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LIQUID-PHASE EPITAXIAL GROWTH, ELECTRON VELOCITY, AND MAXIMUM DRIFT VELOCITY

OF $\text{In}_{1-x}\text{Ga}_x\text{As}$ ($x \approx 0.5$) FOR MICROWAVE DEVICES

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I. Introduction The silicon is a material being commonly used for devices such as transistors. However, it is not satisfactory in an electron mobility and a maximum velocity for transistors to operate in a microwave frequency region and in a very high switching speed. Thus, GaAs which has a higher mobility (about six times) as compared with silicon is normally used for microwave FETs. Today, GaAs MES (metal-semiconductor) FETs have shown highest frequency operation (80 GHz) and fastest switching speed (4 pico joule) of all transistors. [1]

The InSb and InAs have very high mobility such as 78000 and 33000 $\text{cm}^2/\text{volt}\cdot\text{s}$, respectively. However, these materials cannot be used for transistors, because of a very narrow band gap, 0.18 and 0.36 eV, respectively. The mixed crystal of InAs and GaAs can be expected to yield a higher mobility than GaAs and a wider band gap than InAs. Near a half composition rate ($x \approx 0.5$), the band gap, E_g , becomes about 0.75 eV at which the carrier concentration ($>10^{15}\text{cm}^{-3}$) is not affected by the variations of the intrinsic carrier concentration ($\sim 10^{11}\text{cm}^{-3}$). Further, the energy difference, ΔE , between the central and satellite valleys in the conduction band becomes wider with the increase of the composition rate of InAs. Near $x \approx 0.5$, ΔE is expected to equal E_g . [2] This does not make the electron velocity decreased by the Gunn effect. At this condition, the largest maximum velocity can be obtained.

We describe here the epitaxial growth of a very uniform single layer of $\text{In}_{1-x}\text{Ga}_x\text{As}$ ($x \approx 0.5$) which can be considered a type of a tailor-made or designed material. We present the higher electron mobility and the larger maximum velocity of $\text{In}_{1-x}\text{Ga}_x\text{As}$ ($x \approx 0.5$) than those of GaAs.

II. Epitaxial Growth The mixed crystal is grown by the liquid-phase epitaxial method with a sliding graphite boat in a pure hydrogen gas atmosphere. The solution method has not yet grown a uniform composition rate of crystal, because the segregation coefficients of In, Ga, and As are much different each other. [3], [4] By the vapour-phase epitaxial method, such a material has not yet grown that the composition rate is uniform and the mobility is greater than that of GaAs. It has to be encountered in the epitaxial growth of a mixed crystal that the lattice constant is not equal to that of composite compound material, e.g., InAs or GaAs in case of $\text{In}_{1-x}\text{Ga}_x\text{As}$. This lattice mismatch is considered a main severe cause to the defects and mechanical strain in a mixed crystal. [5], [6] This problem could be avoided by adopting InP as a substrate whose lattice constant exactly matches with that of $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$. In taking this advantage, we could successfully grow the mixed crystal with a mirror-like smooth surface which must be at least satisfied by materials for devices. An as-grown surface and a cleaved surface of the mixed crystal grown at 700°C are shown in Fig. 1. The composition rate along a grown layer was confirmed very uniform by the electron probe micro-analyzer as shown in Fig. 2.

III. Electron Mobility Besides the scatterings with phonons and ionized impurities, additional scattering takes place in the electron transport in a mixed crystal. This scattering has been considered due to the disorder alignment of composite elements, i.e., In and Ga in $\text{In}_{1-x}\text{Ga}_x\text{As}$, and called the disorder scattering. [7] So far as the materials, with a uniform composition rate, grown by the liquid-phase epitaxial method, the electron mobility is rather lower than GaAs in the region of $x > 0.5$. This has been understood due to the disorder scattering which may take away the possibility to the increase of the mobility by the mixed-crystal approach.

