Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo, 1986, pp. 423-426 **D-6-1**

Invited

Laser Assisted MOVPE Growth of III-V Compounds

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The state of the art of the laser assisted MOVPE growth of GaAs and AlGaAs is described, with emphasis on the selective area control or modulation of properties of epitaxial layers. Carrier concentration and conductivity type in GaAs and alloy composition in AlGaAs can be changed by excimer laser induced decomposition of source materials retaining the crystalline quality of the irradiated and unirradiated area satisfactorily high. Potential applications of this growth technique for electronic and optoelectronic devices are discussed based on our recent study of E/D type GaAs MESFET.

1. Introduction

Since the first proposal and experiment of the epitaxial growth under light irradiation,[1,2] followed by the development of lasers, there has been an increasing interest in laser assisted vapor phase epitaxy (VPE) of a variety of semiconductors. Recent growths of III-V compounds, especially of GaAs, by metalorganic vapor phase epitaxy(MOVPE) as well as halide transport VPE utilizing Ar or excimer lasers[3-8] have demonstrated many attractive features such as lower growth temperature, higher growth rate and higher crystalline quality compared to conventional VPE although the growth mechanism is not yet clearly known.

Taking advantage of these features, one can expect selective area growth, which would be useful for the semiconductor device processing. In achieving the ideal selective area growth, i.e., epitaxial growth in the region irradiated with laser light and no deposition in the unirradiated region, the growth temperature must be remarkably low. The state of the art technology of the laser assisted selective deposition has shown that high crystalline-quality layers can be grown at an extremely enhanced growth rate but some deposition takes place also in the unirradiated region and that on the other hand the deposition of low crystalline-quality layers occurs in the irradiated area at temperatures low enough to avoid any deposits in the unirradiated area.

As another application of the laser assisted MOVPE growth, the authors group has proposed[9] the selective control or modulation of the properties of epitaxial layers, e.g., carrier concentration, conductivity type and alloy composition, retaining their high crystalline quality. This growth, the concept of which is schematically shown on the right hand side of Fig. 1, would take place at the temperature optimized to obtain high quality MOVPE layers.

The present talk is concerned with the state of the art of the laser assisted MOVPE growth, with emphasis on the selective area control based on our recent experimental results. Some of the potential device applications of this growth are also described.

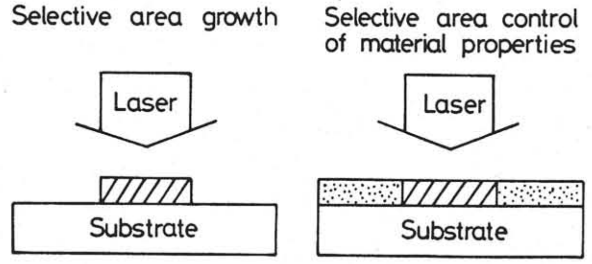

Fig. 1 Two concepts of laser assisted MOVPE are illustrated.

2. Growth Technique

The growth system in our studies,[9,10] shown in Fig. 2, is composed of a conventional low pressure MOVPE apparatus and an excimer laser light excitation source. A horizontal quartz reactor with an optical window made of Suprasil is of double tube structure to prevent unwanted deposits on the window; source gases are introduced into an inner tube and the H_2 gas is into the outer tube. The substrate is irradiated at normal incidence with laser light passing through a mask.

The growth conditions were optimized for the conventional MOVPE growth of high quality GaAs and AlGaAs. The 193nm light from the ArF excimer laser were used, since the main absorption peaks of trimethylgallium(TMGa), trimethylaluminum(TMAl), AsH_3, tetramethylsilane(TMSi) and dimethylzinc (DMZn) are located around 200nm. The pulse energy density used is typically $0.03 J/cm^2$ and the temperature rise on the substrate would not be so important. A typical growth rate of 6μm/h was not influenced by laser irradiation at growth temperatures from 600 to 800 °C.

