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THE OMVPE GROWTH OF GaAs AND GaAlAs ON A LARGE SCALE

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Résumé

Ce papier décrit une tentative positive d'industrialisation de la méthode organométallique, effectuée à deux niveaux.

Premièrement avec le système GaAs/GaAlAs on a essayé différentes géométries de suscepteurs placées dans un réacteur horizontal pour faire des diodes lasers sur des surfaces supérieures à 50 cm².

Deuxièmement un réacteur vertical de grande capacité capable de traiter 20 plaques de diamètre trois pouces a été conçu et réalisé en collaboration avec la Société "Metal Research" pour assurer la croissance de GaAs.

Les caractéristiques des couches : uniformité de composition d'épaisseur et de dopage sont discutées pour chacune des géométries.

Abstract

In this paper we discuss the design of "scaled up" OMVPE reactors and describe the characteristics of a horizontal reactor for which we have designed a susceptor geometry having a capacity of 60 cm² of substrate. This is followed by a description of the growth behaviour of a very large scale vertical reactor, which was designed in collaboration with Metals Research and has a capacity of 900 cm², i.e. twenty 3" slices of GaAs.

2. Introduction

The organometallic vapour-phase-epitaxy (OM VPE) growth of III-V compound semiconductors is based on the pyrolysis of an organic compound containing the group III element and generally a hydride of the group V element. The technique is now well established in several research laboratories where it has been successfully applied to the growth of GaAs and GaAlAs for laser structures, photocathodes and FETs.

In the next stage, as OM VPE enters the production environment, growth characteristics such as yield, reproducibility, layer uniformity and substrate area become important.

We have successfully scaled up the growth capacity of our standard low pressure horizontal system from 10cm² to 50cm² while maintaining a good uniformity of layer and device characteristics. An understanding of the gas flow conditions and other critical features of this horizontal system has allowed us, in collaboration with Metals Research, to scale up this design to a capacity of 900 cm² in the form of the MR 200 vertical OMVPE reactor.

We will discuss the flow conditions and growth regime in these reactors and in each case give layer and device characteristics.
3. A comparison of the growth behaviour of horizontal and vertical OMVPE reactor geometries.

Most OMVPE growth so far reported has been carried out in one of the two reactor geometries shown schematically in figure 1. Figure 1.a. shows the horizontal system that we at Thomson-CSF have developed. It features a horizontal reaction tube and gas flow, with the substrate lying in a plane which makes a shallow angle (0° to 10°) with the horizontal. This type of reactor has been successfully used to grow GaAs, GaAlAs and the indium based III-V compounds and in all cases has been operated at reduced pressure as explained in a previous publication (1).

![Horizontal Reactor Diagram](image)

Figure 1.b. shows the commonly used atmospheric-pressure vertical OMVPE reactor in which the substrate is positioned in the horizontal plane on a rotating "disc" shaped susceptor and the gases are injected at the top of the reaction tube.

"State of the art" device results have been obtained in both geometries of OMVPE reactor (2) (3) and for small areas of substrate (< 10cm²) the variation in layer thickness is less than ± 5%. We believe however that the reactor geometry becomes more important when a larger growth capacity is required and in this case the reduced-pressure horizontal-reactor offers advantages over the atmospheric pressure vertical reactor. These advantages are related to the gas flow dynamics of the horizontal reactor and will become apparent as we compare the two geometries.

We first consider the horizontal system under normal operating conditions as shown in figure 2. The system is designed to have a fast, laminar gas flow in the vicinity of the susceptor and this is achieved by keeping the average gas velocity at a value less than that determined by Gilling (4) for the onset of turbulence (70 cm s⁻¹) but at a value high enough to prevent significant convection currents between the hot susceptor and the cooler reactor walls. The use of a low reactor pressure reduces gas phase heating and eliminated homogeneous reactions in the gas phase.
Gas Flows (measured at 1 Atm)
\[ H_2 = 25 \text{l/mn.} \]
\[ \text{TMG} = 2.7 \text{cc/mn.} \]
\[ \text{TMA} = 0.6 \text{cc/mn.} \]
\[ A_sH_3 = 0.350 \text{l/mn.} \]

Fig.2 HORIZONTAL REACTOR UNDER NORMAL OPERATION

Under these conditions the growth rate and composition of the epitaxial material are independent of temperature between 600°C and 900°C, of pressure between 200 mbar and 500 mbar and of the mole fraction of the group V element (5) (6). The growth rate is solely controlled by the mole fraction of the group III compound, trimethyl gallium (TMG).

