

Rapid thermal low pressure metalorganic chemical vapor deposition of $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ films using tertiarybutylarsine

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Rapid thermal low pressure metalorganic chemical vapor deposition (RT-LPMOCVD) of lattice-matched epitaxial $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ films onto InP substrates was successfully performed using tertiarybutylarsine (TBA) and growth temperatures in the range of 500–550 °C. The undoped, featureless films were grown with a low V:III ratio of 2, and exhibited an excellent morphology with a minimum backscattering yield (χ_{min}) of 3.6% and narrow x-ray full width at half-maximum peak of 28 arcsec of the InGaAs layer on InP, reflecting a lattice mismatch of 0.02%. These films presented good electrical properties, with hole mobility values of about 75 $\text{cm}^2/\text{V S}$ measured at 300 K for nominally undoped layers with $p < 5 \times 10^{15} \text{ cm}^{-3}$.

The metalorganic chemical vapor deposition (MOCVD) technique has been widely used to grow photonic and electronic devices, using either arsine (AsH_3) and phosphine (PH_3) gases, or tertiarybutylarsine (TBA) and tertiarybutylphosphine (TBP) metalorganics, as the group V precursors for the reaction.^{1–5} Among others, the major advantages of the TBA and TBP over the hydrides are: their being less toxic and hazardous, incorporating only little amount of carbon through the reaction, minimal vapor phase reaction with group III sources, and higher decomposition rates at lower temperatures. These characteristics make the metalorganic group V precursors very attractive alternatives for the epitaxial crystal growth of a variety of semiconductor devices. In addition to reduction of both the deposition temperature and the V/III ratio as a result of introducing the TBA and TBP, one can further reduce the thermal budget of the growth reaction by executing the RT-LPMOCVD technique. This technique has been demonstrated successfully for the growth of semiconductors such as GaAs and AlGaAs on GaAs substrates^{6,7} and recently undoped and doped InP thin films on InP substrates.⁸

In this letter, we report on the epitaxial growth of a single layer undoped $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ on InP substrates by means of the RT-LPMOCVD technique. InGaAs layers were grown on Fe-doped, semi-insulating (SI) (100) InP substrates using an A.G. Associates Heat-pulse CVD-800TM system.⁹ The horizontal quartz chamber, heated from both sides by two arrays of six high power halogen-tungsten lamps each, is 10 in. long, with an elliptic cross section shape 6 in. wide and 1 in. high.

Prior to loading the wafers into the reactor load lock, the InP substrates were cleaned sequentially with chloroform, acetone, and methanol, followed by a sequence of de-ionized water, H_2SO_4 , de-ionized water, and finally blown dry with filtered N_2 .

Trimethylindium (TMIn), tertiarybutylarsine (TBA), and trimethylgallium, (TMGa) were used as the indium, arsenic, and gallium sources, respectively. Hydrogen, purified by a palladium diffuser, was used as the carrier gas for the indium and gallium metalorganic precursors.

The optimum growth conditions were identified through a set of growth runs, through which the key growth parameters were modified. The temperature was varied in the range of 450–550 °C, pressure in the range of 1–5 Torr, growth duration in the range of 30 s–10 min and metalorganic flow rates in the range of 1–50 standard cubic centimeter per minute (sccm). The best results were achieved flowing 1 sccm of Ga, 10 sccm of In, and 20 sccm of As into the chamber, keeping the metalorganic bubbles at temperatures of 0, 50, and 0 °C, respectively.

Rutherford back scattering (RBS), double crystal x-ray diffractometry, secondary ion mass spectroscopy (SIMS), and Auger electron spectroscopy (AES), were used to characterize the InGaAs film quality and properties. For the SIMS, a Cs^+ primary beam was used and positive secondary molecular ions of MCs^+ , where M is the element of interest, were detected. Room-temperature Hall measurements (Hg-In alloyed contacts) were used to obtain the sample sheet resistance and mobility.

