95°, and 81.74°, which correspond to the reflection planes of (-201), (-402), (-603), and (-804), respectively.
- ❑ The peaks of the sapphire substrate at 20.51°, 41.44° and 64.12° correspond to the planes of (001), (006), and (009), respectively.
- ❑ We observed an additional peak at 30.64° for high oxygen pressure, which corresponds to the cubic (222) plane.
- ❑ But this diffraction peak is not prominent at low oxygen pressure.

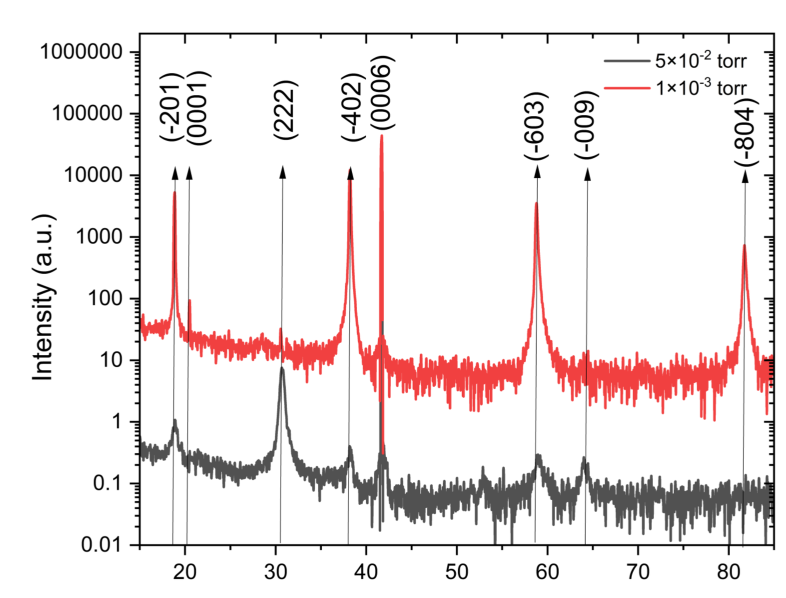

Fig 3: XRD patterns for IGO films at different oxygen pressure of $5×10^{-2}$ and $1×10^{-3}$ torr.

XPS data analysis

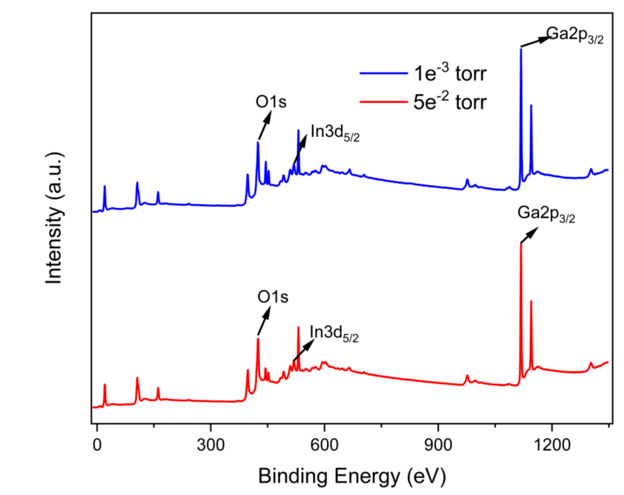

Fig 4: The survey spectrum of X-ray photoelectron spectroscopy (XPS) of IGO thin film.

- ❖ The peak of the O 1s, located at 529.78eV, denotes the metal oxide (M-O) lattices.
- ❖ The metal hydroxide (M-OH) or C-O bond for surface contamination is represented by the peak at 531.9 eV.
- ❖ The intensity of metal oxide (M-O) signal is much higher in $5×10^{-2}$ torr than in $1×10^{-3}$ torr.
- ❖ Metal oxygen lattices can help to reduce trap sites, which can lead to a large concentration of free electrons [3].
- ❖ This may occur at the high growth pressure because more oxygen is introduced into the chamber, and the mean free path of the ablated plumes in the chamber becomes shorter which causes more intense interaction.

