Growth of InP epitaxial layers by rapid thermal low pressure metalorganic chemical vapor deposition, using tertiarybutylphosphine

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High-quality InP layers with low impurity backgrounds have been grown by means of the rapid thermal low pressure metalorganic chemical vapor deposition technique, using tertiarybutylphosphine as the phosphorus source. The films were grown at a P:In ratio of 75 or higher, temperatures between 500 and 525 °C, a pressure of 2 Torr and growth rates as high as 2 nm/s. The undoped films were defect-free with exhibited featureless morphologies, and minimum backscattering yields (Xmin) as low as 3.1%, measured by ion channeling. The electrical quality of the films ($N_d=2.5\times 10^{16}$ cm^{-3}, $\mu=4200$ cm^2/V s) was also excellent.

After developing the processes for rapid thermal, low pressure metalorganic chemical vapor deposition (RT-LPMOCVD) of dielectric films,[1,2] and conducting layers,[3,4] it is necessary to grow InP layers by the same technique in order to demonstrate the ability of processing complete InP-based optoelectronic devices by means of the single wafer integrated process (SWIP), using RT-LPMOCVD modules.[5]

The growth of III-V semiconductors by means of RT-LPMOCVD, earlier realized successfully for GaAs and AlGaAs on GaAs substrates,[6–8] uses rapid and precise changes in the substrate temperature, driven by switching of halogen-tungsten lamps, to control layer growth rather than applying the gas phase switching technique, normally used in the standard MOCVD technique.

The ability to control the growth of abrupt interfaces is advantageous for currently used InP-based devices for optical communication systems, such as multilayer heterostructures and multiquantum well distributed feedback (MQW-DFB) lasers. In view of this need, the RT-LMPOCVD technique looks even more attractive, carrying the potential of a control to the monolayer level for *P*-based compounds, as a result of the rapid elevation and reduction of the wafer temperature above and below the reactive temperature.

In this letter, we provide the first demonstration of the epitaxial growth of a single layer of high quality, undoped InP by means of the RT-LPMOCVD technique, onto an InP substrate.

InP layers were grown on Fe-doped, semi-insulating (100)InP substrates by the RT-LPMOCVD technique, using an A. G. Associates Heatpulse CVD-800™ System. This is a low pressure, load-locked, horizontal, and laminar flow reactor, heated by two sets of high power halogen-tungsten lamps (12 lamps of 1.5 kW each) and is capable of processing a single wafer, under inert, hazardous, or corrosive ambients.[2]

Prior to growth, the InP substrates were cleaned with chloroform-acetone-methanol, followed by a sequence of de-ionized water, H_2SO_4, de-ionized water and finally blown dry with filtered N_2, and immediately loaded into the reactor. Trimethylindium (TMIn) and tertiarybutylphosphine (TBP) have been used as the indium and phosphorus sources, respectively. Hydrogen, purified by a palladium diffuser, was used as the carrier gas for the metalorganic precursors.

We investigated a range of values for the key growth parameters. The optimum growth conditions in our particular system were found to be at temperatures of 500–525 °C, a pressure of 2 Torr, for durations of up to 10 min at growth rates of up to 2 nm/s. The optimum TBP flow rate was 75 standard cubic centimeter per minute (sccm), with a TMIn flow rate of 1 sccm.

Rutherford backscattering (RBS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), double crystal x-ray diffractometry, photoluminescence (PL), and secondary ion mass spectrometry (SIMS) were used to characterize the InP film quality and properties. Room-temperature Hall measurements (Hg-In alloyed contacts) were used to obtain the sample sheet resistance and mobility. The RBS was performed on a 1.8 MeV Van de Graaf generator using a He^+ ion beam. The PL measurements were obtained using an Ar^+ ion laser, with the sample held at room temperature. The SIMS measurements were performed on a Cameca IMS-4f system, using a Cs^+ ion beam. The impurity concentrations were derived from comparison with ion-influenced InP standards.

Figure 1 shows a TEM plan-view [Fig. 1(a)] and cross section [Fig. 1(b)] of a 100 nm undoped InP layer grown by RT-LPMOCVD on a SI-InP substrate. An excellent interface quality, and defect-free structure are apparent from the TEM analysis. The featureless layers were measured to have n-type background doping levels of $N_d \leqslant 2.5\times 10^{16}$ cm^{-3}, and 300 K mobilities of 4200 cm^2/V s. Luminescence intensities typical of layers grown by conventional MOCVD were also measured. The excellent electrical and optical properties of the InP is indicative of the high quality layer grown by the RT-LPMOCVD technique.

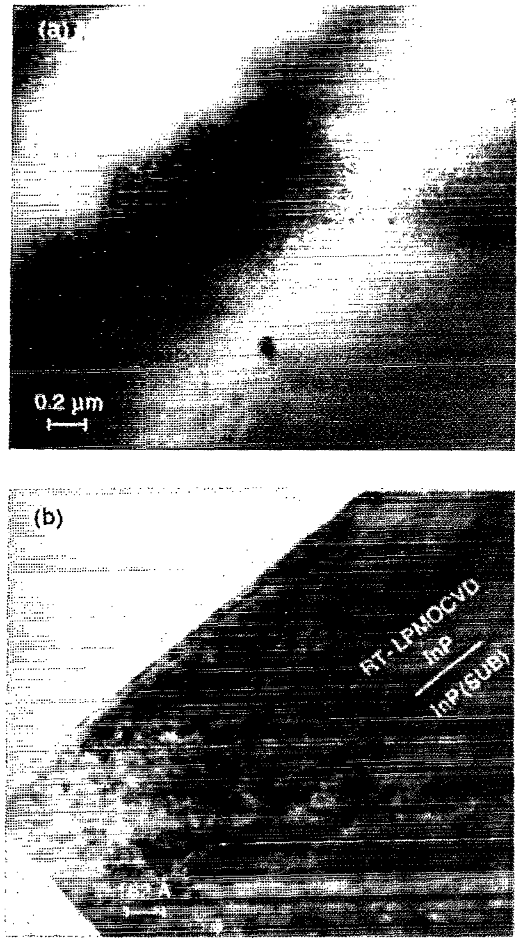

FIG. 1. Bright-field TEM micrographs of an undoped RT-LPMOCVD InP layer grown on SI-InP substrate, at 500 °C for 10 min.