The mixed crystals which we have grown avoiding the lattice mismatch give a higher mobility than GaAs. The results are shown in Fig. 3 where the theoretical curve of electron mobility of GaAs is plotted for comparison. This curve is commonly considered agreeable with the experiment-

ally measured data of GaAs.

The mixed crystal grown here may still involve the disorder scattering. However, our results show that the mobility decrease in the past results would be due to the crystal defects and mechanical strain by the lattice mismatch and that the disorder scattering would not be serious in the electron mobility. By the experiments of the infrared absorption through $\text{In}_{1-x}\text{Ga}_x\text{As}$, we have confirmed that the mixed crystal grown here has a very sharp edge of the band gap.

IV. Maximum Velocity It becomes possible to apply a high electric field to $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ since then a uniform single layer has been grown here. We have measured the velocity-field characteristic by applying a pulse voltage to keep the crystal temperature constant. As shown in Fig. 4, the result indicates the tendency to increase further in contrast to the velocity of GaAs where the velocity does not increase beyond 2×10^7 cm/s as well known from the velocity-field characteristic of GaAs. The result can be understood due to the increase of ΔE in the mixed crystal by which the Gunn effect does not occur in the range of the electric field in the experiments. Further investigations to the saturated velocity of $\text{In}_{0.57}\text{Ga}_{0.43}\text{As}$ will be studied.

V. Conclusions Taking the concept of the tailor-made or designed materials, we have successfully grown the mixed crystal of InAs and GaAs. It has shown a higher mobility and a larger maximum velocity than GaAs. This mixed crystal can be understood desirable material in electronic properties for devices in a microwave frequency region and in a very high switching speed.

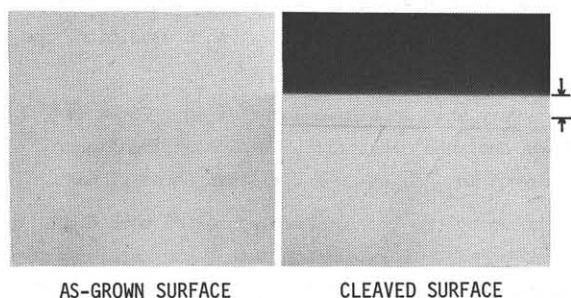


Fig. 1

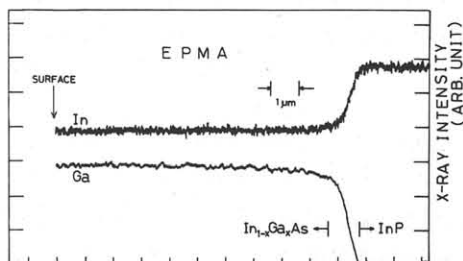


Fig. 2

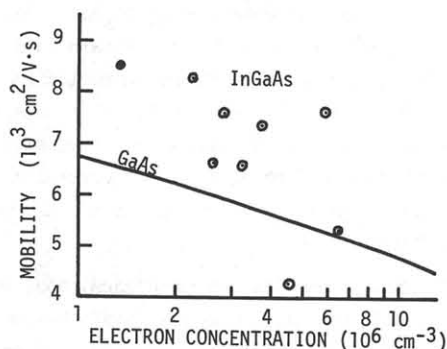


Fig. 3

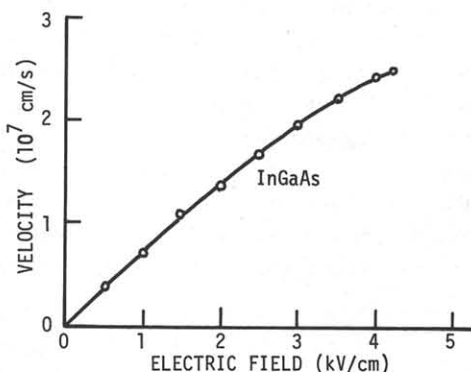


Fig. 4

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