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Rapid Composition Modulation of $In_xGa_{1-x}As$ Quantum Wells by Fast Dimer Arsenic Flux Change Using a Valved Arsenic Cracker

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By fast change of the As_2 flux using a high temperature valved cracker, we have demonstrated the growth of strained $In_xGa_{1-x}As$ quantum wells with different compositions. The modulation of composition is due to the change in incorporation rates of the group III atoms under different As_2 fluxes. Photoluminescence (PL) emission from the quantum wells clearly indicates the change in composition. A change of In composition from 16.4% to 8.5%, has been achieved by changing the V/III beam-equivalent-pressure ratio from 11.7 to 3.9.

1. TEXT

Molecular beam epitaxy (MBE) has become one of the most important tools for growing epitaxial films for high speed and optoelectronic devices. In MBE grown III-V compounds, the crystal growth usually takes place in the group V (e. g. As) stabilized growth condition, where group III atoms such as Ga, Al, or In incident on the surface of the substrate form bonds with group V atoms immediately.[1,2] The excess group V species desorb so that the control of stoichiometry of III-V MBE compounds is easily achieved. The growth rate and the composition of the compounds are controlled by the incident fluxes of group III atoms. However, a "Ga-stabilized" growth, which is characterized by a (4x2) or (8x2) surface structure, is seen at high substrate temperatures and at low group V to group III flux ratios. In this case, the growth rate and the composition of the compounds are no longer controlled by the flux of group III atoms but dependent on the incident flux of group V species and the substrate temperature.

Recently commercial valved crackers for group V species have become available for fast control of the flux of the cracked molecules into the MBE growth chamber.[3-5] The valve in a cracker can be used to start or stop the output flux rapidly and controllably during MBE growth. Also, the valve is designed to provide an almost linear dependence between the valve position and flux of the cracked molecules. With such capability, we have studied the effect of As_2 flux on the composition of strained $In_xGa_{1-x}As$ quantum wells grown on GaAs. An EPI Model 500V manual valved arsenic cracker was used to modulate the incident arsenic flux. The incorporation of Ga and In atoms and the material composition under various As_2 incident flux were studied by reflection high energy electron diffraction (RHEED) oscillations and 10 ^oK photoluminescence (PL) measurements. Our results show that an 8% shift in In composition can be achieved by varying the incident beam equivalent pressure (BEP) ratios of Group V/ Group III atoms from 11.7 to 3.9.

The reasons for the choice of the InGaAs/GaAs material system for this study are: (1) the In atoms incorporation are much more sensitive to substrate temperature than Ga or Al atoms,[6-8] and (2) the $In_xGa_{1-x}As$ strained-layer QWs are extensively used in many devices such as pseudomorphic high electron mobility transistors (P-HEMT), heterostructure bipolar transistors (HBT), and semiconductor laser devices.

The MBE growth was carried out by a Varian GEN II MBE system on (100) GaAs substrates. The incorporation rates of Ga and In atoms were found to decrease as the V/III BEP ratio decreases by RHEED observations. At a substrate temperature of 570°C, the incorporation rates at V/III = 3.9 become 63% and 36% of those values at V/III = 11.7 for Ga and In, respectively. The results observed here can be understood from the difference in the desorption activation energy, which is 4.5 eV for Ga atoms but 3.4 eV for In atoms.[9]

To see the effect of As_2 flux modulation on the composition change of $In_xGa_{1-x}As$, an InGaAs/GaAs strained-layer quantum well structure shown in Fig. 1 was grown. It consists of three $In_xGa_{1-x}As$ strained quantum wells separated by a 120 Å GaAs and a 500 Å $Al_{0.3}Ga_{0.7}As$ barriers. The quantum well structure and the necessary buffer and confining layers were grown. All the layers in this structure were undoped. The growth temperature for the GaAs and $Al_xGa_{1-x}As$ layers was 600 °C, while 570 °C was used for the growth of three $In_xGa_{1-x}As$ strained-layer quantum wells. The reason for choosing this temperature, which is higher than those usually used for growing the strained $In_xGa_{1-x}As$ thin film,[9-11] is to enhance the effect of flux modulation discussed above. The V/III BEP ratios of 11.7, 6.5, and 3.9 were used to grow the three $In_xGa_{1-x}As$ quantum wells labeled QW A, QW B, and QW C starting from the bottom, respectively.

The result of 10 °K PL measurement is shown in Fig. 2. Three obvious emission peaks were obtained. The wavelength shift was about 670 Å which was larger than the value predicted, 440 Å. The PL result shown in Fig. 2 indicates that strained $In_xGa_{1-x}As$ QWs with good optical quality can be obtained even with low As_2 fluxes.

In conclusion, we have demonstrated composition modulation of $In_xGa_{1-x}As$ by rapid and accurate changes in As_2 flux using a valved cracker. This method provides an alternative and convenient way of growing III-V ternary compounds with different compositions. Because the flux of the group V species can be rapidly changed, this technique should find applications in various quantum well and heterostructure devices.

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2. FIGURES

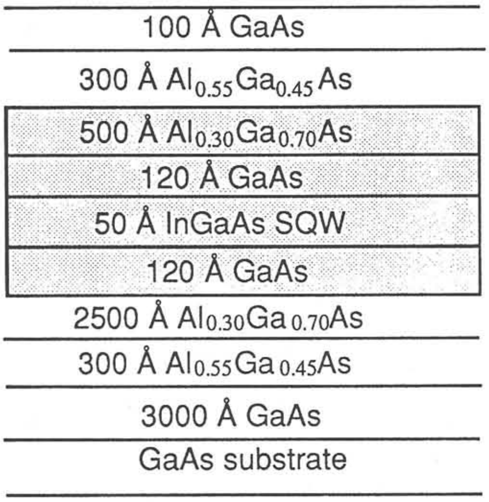

Fig. 1. Layer structure used in this study of composition modulation of strained InGaAs/GaAs QWs. In the dotted area, three QWs were grown consecutively on the same wafer, and are denoted as QW A, QW B, and QW C starting from the bottom. The related V/III BEP ratios of QW A, B and C were 11.7, 6.5, and 3.9, respectively.

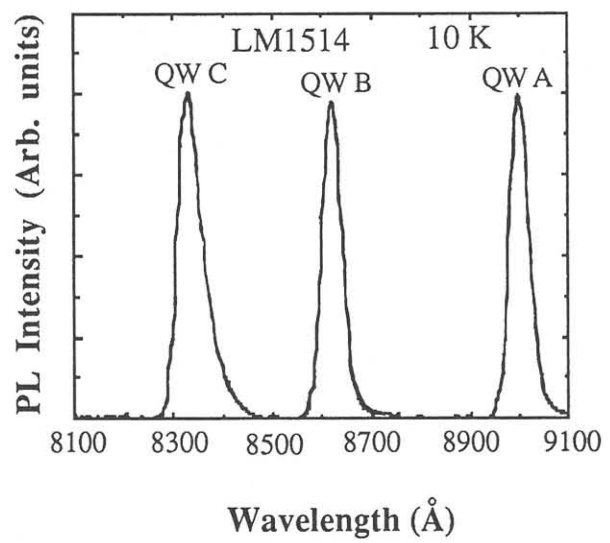

Fig. 2. 10 °K PL spectrum of the sample shown in Fig. 1. Three emission peaks corresponding to different quantum well compositions are clearly seen.

3. REFERENCES

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