MICROELECTRONICS

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MOLECULAR BEAM EPITAXY FOR THE FUTURE

(Topics of MOMBE)

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I. INTRODUCTION

MBE today is most commonly used to fabricate superlattices, high electron mobility transistors (HEMT), multiquantum well lasers, and other new semiconductor devices by utilizing its excellent controlability. MBE for the future is presumed to include other techniques, such as metalorganic chemical vapor deposition (MOCVD), photo-chemical reaction process using gas sources, and ion implantation technique and so on as shown in Fig. 1. These various techniques can be harmonized with MBE, and MBE will evolve into a new crystal growth technique in which many processes are done in one chamber without exposing a wafer to the air.

As a first step to the future MBE, we have already reported on the Zn ion doping.[1] Here, as the second step, we report on the crystal growth of GaAs using metalorganics, trimethylgallium (TMG) and triethylgallium (TEG), which are usually used in MOCVD, as gaseous sources of gallium in an MBE system.

II. EXPERIMENTAL

High purity 99.9999 % TMG or TEG was introduced into a growth chamber through a UHV leak valve and directed towards the substrate. Since no cracking process of metalorganics was carried out, thermal decomposition takes place at the surface of the substrate. As an arsenic source, a usual effusion cell made of quartz was used to produce As_4 flux.

GaAs epitaxial layers were grown on (100) Cr-doped semi-insulating substrates which were covered with SiO_2 mask formed by CVD. The substrate cleaning and chemical etching process were similar to that reported so far. Before crystal growth, the substrate was heated to 650°C for about 5 min under an arsenic flux in order to remove the oxide. The typical growth conditions were as follows: $T_{sub.}$=500~650°C, P_{MO}(partial pressure of TMG or TEG)= $5\times10^{-6} \sim 4\times10^{-5}$ Torr. Samples were characterized by RHEED, SIMS (Secondary Ion Mass Spectrometory), photoluminescence and van der Pauw Hall measurements.

III. RESULTS

1. Growth Rate

The growth rate has been studied varying the substrate temperature (520-630°C) and the partial pressure of TMG. The dependence of the growth rate on the substrate temperature for the TMG pressure of 2×10^{-5} Torr is shown in Fig. 2. When the substrate temperature is higher than 550°C, the growth rate is insensitive to the growth temperature, which indicates that the thermal decomposition of TMG does not limit the growth process in this temperature range. Below 550°C, the growth rate decreases rapidly. Then the growth process is believed to be limited by the TMG decomposition.

Figure 3 shows the dependence of the growth rate on the partial pressure of TMG for the substrate temperature of 560°C. The growth rate increases linearly with increasing the TMG pressure. Such a linear relationship is observed in MOCVD and MBE.

3. Selective Epitaxial Growth

It is worth noting that in TMG-As_4 system, no deposition was observed on a SiO_2 film. This is in contrast with conventional MBE where polycrystalline GaAs deposits on the SiO_2 masked region.[2] Figure 4(a) shows microscopic photograph of the substrate after the growth. It was found that monocrystalline GaAs was grown on the bare substrate with the narrow-stripe patterns and that the growth did not take place on the large rectangular parts of SiO_2 covered area. Figure 4(b) shows a scanning electron micrograph of the same sample after cleaving. It is clear from the photograph that the growth occurs only on the window area (i.e. on the bare substrate). The growth mechanism which cause this remarkable feature is not clear at present but this feature must be owing to the surface catalyzed growth process.

4. Characteristics

RHEED measurements indicated that GaAs epitaxial layers were monocrystalline. The epitaxial layers grown from TMG and As_4

showed p-type with high carrier concentration (>10^{19} cm^{-3}). This high carrier concentration must be due to the residual carbon.

In order to reduce the high p-type carrier concentration of the epitaxial layers grown in TMG-As_4 system, molecular hydrogen and ionized hydrogen were introduced into the growth chamber. The apparatus used to ionize hydrogen is illustrated in Fig. 5. The partial pressure of hydrogen was 1×10^{-5} ~ 4×10^{-5} Torr and the ionization voltage V_i and ion current I_i were -300 ~ -400 V and about 1 mA, respectively. Figure 6 shows photoluminescence spectra of the samples grown in TMG-As_4, TMG-As_4-H_2 and TMG-As_4-ionized H_2 system. Introducing molecular hydrogen improved the quality of the epitaxial layer as shown in Fig. 6 and it was found by Hall measurements that the carrier concentration slightly decreased from 1×10^{20} cm^{-3} to 5×10^{19} cm^{-3}. On the other hand, the films grown with ionized hydrogen showed still p-type conduction but the carrier concentration was drastically reduced to 1×10^{18} cm^{-3} and the PL peak at room temperature was observed at 1.43 eV. The dominant impurity in MOMBE grown GaAs is presumed to be carbon. It was found from SIMS analysis that the carbon concentration of the films grown with molecular hydrogen and ionized were 3×10^{19} cm^{-3} and 1×10^{18} cm^{-3}, which agree with the values obtained from Hall measurements. Consequently, the presence of ionized hydrogen is essential for improving the quality of MOMBE grown GaAs.

We have also tried to use TEG as a Ga source to reduce carbon contamination. Using TEG, the epitaxial layers grown at the temperature below 580°C showd n-type while the films grown at the higher temperature showed p-type conduction as shown in Fig. 7. The carrier concentration of these layers was 10^{17} cm^{-3} ~ 10^{18}

cm^{-3} and the electron mobility of 1600 $cm^2/V \cdot s$ was obtained. This p-n conversion might be due to the change of TEG/As_4 ratio at high temperature.

IV. CONCLUSIONS

The carrier concentration could be reduced by introducing ionized hydrogen in $TMG\text{-}As_4$ system and $p=1\times10^{18}$ cm^{-3} was obtained. The crystal growth of GaAs using TEG was also examined and the undoped epitaxial layers grown at low temperature showed n-type and the films grown at high temperature showed p-type conduction with the carrier concentration of 10^{17} cm^{-3}. Furthermore, it was observed that monocrystalline GaAs was selectively grown on the bare substrate and that no deposition took place on the SiO_2 masked region in $TEG\text{-}As_4$ system as well as in $TMG\text{-}As_4$ system.

REFERENCES

1) M. Naganuma and K. Takahashi, Appl. Phys. Lett. 27 342 (1975)

2) A. Y. Cho and W. C. Ballamy, J. Appl. Phys. 46 783 (1975)

