New OMVPE Reactor for Large Area Uniform Deposition of InP and Related Alloys

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The deposition uniformity in a chimney reactor, with a sidearm to accommodate susceptor rotation and mechanized substrate loading, has been characterized by mapping the thickness of InP deposited on 50-mm-diam. GaAs substrates. Susceptor rotation improves the thickness uniformity by approximately a factor of seven, with the thickness uniformity reproducibly held to less than 3% across 40 mm, under typical growth conditions. The deposition pattern is independent of rotation rate from 3 to 120 rpm, which corroborates the existence of a slow-rotation regime (observed in an earlier flow visualization study) where susceptor rotation does not disturb the gas flow. In agreement with that interpretation, the observed deposition pattern with susceptor rotation is about the same as that predicted from a circular average of the results without rotation. Also, some discussion is given of growth parameters which influence the surface morphology of heteroepitaxial InP on GaAs.

Key words: InP, OMVPE, large area deposition

INTRODUCTION

A new reactor has been designed for OMVPE growth of InP and InGaAsP alloys. Lattice matching requirements with these materials make it essential that the flow in the reactor be free of vortices and convective cells. In addition, this reactor should be capable of high purity growth, and it should have state-of-the-art doping and thickness uniformity (a few percent) across a 50 mm diam wafer. Preliminary measurements have shown that in fact this reactor achieves all these goals, a full characterization of thickness uniformity has been completed, and those results are reported here.

Initially we undertook an extensive study of OMVPE reactor designs using flow visualization and tracer gas measurements to determine flow and switching characteristics for several reactor geometries. It was concluded from this study that atmospheric pressure operation would be desirable (1) for reasons specific to the growth of InP alloys, (2) for its general virtue of operational simplicity, and (3) for reduced use of hydrides, an especially important consideration for growth of high purity InP. At atmospheric pressure thermal convection plays an important role and can lead to flow instabilities. These instabilities are minimized in the chimney geometry because the thermal buoyancy forces add to inertial forces to give improved flow characteristics.

We have also chosen a parallel-flow reactor geometry, in contrast to the stagnation-flow geometry, in order to minimize preheating of entering gases. Premature pyrolysis has been shown to cause reproducibility problems with trimethylindium as a precursor. Two consequences of the parallel-flow geometry are a boundary layer thickness that increases with distance from the leading edge of the susceptor and potential source depletion with distance, both giving rise to a decreased growth rate along the flow direction. Attempts to counteract this effect have been made by tilting the susceptor or decreasing the reactor cross-sectional area in the vicinity of the susceptor. Alternatively, it has been shown by Okamoto in AlGaAs/GaAs and Mircea in InGaAsP/InP that improved uniformity can be achieved in parallel-flow horizontal reactors by rotating the susceptor during growth.

Our reactor incorporates two new features into the parallel-flow chimney design. First, the reactor has a rotating susceptor to average the decreasing growth rate along the flow direction. Rotation was accomplished by attaching a sidearm tube for a rotation shaft. The sidearm tube also provides a route for substrate loading, an operation which is fully mechanized. Second, with substrate replacement carried out through the sidearm tube, the chimney dimension perpendicular to the plane of the susceptor can be made small, simultaneously allowing relatively high gas velocities and low flow rates. We chose to use commercially available 7.4 cm × 1 cm ID rectangular fused silica for the chimney. This large aspect ratio permits atmospheric pressure growths on 50-mm-diam. substrates under typical conditions of 16 cm/s gas velocity and 7 slpm flow. As shown previously and below, the high gas velocities improve the growth thickness uniformity. The high gas velocities are also expected to lead to better doping and alloy uniformity, and more abrupt interfaces.

In a previous report details of the reactor design and mechanized substrate loading were given. Results of growth uniformity measurements for a stationary susceptor were presented there. It is the purpose of this present paper to show the effects of susceptor rotation on growth uniformity with this new reactor design.
EXPERIMENTAL

Epitaxial layers were grown in a sidearm chimney reactor operated at atmospheric pressure. Figure 1 shows a schematic of the growth tube. Details of the chimney reactor design with susceptor rotation and mechanized substrate loading are published elsewhere. The gas manifold system has a fast-switching low-dead-volume manifold with vent-run balancing. The system can be run with H₂ and/or N₂ carrier gas. The total carrier gas flow for these experiments was either 7 or 14 slpm H₂. A previous study with a non-rotating susceptor established the ranges of carrier gas flows and source concentrations that minimize leading-to-trailing edge thickness variations. Although a mixed H₂-N₂ (high density) carrier gas improves the uniformity in a low-flow (buoyancy) regime much greater improvements can be achieved by using high flows (>7 slpm). In the high-flow (inertial) regime the H₂ carrier gave better results than the mixed H₂-N₂ carrier, and the H₂ carrier has been used for the results presented here. A side-arm flush of 1 slpm H₂ was used which resulted in a gas velocity of 5 cm/s in the narrow annulus between the susceptor and wall. This flow is sufficient to prevent back diffusion and deposition in the side-arm, yet low enough so the flow through the reactor is not measurably disturbed.

Substrates were mounted on a molybdenum block and held in place with molybdenum clips and screws. The wafer mounting scheme is shown in Fig. 2. Normally, the substrate surface is 0.64 mm below the front surface of the susceptor, and the holding clips extend 1 mm over the surface of the substrate. As will be discussed below, these dimensions were altered in some experiments to show that under some conditions they affect the deposition near the edge of the substrate. The temperature uniformity measured with an optical pyrometer (and thermocouples) is 1–2°C across the 62-mm-diam susceptor. Susceptor rotation rates were varied from 3 to 120 rpm. Previous flow visualization studies revealed that above 120 rpm the rotation began to disturb the gas flow pattern. Trimethylindium (TMIn) and 100% PH₃ were used as source material; the mole fraction of PH₃ was 0.02 during growth initiation and reduced to a V:III ratio of 150–300:1 during growth. The TMIn bubbler was held at 25°C for a growth rate of 2.5 μm/hr. Typical layer thicknesses were 1 to 5 μm.

A technique involving the growth of InP on 50-mm-diam. GaAs substrates has been used to evaluate deposition uniformity and has been previously described in detail. This takes advantage of the lower cost of GaAs substrates, compared to InP, and of the chemical etching differences between GaAs and InP. After epilayer growth, the wafer was patterned with a grid of 2 mm squares using photolithography and selective etching, and numerous InP layer thickness measurements were made using a surface profilometer.

For heteroepitaxial growth specular surfaces can be obtained by using a two step growth sequence, similar to that used for GaAs on Si. First, a thin (100–200Å) layer of InP was deposited at low temperatures (400°C) and then the temperature was raised to 650°C for the remaining growth. Growth of InP on GaAs without this low temperature step results in an increased surface roughness caused by island growth. The average surface roughness of the