THE APPLICATION OF GAS FOIL ROTATION FOR GROWTH OF InP-BASED III-V COMPOUND SEMICONDUCTORS IN A HORIZONTAL LP MOVPE REACTOR

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Abstract: In this paper we will discuss for the first time the use of the new "gas foil rotation" technology for growth in a low pressure reactor. InP, GaInAs and GaInAsP layers grown on 2" substrates applying this substrate rotation show film thickness variations less than 2% over the entire wafer. Also resistivity measurements on doped binary layers showed variations below 2%. The lattice mismatch variation of ternary and quaternary layers was smaller than $5x10^{-4}$. The electrical properties of GaInAs and InP as residual carrier concentration and electron mobility in undoped layers were identical to those measured on reference layers grown in the same reactor on a static susceptor. Growth parameters had not to be modified when using this technique.

1. Introduction

The manufacturing of state of the art III-V compound semiconductor devices requires highly reliable epitaxial reactors. The sophisticated architecture of device structures needs well developed epitaxial processes capable for growth of thin films with abrupt interfaces. Production aspects force reactor development to high throughput as well as increasing wafer area.

LP MOPVE processes in horizontal reactors developed for high quality III-V semiconductor materials have already proven to produce structures on industrial fabrication level on 2" and 3" substrates (GaAs as well as InP). Device quality obtained from these processes is excellent and yield (related to wafer homogeneity) is on a level sufficient for the most applications [1, 2].

Further improvement of wafer uniformity (especially in multiwafer reactors) can be achieved by using the technique of substrate rotation to overcome gas phase depletion problems and geometrical non uniformities. Techniques for the practical realization of such systems using a mechanical drive have been described earlier [3]. However, the technical solution for substrate rotation, using mechanical feed throughs was only applied to a small, laboratory scale system.

A relatively new approach to this engineering problem is the use of a technique where the wafer carrier is levitating on a gas foil. The same gas stream, which is causing the levitation provides the momentum for wafer rotation ("gas foil rotation") [4, 5].

Originally the gas foil rotation reactor was developed for growth of GaAs/AlGaAs heterostructures with high requirements on film homogeneities such as HEMTs [5]. The reactor was designed for 7 wafers rotating in planetary motion in a radial-symmetric horizontal flow system. This technology has been applied in this study to a well proven horizontal low pressure reactor.

The gas foil rotation assembly does not require mechanical drive parts, feed through etc., and thus does not generate particles; it can easily replace the standard static susceptor with only minor changes in the gas supply system.

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2. Experimental

The commercial reactor is a standard type LP MOVPE system with a horizontal laminar flow process chamber. The reactor is capable to grow on 2" or 3" wafers and is equipped with sources for materials in the Al – Ga – In – As – P system. The growth chamber has already been discussed in various publications [1, 2].

The application of gas foil rotation made it necessary to design a modified type of susceptor; no additional mechanical modifications had to be made to the growth chamber. The susceptor consists of the graphite body with a central depression. A flat graphite plate with cylindrical shape and smooth surface finish is placed into this depression. A system of circularly shaped grooves at the bottom of the depres – sion allows introduction of gas in such a way that the plate is floating on a gas foil. Since the gas is forced to flow with a circular component, the plate with the substrate is put into rotational motion. A circular groove at the outer rim and a draining channel collect the gas and lead it to the exhaust. By doing so, it is avoided, that the driving gas is released into the growth atmosphere above the substrate and changes its composition.

The driving gas is purified H_2 which is also used as carrier gas. The amount of H_2 to achieve a rotating speed of 2 s^{-1} (1 to 2 revolutions per monolayer) as used during all experiments in this study (deposition temperature 640 ^{o}C; total pressure 20 mbar) is around 8 – 12 ml/min. This flow is much smaller than the total gas flow in the reactor (6 slm).

At optimized dimensions of the graphite parts the growth parameters adjusted for binary, ternary and quaternary InP based compounds do not differ from those providing good material quality on static susceptors in the same reactor.

3. Results and Discussion

As mentioned above the gas foil rotation system has been developed initially for AlGaAs/GaAs growth [1]. The results obtained on 2" wafer QW structures were drastically improved compared to most multiwafer reactor outputs. A homogeneity of sheet resistivity of 1.5% over 7x2" wafers was achieved.