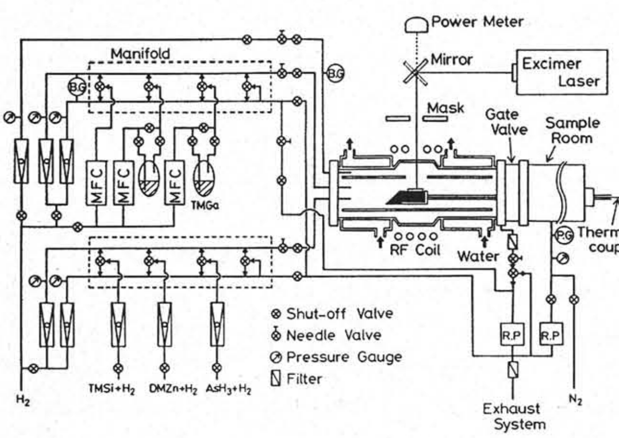

Fig. 2 Schematic diagram of the laser-assisted MOVPE system.

3. Control of Carrier Concentration

Figure 3 shows the carrier concentration and mobility at room temperature in undoped GaAs layers grown at various V/III source material ratio. The carrier concentration in the n-type region is higher for the irradiated area, and that in the p-type region is lower. It is noted that hole mobility is lower for the irradiated part. This implies that the laser-induced incorporation of the n-type impurities involved in the reactants. Secondary ion mass spectroscopy(SIMS) analysis has shown that the Si impurity concentration is higher in the irradiated area than in the unirradiated area.

Laser-assisted growth of doped GaAs has been carried out using TMSi and DMZn as dopant sources under the conditions shown in Table 1. When TMSi was intentionally introduced during growth, a dramatic increase in electron concentration in the irradiated area was observed as shown in Fig. 4. This effect is evidently due to the laser-enhanced decomposition of TMSi, because no effect was observed when silane, which has no absorption around 200nm, was used instead of TMSi. The growth of p-type GaAs at 700°C using DMZn as a dopant has shown that the hole concentration is not influenced by laser irradiation, since DMZn is sufficiently decomposed thermally at this growth temperature. Therefore, we can expect conversion from p- to n-type conductivity in the irradiated area with increasing TMSi flow rate, by introducing DMZn and TMSi simultaneously. This was realized as seen in Fig. 5. It is noted from Figs. 4 and 5 that we can fabricate semi-insulating area surrounded with n- or p-type area selecting appropriate growth temperature and dopant flow rate.

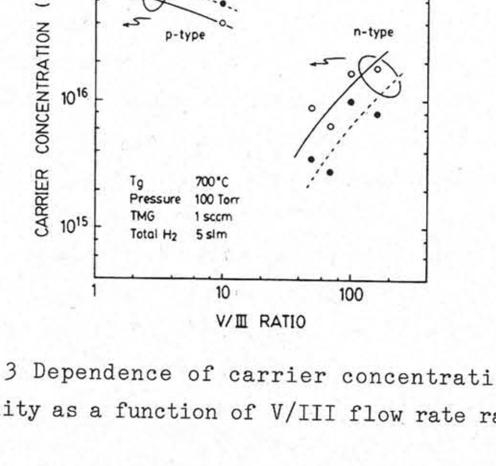

Fig. 3 Dependence of carrier concentration and mobility as a function of V/III flow rate ratio.

Table 1 Growth conditions for laser-assisted MOVPE of doped GaAs epitaxial layers.

	GaAs:Si	GaAs:Si,Zn
Substrate	GaAs:Cr (100) 2°off	
Growth temperature ($^{\circ}$C)	600~800	700
Reactor pressure (Torr)	100	100
Flow rate (sccm)		
TMGa	0.4	0.4
AsH_3	20	20
TMSi	0.002~0.012	0.001~0.012
DMZn	—	6.25×10^{-3}
Total H_2	5000	5000
Excimer laser (ArF)		
Wavelength (nm)	193	193
Average power density (W/cm^2)	1.5	1.1
Repetition rate (Hz)	50	50
Pulse energy density (mJ/cm^2)	30	22