Typically we use a substrate area of 10 cm² and in this case the uniformity of layer thickness was better than ±5%, which in our case was the limit of resolution of the thickness measurement. In the case of growth of a ternary compound, e.g. Ga\(_{0.84}\)Al\(_{0.16}\)As, the average composition (\(\langle X \rangle\)) was \(\langle X \rangle = 0.16\) with a standard deviation (\(\sigma\)) of \(\sigma = 0.0008\), measured by band to band photoluminescence over an area of 12 cm².

The stability of the "laminar-gas-flow" growth regime was also reflected in the reproducibility and controllability of the growth process, with consequent in the reproducibility of device characteristics. For example in a series of 12 double heterostructure laser slices (active layer thickness 1400 Å) grown during a period of 4 months, the average value of threshold current density was 996 A cm⁻² with a standard deviation of only ±7%.

From the behaviour of the growth rate in this regime we assume, by analogy with silicon growth (1), that the growth is limited by the diffusive transport of material to the substrate. In the case of GaAs growth by OMVPE the diffusing species is the organometallic (TMG) molecule which diffuses from the volume of gas above the susceptor. Since the gas flow is believed to be laminar the whole of this gas volume can be considered as the diffusion source of TMG. In reality, due to the velocity profile across this volume, the main contribution to growth comes from the slower moving lamellae adjacent to the substrate and thus only a small portion of the total gas volume will be depleted.
A disadvantage of using the laminar flow regime for small substrate areas is, therefore, that most of the source species is swept past the substrate and into the reactor waste line. Accordingly epitaxial growth rates in this regime are lower (100 to 500 Å min\(^{-1}\)) than those measured in an atmospheric pressure vertical system (1000 Å min\(^{-1}\) to 5000 Å min\(^{-1}\)). This partial depletion of the gas phase can, however, be used to advantage when growing on larger areas of substrate and we will show later that if the susceptor is tilted at a shallow angle to the gas flow an excellent value of layer uniformity can be attained.

The vertical reactor, see figure 1.b., under normal operation exhibits a significantly different behaviour to that described above.

The epitaxial growth rate is dependent on the susceptor temperature and on the flow rate of carrier gas. This behaviour is thought to result from the presence of homogeneous gas phase reactions, which are normally observed upstream from the susceptor and also from the non-laminar gas flow above the susceptor, where it is dominated by convection currents. The homogeneous reaction can dramatically reduce the growth rate of the susceptor due to the large surface-area to weight ratio of the particles produced by this reaction. The convection currents will locally disturb the diffusive transport of source molecules to the surface causing local variations in growth rate and hence in layer thickness.

For the growth of GaAlAs the variation in growth rate and composition can be as high as + 10% within an area of 10 cm\(^2\). A correlation has been observed between the thickness and composition variations for growth under these conditions, the aluminium fraction being greater in regions of lower growth rate. The uniformity of layer thickness and composition can be improved by rotating the substrate. Even with rotation however, a significant variation in layer thickness, of up to 20%, was observed for growth on a substrate of diameter 5 cm (7).

It is apparent therefore, that the growth regime in the vertical, atmospheric-pressure OMVPE reactor is inherently less stable than that in the horizontal low pressure system: although epitaxial material of excellent quality has been grown in vertical systems we feel that the stable "fast-laminar-flow" regime, that is offered by the horizontal system, lends itself more easily to "scaling up". Therefore in our attempts at scaling up the growth capacity we have tried to maintain the "fast-laminar-flow" growth regime as described above.