The application of the technique on InP based compounds including ternaries and quaternaries is described below. The binary InP has been investigated first. GaInAs/InP heterostructures have been grown on 2" wafers and were evaluated by surface profiling after selectively etching grid structures in the InP. The variation of InP film thickness on a 2" wafer has been plotted in Fig. 1.

The determined film thickness variation is less than 1.5% over most of the area. A few data points revealing a variation of more than 1.5% seem to be isolated and are probably caused by measurement errors. A strictly rotational or any other sym – metrical pattern of film thickness seems not to appear.

The above InP layer has been doped intentionally with Si by injecting SiH_4 into the reactor during growth. The carrier concentration has been determined by the van der Pauw method taking into account the film thickness evaluation from Fig. 1. Fig. 2 shows the variation of carrier concentration over the 2" wafer. As can be seen, the variation is less than 1.5×10^{15} cm^{-3} over the entire area (average absolute concentration 3.36×10^{16} cm^{-3}). The carrier mobility was 3.500 cm^2/Vs at 300 K.

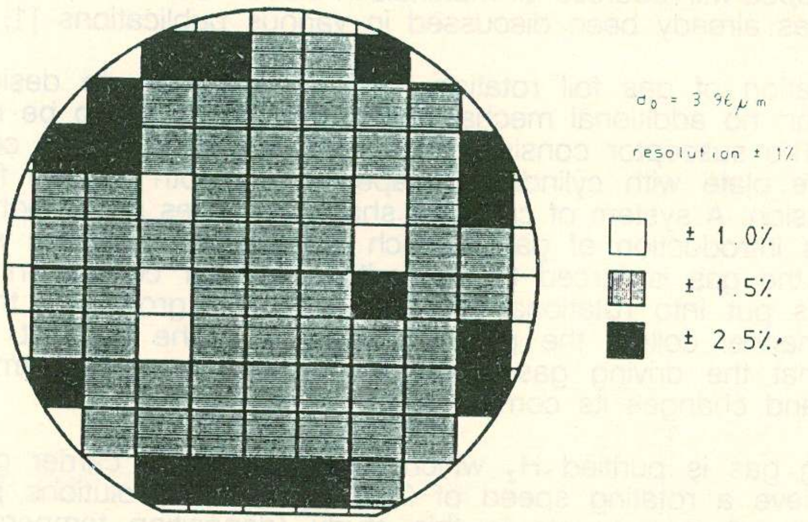

Fig. 1: Variation of InP film thickness over a 2" wafer

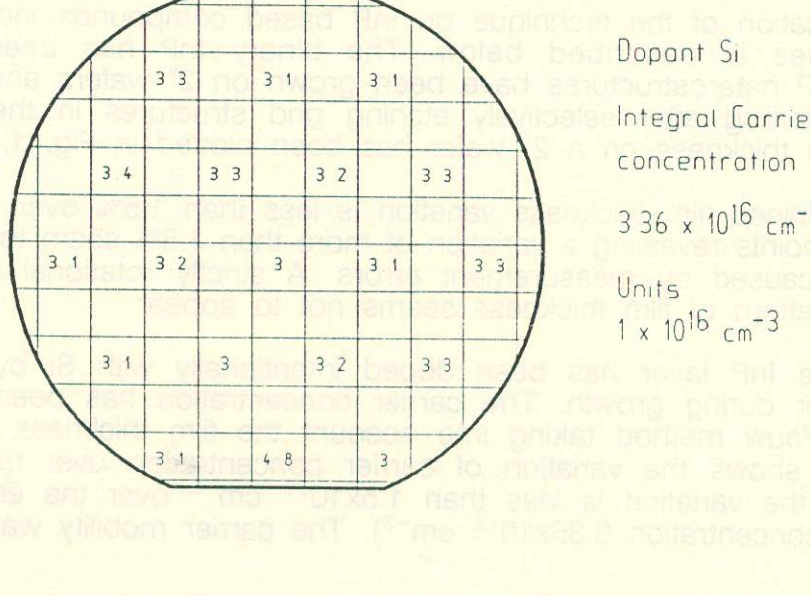

Fig. 2: Variation of donor concentration in InP over a 2" wafer

The possibility to grow GàlnAs was one of the requirements to prepare the structure for InP film thickness evaluation by selective etching. The position of the wafer in the reactor and all parameters adjusted for growth have been similar to that usually used on the static susceptor. Fig. 3 and Fig. 4 show the variation of GaInAs film thickness over a 2" wafer and the distribution of lattice mismatch along two perpendicular lines.

As can be seen from the diagrams, the film thickness variation (+/−1%) is even lower than in case of the InP. The lattice mismatch variation is lower than +/− 1×10^{-4} over most of the 2" wafer area and only slightly larger near the wafer edges. Also electrical data of the undoped layers ($n_{300} = 2 \times 10^{15}\ cm^{-3}$ and $\mu_{300} = 10.000\ cm^2/Vs$) are comparable to results usually obtained from this process on a stationary susceptor.

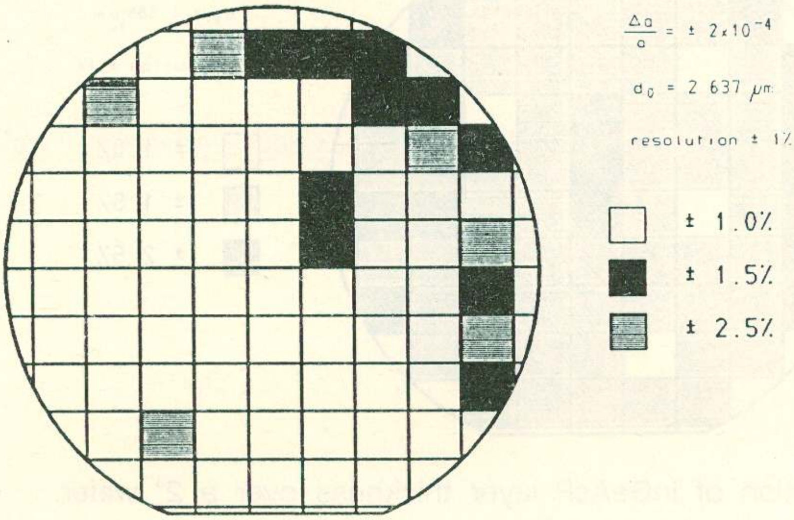

Fig. 3: Variation of GaInAs film thickness over a 2" wafer

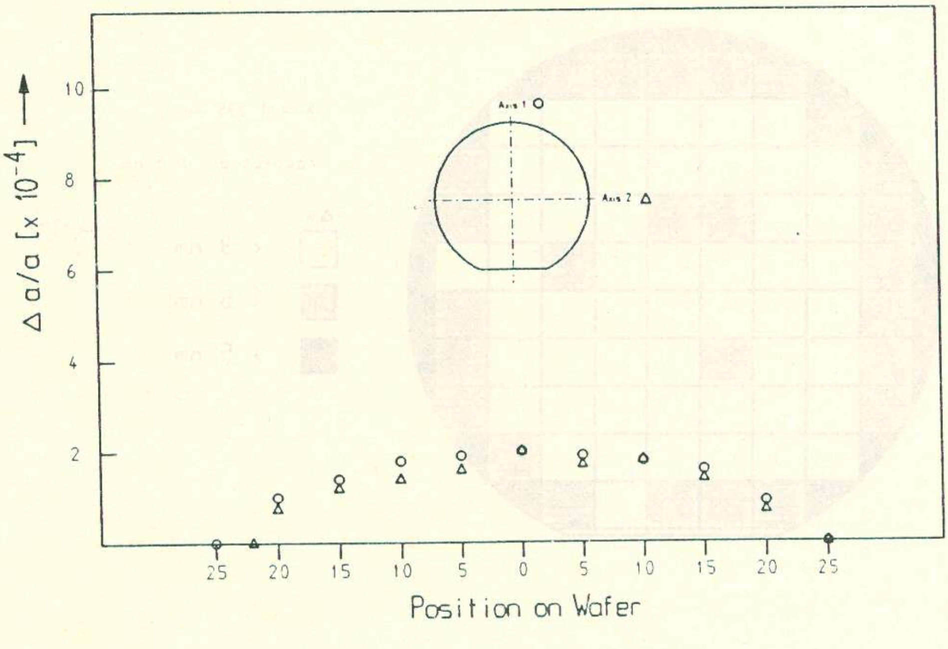

Fig. 4: Variation of GaInAs lattice mismatch over a 2" wafer

Finally the quaternary material has been investigated. For this example the 1.3 µm quaternary composition has been chosen. This composition, used for waveguide and laser production, is more sensitive to variations of the growth process parameters than the longer wavelength material. Fig. 5 and Fig. 6 show the film thickness and an emission wavelength variation over a 2" wafer area of GaInAsP grown lattice matched to InP.