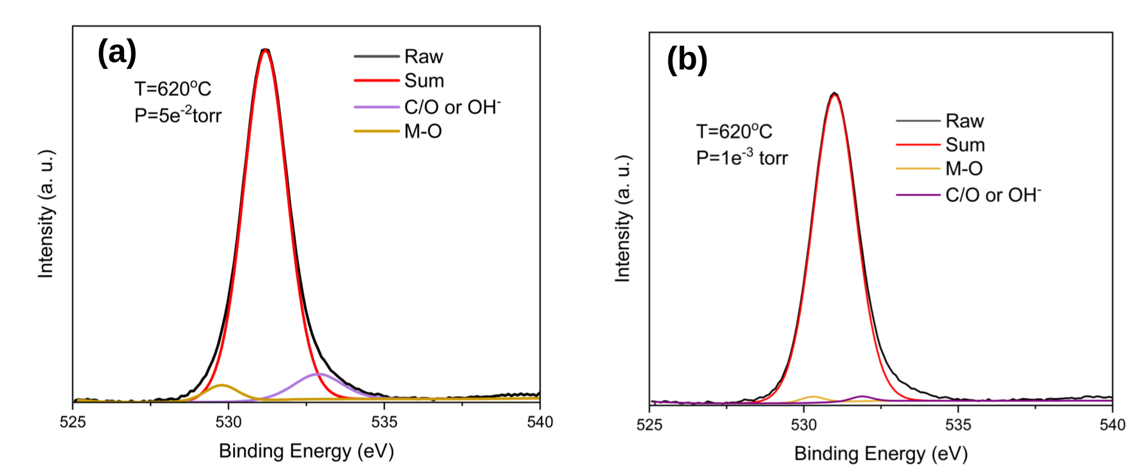

Fig. 5: XPS spectra of O 1s core level for IGO films grown at (a) oxygen pressure of $5×10^{-2}$ torr, (b) $1×10^{-3}$ torr.

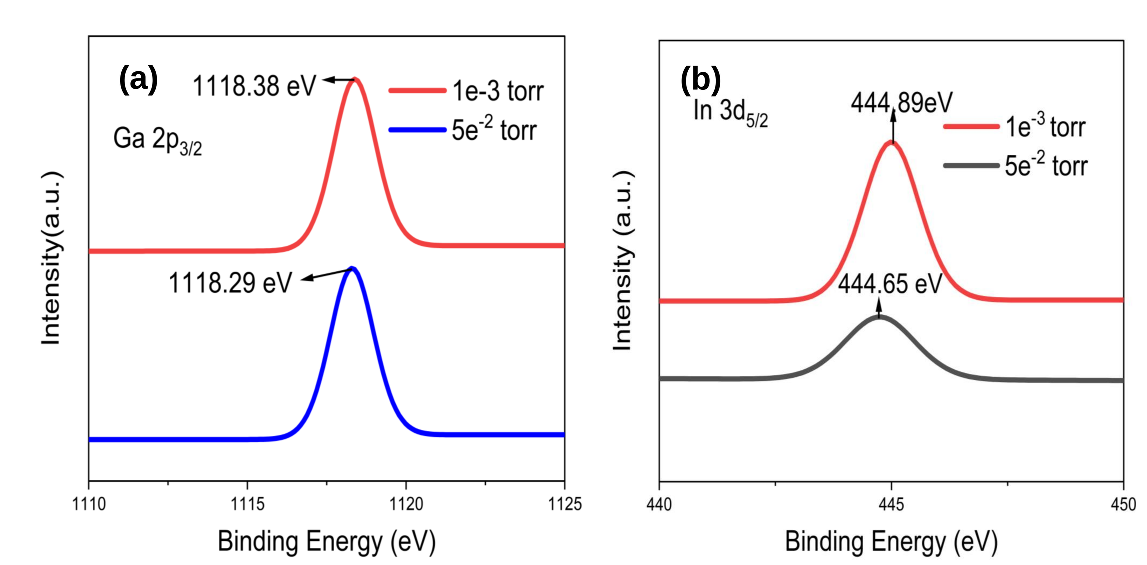

Fig. 6: XPS spectra of (a) $Ga2P_{3/2}$, and (b) $In3d_{5/2}$ for IGO films grown at oxygen pressure of $5×10^{-2}$ torr, and $1×10^{-3}$ torr.

- ➢ It is found that at $5×10^{-2}$ torr oxygen pressure, the intensity of binding energy is slightly shifted for both $Ga2P_{3/2}$ and $In3d_{5/2}$ spectrum.
- ➢ Moreover, we observed a peak at 531.9 eV in O1s spectrum. So, at higher pressure there is a possibility to have oxygen that operate as shallow donors and generate free electrons.

Hall Measurements

Table 1: Hall measurement result for conductive sample grown at $5×10^{-2}$ torr.

Parameters	Value
Resistivity	0.05118 Ω-cm
Carrier concentration	$1.737×10^{19}$ cm^{-3}
Mobility	7.02 cm^2Vs^{-1}
Sheet resistance	$4.27×10^{14}$ Ω/□

We observed that, increasing the chamber pressure from $1×10^{-3}$ to $5×10^{-2}$ torr results in a sufficient carrier concentration of 1.7 × 10^{19} cm^{-3}. For this high concentration, we got a significant Hall mobility of 7.02 cm^2Vs^{-1} and a reasonable resistivity of 0.05118 Ω-cm.

Thickness measurements by Ellipsometry

Table 2: The thickness of the samples.

Sample with specific pressure	Thickness (nm)
$5e^{-2}$ torr	250
$1e^{-3}$ torr	210

Conclusion

- ✓ 25% IGO with high pressure exhibits good conductivity whereas IGO grown at low oxygen pressure exhibits poor carrier mobility.
- ✓ Comparative surface analysis of these two samples were performed to investigate these phenomenon.
- ✓ Further studies on structural-property correlation of IGO thin films will enable us to fabricate efficient next-generation HEMT devices.

References

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