The InP layers were examined by double crystal x-ray diffractometry, yielding well defined, narrow single peaks, as shown in Fig. 2, also suggesting a high quality InP epitaxial layer growth. The full width at half-maximum (FWHM) of the InP peak was measured to be 20 arcsec. Good crystallinity was also observed by the RBS analysis. Figure 3 shows an ion channeling spectra (He^+, 1.8 MeV) of a 0.2 μm thick InP epitaxial layer grown at 500 °C for 10

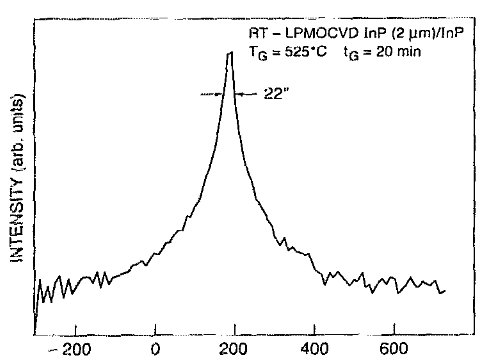

FIG. 2. Double crystal x-ray diffractometry of an undoped RT-LPMOCVD InP layer grown on SI-InP substrate at 500 °C for 10 min.

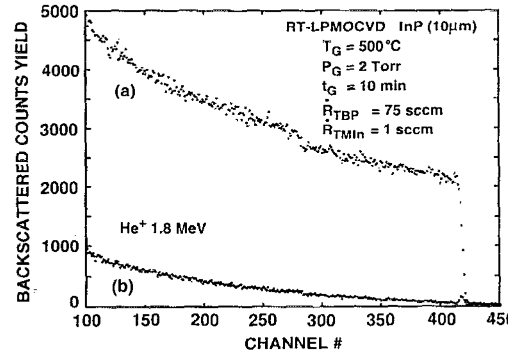

FIG. 3. RBS of an undoped RT-LPMOCVD InP layer grown at 500 °C for 10 min, both at rotating direction (a) and along ⟨100⟩ lattice axis (b).

min both at rotating random direction and along the ⟨100⟩ lattice axis. These spectra, which were found to be typical for layers grown at temperatures above 500 °C, show no evidence of extended crystal defects and reveal a minimum yield (Xmin) of 3.1%, which is essentially identical to the measured 3% value of a bare InP wafer. In evaluating Xmin, 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. Higher Xmin values, up to 11.2%, were measured in layers grown at lower temperatures, below 500 °C, indicating a lower degree of crystalline quality of the InP layer.

The concentrations of oxygen and carbon impurities in the RT-LPMOCVD InP film were analyzed by SIMS, and found to be 1.5×10^{17} cm^{-3} and 9×10^{17} cm^{-3}, respectively, as is shown in Fig. 4. The carbon concentration is relatively high for InP, and generally C behaves as a donor in this material. However, our electrical measurements show low n-type conductivity and hence the C is not all electrically active. Since we do not see any evidence for defect clusters, at least to the resolution of TEM, it is not clear as to the nature of this carbon contamination. It is, however, recognized that by using the TBP metalorganic

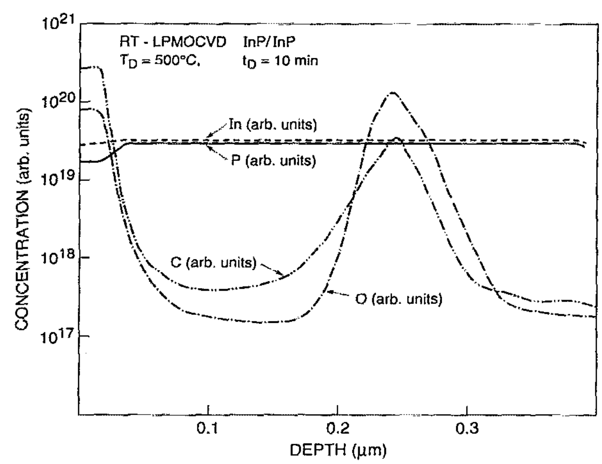

FIG. 4. SIMS depth profile of an undoped RT-LPMOCVD InP layer grown onto SI-InP substrate at 500 °C for 10 min.

source a higher amount of C is in-coupled into the film than by using phosphine, as the P source. Thus, in order to verify this claim it will be essential to grow an InP layer by means of RT-LPMOCVD using phosphine, which is at this point beyond the scope of this study.

Layers grown at temperatures below 500 °C often showed relatively rough morphologies, correlating with the poorer crystallinity measured by ion channeling and also did not luminesce at room temperature.

In conclusion, we have demonstrated for the first time RT-LPMOCVD of high quality epitaxial InP layers onto InP substrates. These layers are characterized with microstructural, morphology, and electrical properties which are as good or similar to the widely reported InP layers grown by the standard MOCVD process. This study provides another needed technology to realize a complete single wafer integrated processing of InP-based laser devices, added to the RT-LPMOCVD of SiO_2 layers and blanket and selective deposition of conducting layers. Further work will address n- and p-type doping of the epitaxial InP layer, and growth of ternary and quarternary materials.

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