4. Results

4.1. Growth on an area of 50 cm\(^2\) in the horizontal OMVPE reactor

Using the susceptor shown in figure 3 in the "fast laminar flow" growth regime we have grown single and multiple layer structures of good uniformity on 4 "D" shaped GaAs wafers; the total substrate area was 53 cm\(^2\) for each growth. Figure 4 shows the variation of thickness of the zinc doped Ga\(_0.65\)Al\(_0.35\)As confinement layer of a laser structure as a function of position on the susceptor. The layer thickness is quite uniform (2.21 μm + 4%) over most of the susceptor surface but at the downstream end there is a rapid drop in growth rate. This abrupt change is believed to be due to turbulence at the trailing edge of the susceptor, as depletion of the gas phase would be expected to give a gradual change in thickness along the susceptor.
Broad area lasers were fabricated from the "hatched" areas of these slices and the averaged characteristics of these lasers are given in TABLE 1.

**TABLE 1.** The averaged characteristics of broad area lasers fabricated from the hatched regions shown in figure 4 (Active layer thickness 1,400 Å)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Average value</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold current Density ($J_{TH}$)</td>
<td>892 A cm$^{-2}$</td>
<td>± 12 %</td>
</tr>
<tr>
<td>Emission wavelength ($\lambda$)</td>
<td>849 nm</td>
<td>± 0.3 %</td>
</tr>
<tr>
<td>Differential External Quantum Efficiency</td>
<td>60 %</td>
<td>± 9 %</td>
</tr>
</tbody>
</table>
The uniformity of composition is reflected in the very small standard deviation of emission wavelength ($\lambda$) of these lasers, which have a nominal active layer composition of Ga$_{0.94}$Al$_{0.06}$As. The standard deviation of $\pm$ 12% for the threshold current density is acceptable but this may be further improved by minimising turbulence effects at the extremities of the susceptor.

4.2. Growth in the MR 200 vertical reactor

The growth chamber of the MR 200 OMVPE reactor is shown schematically in figure 5. The gases are injected via the central column at the top of the inner bell jar and they flow down past the substrates to be extracted at the base of the growth chamber. The substrates are mounted on a graphite "barrel" which is heated by IR radiation from an array of lamps which are situated inside the inner bell jar.

Although this system has a vertical geometry it was designed to operate in the "fast laminar flow" regime, thus the substrates lie at a shallow angle to the gas flow direction. The main gas flows, see figure 5, were approximately determined by a direct "scale up" from the smaller horizontal system (figure 2).
The objective of this study was to obtain a good uniformity of layer morphology, thickness and doping for the growth of n-type GaAs over the whole of the 900 cm$^2$ growth area. The arsine to gallium ratio, as with smaller reactors (8), was found to control the residual doping type and concentration; it was adjusted to give a low n-type doping. As with the smaller reactor operated in the "fast laminar flow" regime the growth rate in this reactor was insensitive to temperature and pressure and was controlled by the molar flow of the group III element TMG.

Figure 6 shows the variation of thickness around the "barrel" at two levels A and B (see figure 5). The variation around the barrel is small but the growth rate downstream at level B is lower than that at level A due to gas depletion.

![Graph showing variation of growth rate around "barrel".](image)

Fig. 6 VARIATION OF GROWTH RATE AROUND "BARREL"

Figure 7 shows the uniformity, on a single 2" diameter GaAs wafer, of layer thickness and doping level in the active layer of a simple two-layer FET structure shown in figure 8. The standard deviation on the thickness is $2\%$; that on the doping concentration is $5\%$ on a nominal level of $1.5 \times 10^{17}$ cm$^{-3}$. For a 2" diameter slice the average pinch off voltage is 3.1 V with a variation of $0.05$ V.

The slice to slice variations in layer thickness and doping concentration have maximum values of $15\%$ and $20\%$ respectively.
Conclusions

We have shown that the "fast-laminar gas flow" growth regime can be applied to large scale OMVPE reactors. The capacity of the standard horizontal reactor has been extended to 50 cm² with an adequate uniformity of layer and laser device characteristics.

The same approach has allowed the successful operation of the MR 200 OMVPE reactor for the application of FET material growth. Here the uniformity of characteristics is adequately good on single slices of 2" diameter but slice to slice variations need to be reduced further. We are confident, however, that further improvements in the slice to slice uniformity can be achieved with minor modifications to the growth chamber.

References:


