Multi-wafer Growth of Highly Uniform InGaP/GaAs by Low Pressure MOVPE

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This paper reports on the large area growth of InGaP/GaAs heterostructures for short wavelength applications (λ ~ 650 nm) by low pressure MOVPE in a vertical, high speed, rotating disk reactor. Highly uniform films were obtained both on a single 50 mm diameter wafer at the center of a 5 inch diameter wafer platter and on three, 50 mm diameter GaAs wafers symmetrically placed on a 5 inch diameter platter. Characterization was performed by x-ray diffraction, SEM, and room temperature photoluminescence (PL) mapping. For the single wafer growth, PL mapping results show that the total range on wavelength was ±2 nm with a 2 mm edge exclusion. The standard deviation of the peak wavelength, σ_w, is 0.7 nm. Thickness uniformity, measured by SEM, is less than 2%. Similar results were obtained for the multi-wafer runs. Each individual wafer has a σ_w of 1.1 nm. The wafers have nearly identical PL maps with the variation of the average wavelength from the three wafers within ±0.1 nm.

Key words: InGaP, growth uniformity, PL mapping, visible lasers

INTRODUCTION

There is increasing interest in the growth of InGaAlP/InGaP lattice matched to GaAs for visible light emitting devices emitting approximately in the 650 nm range.1-3 These devices have considerable potential for commercial optoelectronic applications. Such applications include semiconductor lasers, bar code readers, high density optical recording, target marking/pointers, and laser printers. As the demands for these devices grow, the need for larger throughput growth techniques becomes important. However, large-scale production using MOCVD has been limited due to the non-reproducibility of the thickness, wavelength, and doping uniformity. Under a given set of operating conditions, where growth is mass transport limited, recirculating flows can produce thickness and compositional variations across the wafer and limit the sharpness of the heterostructure composition profiles.4 These random fluctuations impede their use for complex heterostructure devices. The purpose of this paper is to investigate the effects of varying low pressure MOVPE growth conditions. Highly uniform growth of InGaP/GaAs heterostructures on single wafer and multi-wafer runs was demonstrated.

EXPERIMENTAL APPARATUS

The experiments described below were performed in a vertical, low pressure, high speed, rotating disk reactor.5 The growth chamber is of stainless steel construction and contains a resistively heated, molybdenum susceptor. Three, 50 mm wafers rest directly on a wafer carrier which is transferred between a UHV, stainless steel loadlock and the growth chamber. The group III and Group V compounds are separately introduced through the top plate of our vertical reaction chamber, thus avoiding parasitic side reactions. This top plate contains three separate zones where the flow of alkyls and hydrides in each of these zones are adjusted with needle valves. As the demands for these devices grow, the need for larger throughput growth techniques becomes important. However, large-scale production using MOCVD has been limited due to the non-reproducibility of the thickness, wavelength, and doping uniformity. Under a given set of operating conditions, where growth is mass transport limited, recirculating flows can produce thickness and compositional variations across the wafer and limit the sharpness of the heterostructure composition profiles.4 These random fluctuations impede their use for complex heterostructure devices. The purpose of this paper is to investigate the effects of varying low pressure MOVPE growth conditions. Highly uniform growth of InGaP/GaAs heterostructures on single wafer and multi-wafer runs was demonstrated.

EXPERIMENTAL PROCEDURE

The In_{0.5}Ga_{0.5}P experiments were grown on Cr-doped (100) 2° off toward (110) GaAs substrates. The sources of the In, Ga, and Al were the organometallic compounds trimethylindium (TMIn), kept at 24°C, triethylgallium (TEGa), kept at 25°C, and trimethylaluminum (TMA), kept at 20°C, and the sources for the As and P were 10% AsH₃ in hydrogen and 100% PH₃. High purity H₂ was passed through the TMIn and TEGa to transport the vapors to the reaction zone. The flow rates were adjusted through the TMIn and TEGa to achieve lattice-matched In_{0.5}Ga_{0.5}P on
GaAs. The growth rate for InGaP was varied between 2.5 and 4.0 μm/hr. The reactor pressure for the runs was 60 Torr and the rotation rate was 1400 rpm. The growth temperature was maintained at 690 °C, where the surface morphology was observed to be both specular and smooth. The V-III ratio varied from 200 to 500. Total hydrogen flow through the reactor was 22 slm. The dopant sources were silane (SiH₄) and dimethylzinc (DMZn).