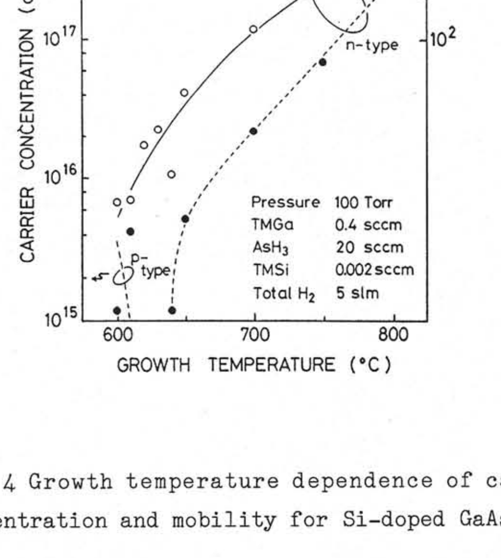

Fig. 4 Growth temperature dependence of carrier concentration and mobility for Si-doped GaAs.

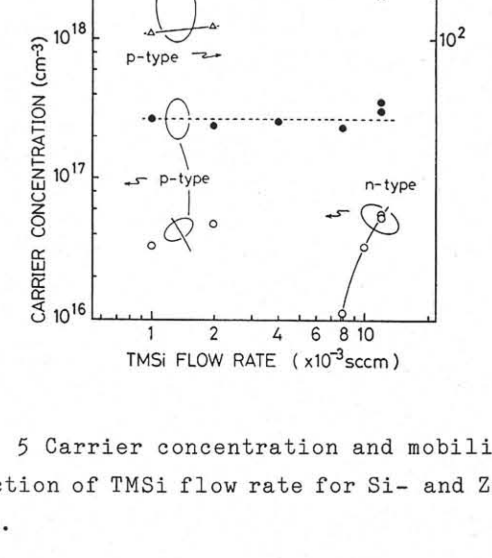

Fig. 5 Carrier concentration and mobility as a function of TMSi flow rate for Si- and Zn-doped GaAs.

4. Control of Alloy Composition

The Al content in AlGaAs increases with growth temperature and is saturated above 700°C. The Al content was increased by laser irradiation during growth particularly at growth temperatures lower than 700°C(Fig. 6). The distribution of Al content evaluated by X-ray double crystal diffraction measurement is shown in Fig. 7. It is clearly seen that the Al content is higher in the irradiated region. These results could be explained by laser-induced thermal or photochemical decompositions.

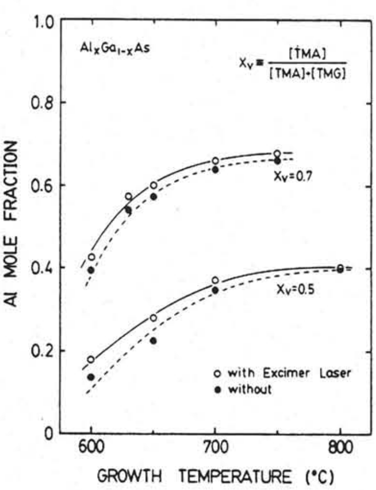

Fig. 6 Growth temperature dependence of Al content in AlGaAs.

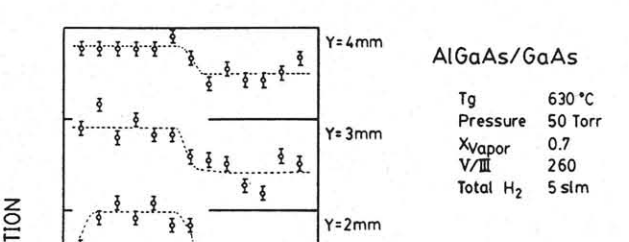

Fig. 7 Distribution of Al content in AlGaAslayers, evaluated by x-ray double crystal diffraction measurements.

5. Potential Applications

The laser assisted MOVPE technique is potentially applicable to the fabrication of a variety of electronic and optoelectronic devices. One of applications is fabrication of the GaAs MESFET logic consisting of E(enhancement)- and D(depletion)-type FET's on a single GaAs substrate. Recently, we have succeeded in making D-FET and E-FET on n^+(irradiated, $5x10^{17}cm^{-3}$) and n(unirradiated, $3x10^{16}cm^{-3}$) regions, respectively. Another application to the GaAs complementary logic consisting of p- and n-channel FET's would also be possible. Further application to semiconductor lasers of current confinement structure utilizing semi-insulating regions is especially expected.

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