The thickness homogeneity shows a similar pattern as achieved for the InP. The variation of PL wavelength indicates the same rotational symmetry which could be further improved by slightly modifying the dimensions of the system.

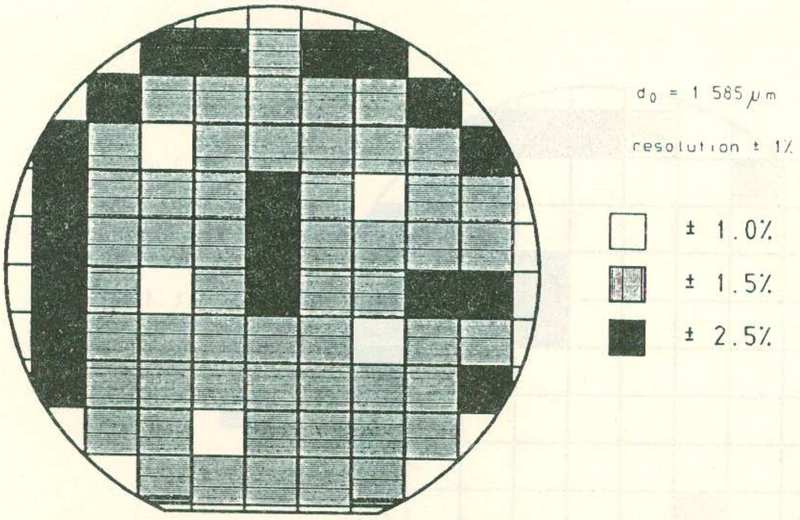

Fig. 5: Variation of InGaAsP layer thickness over a 2" wafer.

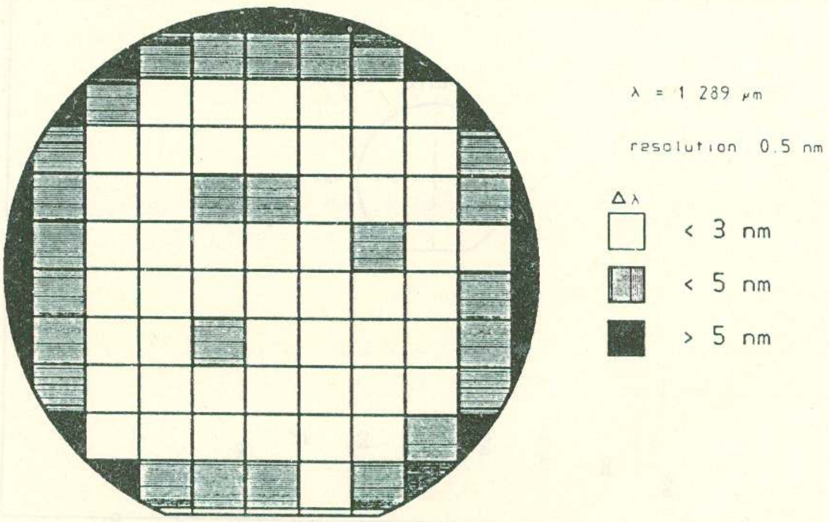

Fig. 6: Variation of PL-wavelength of InGaAsP over a 2" wafer.

4. Conclusion

As shown in the present paper, a standard LP-MOVPE process can be improved by relatively simple adaption of the reactor hardware in a way that gas foil rotation of the substrates enables to achieve compositional and film thickness variations of all materials in the Ga-In-As-P system below 2% over entire 2" wafer areas. Lattice mismatch of ternary materials could be obtained in the 10^{-4} range over the same area. The quality of quaternary material allows for production of optoelectronic devices such as lasers and waveguides with high yields over large wafer areas. Considering the possibility of superposing more than one rotational motion ("Planetary motion") new multiwafer deposition reactors have been developed. The results obtained by Frijlink on 7x2" wafers in the GaAs/AlGaAs system demonstrated the possibility of mass production reactors for quantum electronic devices. On the basis of the promising results on InP based compounds a low pressure planetary production reactor for P-containing compounds has been developed.

References:

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