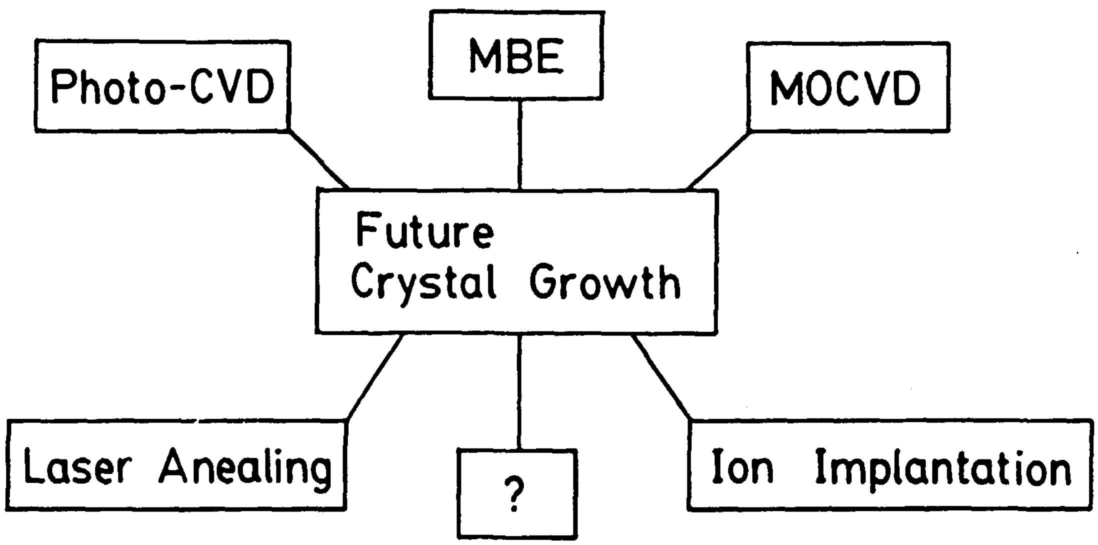

MBE
Photo-CVD
MOCVD
Future
Crystal Growth
Laser Anealing
?
Ion Implantation

Figure 1

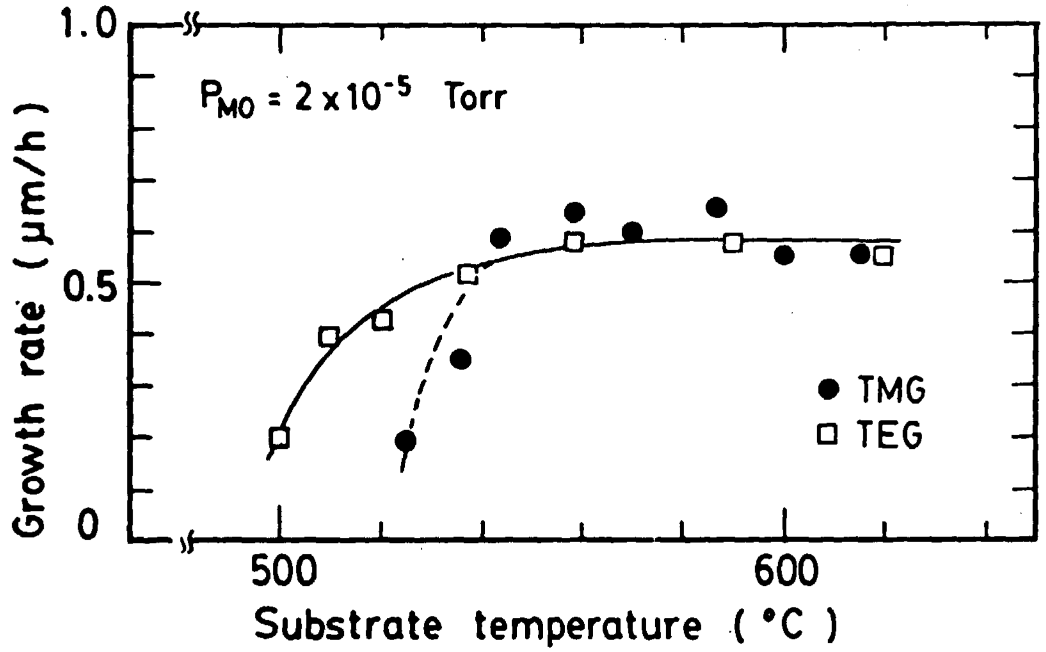