Figure 1 shows a SIMS depth profile of an $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ (about 150 nm thick) layer that was grown by means of RT-LPMOCVD at a temperature of 525 °C

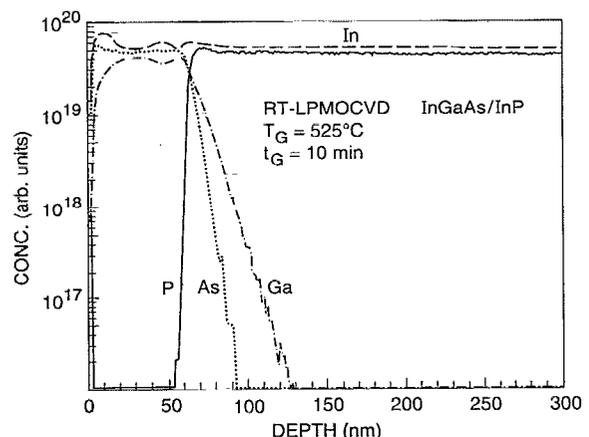


FIG. 1. SIMS depth profile of undoped RT-LPMOCVD $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ layer grown on Si-InP (100) substrate at 525 °C for 10 min.

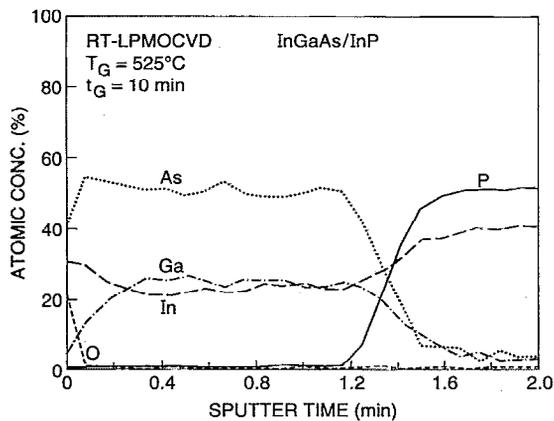


FIG. 2. AES depth profile of undoped RT-LPMOCVD $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ layer grown on Si-InP (100 substrate at 525 °C for 10 min).

and pressure of 4.5 Torr for 10 min, flowing TMI, TMGa, and TBA into the chamber, at rates of 100, 1.5, and 20 sccm, respectively. The InGaAs/InP interface was found to be abrupt with some slight intermixing of Ga into the InP, or was verified by means of transmission electron microscopy.

The AES data, provided in Fig. 2, supports the SIMS observation. A good stoichiometry and a uniform distribution of the elements in the InGaAs layer were observed, with a negligible amount of O and C contaminants incorporated in the film. SIMS analyses did not detect either O or C in the InGaAs above the background sensitivity of the technique ($\sim 10^{17} \text{ cm}^{-3}$) and confirms the low background pressure and cleanliness of the chamber.

RBS and channeling analysis were performed to determine the composition, thickness, and crystal quality of the InGaAs films. Figure 3 provides an RBS channeling spectrum of the $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ film. Ion channeling was used to estimate the fraction amount of disordered or displaced atoms, resulting in an approximate minimum yield (χ_{\min}) of 3.6%, which is essentially identical to the measured

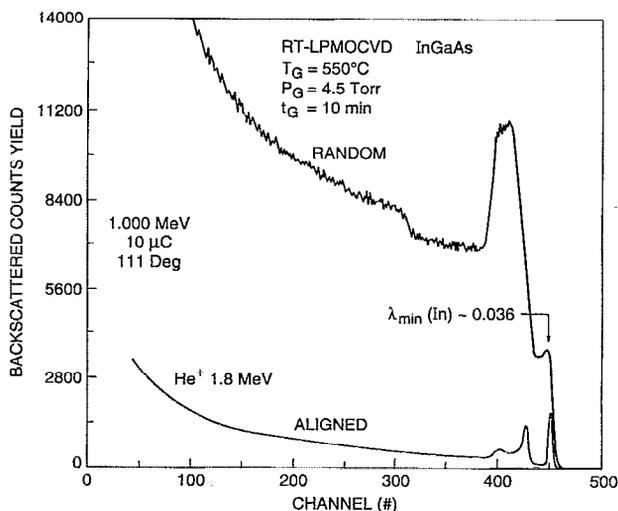


FIG. 3. RBS spectrum of undoped $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ layer grown at 550 °C for 10 min showing both the random and aligned scans.