The experiments were performed on a single 50 mm diameter wafer placed in the center of a 5 inch diameter wafer platter and on three 50 mm diameter GaAs wafers placed symmetrically on a 5 inch diameter platter. The structure consisted of a 0.5 μm GaAs buffer layer, grown at 690 °C, followed by 2.0 μm of In₀.₅Ga₀.₅P at 690 °C. Structures were also grown by adding aluminum in the InGaP to give a film consisting of (Al₀.₁Ga₀.₉)₀.₅In₀.₅P. Thickness uniformity of the as-grown layers were measured by scanning electron microscopy (SEM). Compositional and wavelength uniformity of the layers were determined by x-ray and photoluminescence (PL) measurements at 300 K. Doping uniformity was determined by a non-contact rf sheet resistivity mapping technique.

RESULTS

Single wafer In₀.₅Ga₀.₅P growth runs were performed. The wafers were placed at the center of the 5 inch diameter wafer platter. The V/III ratio was 200 and the growth temperature was 690 °C. Increasing or decreasing the temperature 20 °C did not change the value of the average PL peak wavelength, but increased the variation in the PL uniformity by several nanometers. The results shown in Fig. 1 are obtained from an automated 2000-point PL mapping technique. With a 2 mm edge exclusion, the map shows that the total range in PL wavelength was within ±2 nm, with a standard deviation of the peak wavelength, σₚ, of 0.7 nm. This demonstrates excellent homogeneity of the wavelength over the 50 mm wafer. (Al₀.₁Ga₀.₉)₀.₅In₀.₅P single wafer experiments exhibit the same PL uniformity pattern. The PL spectrum exhibits a peak λ = 650 nm with a FWHM of 51 meV at a carrier concentration of 5 x 10¹⁷ cm⁻³. With a 2 mm edge exclusion, the total variation in wavelength was ±2 nm with σₚ of 0.5 nm.

A multi-wafer run was performed containing three 50 mm substrates symmetrically placed on a 5 inch diameter platter. The growth conditions are the same as the single wafer platter except for an increase in V/III ratio to 500 which was necessary to maintain a specular surface morphology. Automated, 89-point, PL mapping technique, with a 2 mm edge exclusion, was performed on the three wafers and the results are shown in Fig. 2a, 2b, and 2c. The mapping results of each wafer were used to calculate the standard deviation, σₚ, in PL peak wavelength. Each individual wafer has a σₚ of 1.1 nm. The wafers have nearly identical PL maps with the variation of the average wavelength from the three wafers within ±0.1 nm. With a carrier concentration of 1.2 x 10¹⁷ cm⁻³, room temperature PL peak FWHM of 16.7 nm (46.8 meV) at 300 K and 6.1 nm (18.4 meV) at 77 K was obtained.

Figure 3 shows a plot of InGaP thickness uniformity. Thickness measurements were taken at 10 points radially across the wafer by scanning electron microscopy and uniformity was calculated from σ/mean. With a 3 mm edge exclusion, thickness uniformity is better than 1.5%. Full range thickness uniformity as determined by (max-min/2)/(max + min/2) is 2.5%. These results show that layer thickness over the wafer is very uniform. Figure 4 shows the sheet resistance uniformity of a silicon doped, 5 x 10¹⁷ cm⁻³, (Al₀.₁Ga₀.₉)₀.₅In₀.₅P layer grown at a temperature of 690 °C. The surface map is generated by a 55 point, contactless, eddy current technique. Accuracy is verified by using NBS-traceable Si doped standard wafers. The sheet resistance map shows a 1.56% uniformity (σ/mean) across the 50 mm wafer. The sheet resistance uniformity of a silicon doped, 5 x 10¹⁷ cm⁻³, InGaP layer showed a 1.71% uniformity (σ/mean) across the 50 mm wafer.