figura 2

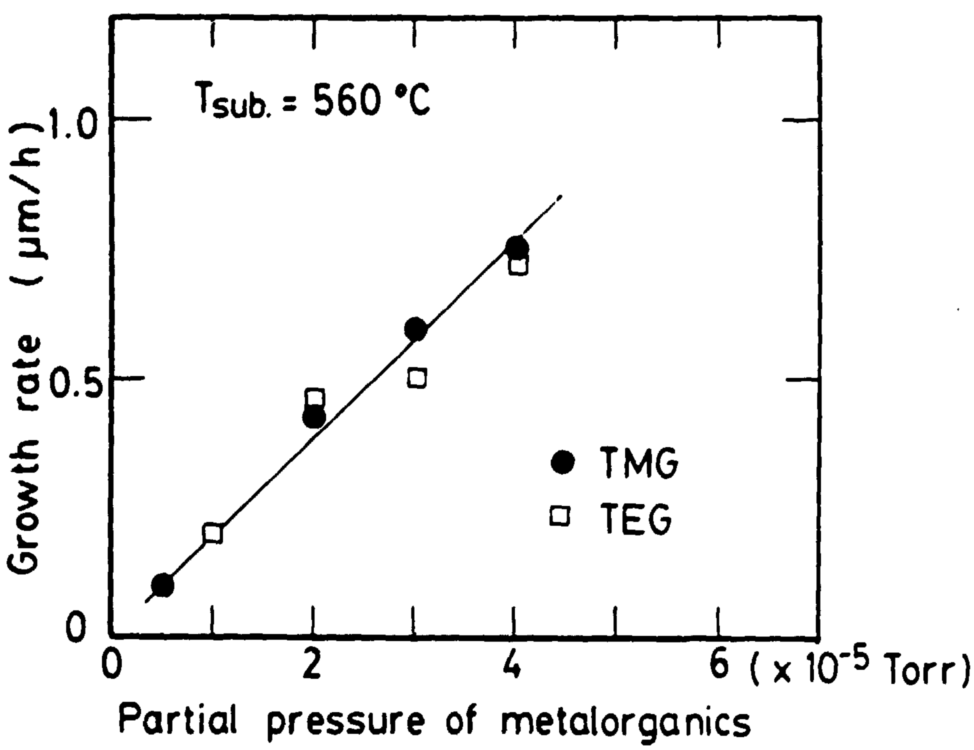
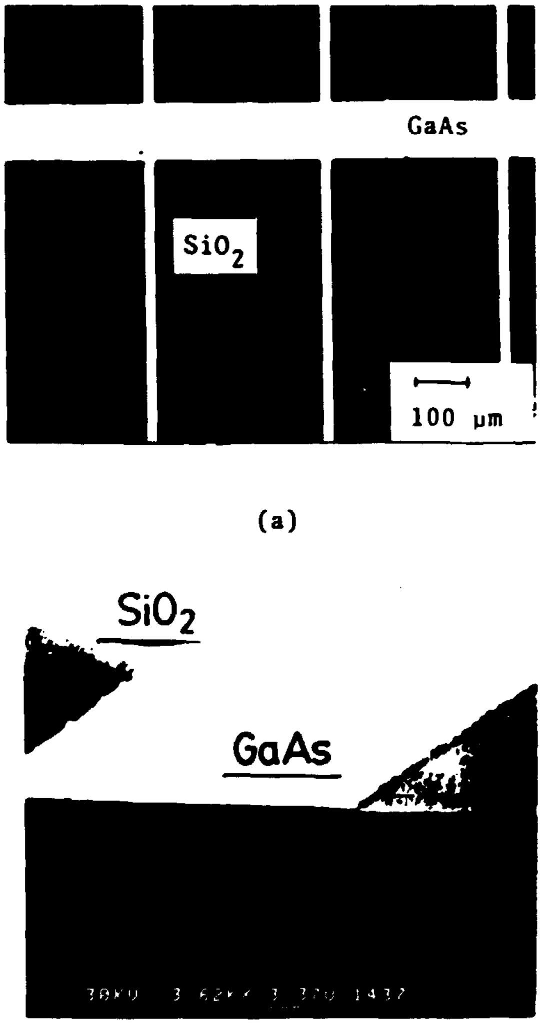


Figure 3



(a)

(b)

figura 4

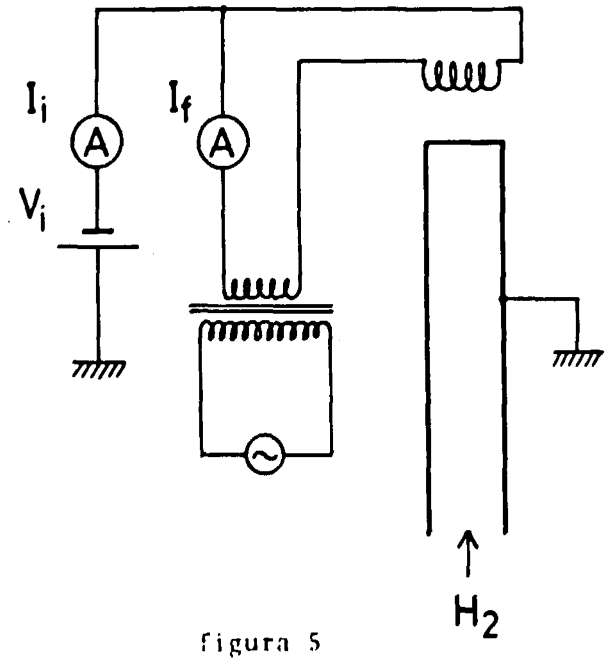


figura 5