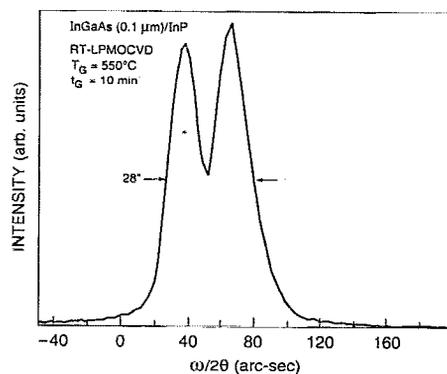


FIG. 4. Double crystal x-ray diffractometry of undoped RT-LPMOCVD $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ layer grown on Si-InP substrate at 550 °C for 10 min.

value of a bare InP wafer. In evaluating the χ_{\min} , the ratio between the integrated backscattering yield obtained in the channeled and random directions was used, including events before the surface peak and within the epitaxial layer. The film chemical composition and thickness values revealed similar values to the AES data, reported above. At higher deposition temperatures the samples displayed poorer crystallinity and were not lattice matched to the substrate.

Figure 4 shows the double crystal x-ray diffractometry spectrum taken from a sample of 0.5 μm layer of $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ that was grown on InP. This examination suggested also a high quality InGaAs epitaxial grown layer, reflected in the narrow semiconductor peak. The full width at half-maximum (FWHM) InGaAs peak was measured to be 28 arcsec, the peak splittings reveal an InGaAs lattice mismatch in the InP substrate of about 0.02%.

A strong dependence of the InGaAs film quality and film thickness, on the RT-LPMOCVD temperature was observed, as is shown in Fig. 5. The optimum growth temperature of 550 °C yielded both the lower film disorder and the highest growth rate at given metalorganic flow ratio and overall chamber pressure.

The undoped films were always *p* type with hole densities $< 5 \times 10^{15} \text{ cm}^{-3}$ and 300 K carrier mobilities of $\sim 75 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. The source of the residual *p*-type doping is as yet unidentified, but is thought to be Zn background in one of our metalorganic sources. Low temperature photoluminescence confirmed the presence of Zn acceptor transitions in the InGaAs, with some correlation between the intensity of the lines and the metalorganic flow rates.

In conclusion, we have demonstrated the RT-LPMOCVD of high quality epitaxial lattice matched $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ layer onto InP substrates. These layers are essential in the complete structure definition of various electronic and optoelectronic devices, mainly used for a device cap contacting layers, to stimulate the ohmic performance of electrical contacts to the devices. The ability to grow InGaAs layer by means of RT-LPMOCVD technique is essential in enabling a complete single wafer-

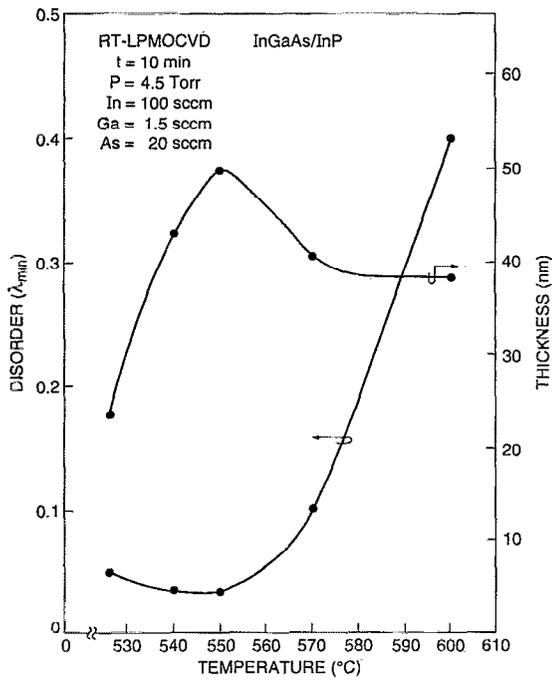


FIG. 5. $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ RT-LPMOCVD film disorder and thickness as a function of the growth temperature.

integrated processing (SWIP) of InP-based devices, by means of an in-site cluster-tool approach, which can now be added to the already demonstrated RT-LPMOCVD of SiO_2 , InP, W, and TiN_x layers¹⁰ ad modules in SWIP processing.

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