Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo, 1985, pp. 433-436

Threshold Voltage Homogeneity and Electrical Properties of GaAs MESFETs on In-Doped Dislocation-Free Substrate

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Abstract—This describes the threshold voltage (Vth) homogeneity and the electrical properties of GaAs MESFETs fabricated on an In-doped dislocation-free GaAs substrate. It is demonstrated that the In-doped substrate exhibits a good Vth homogenity over the whole wafer (σVth=19mV) as well as in the local area (σVth=8mV), and that the doped In gives no serious problems for the electrical properties of GaAs FET, except that Vth is slightly shallower for higher In-concentration.

INTRODUCTION

Because of its high speed and low power characteristics, GaAs LSI has been expected to become a key device of the high performance computers and communication systems. From a practical point of view, however, the fabrication yield of GaAs LSIs is not satisfactory now. One of the most serious problems which make it difficult to produce GaAs LSIs with a reasonable reproducibility and a high yield is recognized to be the crystallographic inhomogeneity of GaAs substrates, giving an unfavorable FET threshold voltage (Vth) nonuniformity in an LSI chip, as well as, over a wafer. Recently, it has been reported that the doping of the isovalent indium (In) suppresses the generation and propagation of dislocations [1)-2)], resulting in Vth-uniformity improvement. The conventional In-doped LEC GaAs substrates used in the previous experiments have, however, an In-concentration of around 1E20 atoms/cm^3, where the growth striation and In-precipitation are still problems to be solved. We have overcome these problems by developing an advanced LEC technique [4)] which enables the reduction of In-concentration necessary for the elimination of the dislocation.

The purpose of this paper is to demonstrate the feasibility of the In-doped GaAs substrates without not only the dislocation but also the striation and In-precipitation, for the GaAs LSI fabrication. GaAs MESFETs fabricated on In-doped LEC substrates with the different indium concentrations have been evaluated from view points of Vth, Vth-uniformity, transconductance (Gm) and the sub-threshold characteristics.

EXPERIMENT

In order to examine In-concentration dependence of FET electrical properties and its distribution over a wafer, LEC GaAs substrates with different In-concentrations ranging from 6E18 to 9E19 atoms/cm^3 were prepared in house. As shown in Fig.1 GaAs crystals having an In-concentration of more than 2E19 atoms/cm^3 give no dislocations. Figure 2 (A) shows an X-ray topograph of the In-doped (4E19 atoms/cm^3) GaAs substrate, exhibiting no observable defects, such as dislocation, growth

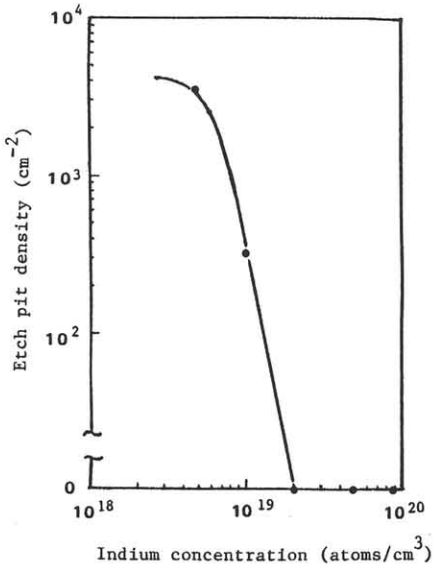

Fig.1 Etch pit density of In-doped LEC substrate for doped In-concentration.

striation, and In-precipitation almost all over a 2 inchϕ wafer. The conventional undoped GaAs substrates having the dislocation density of around 10000/cm^2 (Fig.1(B)) were also prepared for a comparison. The most important thing in carrying out the correct evaluation of the crystal homogeneity is to avoid the inhomogeneities introduced in the device fabrication process. From this point of view, GaAs MESFETs fabricated using the combined technology of SWAT (Side-Wall Assisted selfalignment Technology) and WSi_x gate N^+ selective ion-implantation technology, have been employed, in order to obtain the electrical properties of the practical FET. The Si^+ ion-implantation conditions for N (active layer) and N^+ (contact layer) regions for the MESFET are 30keV, 3E12/cm^2 and 100 keV, 3E13/cm^2, respectively. The implanted Si^+ ions were activated by annealing with a SiN cap in H_2 atomosphere at 800 C° for 20 minutes.

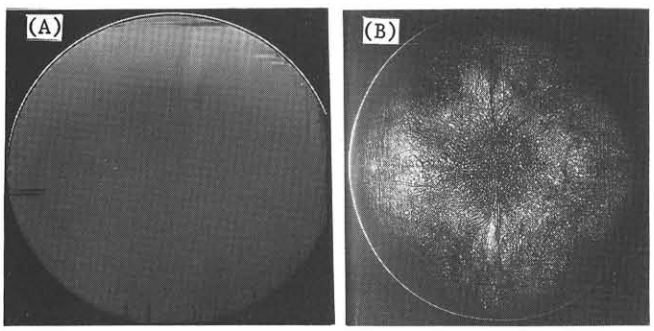

Fig.2 X-ray topogarphs of In-doped (In-concentration: 4E19 atms/cm^3) (A) and undoped LEC substrate (B).

RESULTS and DISCUSSIONS

Figure 3 shows the gate length (Lg) dependences of Vth and its standard deviation (σVth) for FETs on an In-doped dislocation-free substrate and on an undoped substrate. It is seen in Fig.3 that the In-doped substrate exhibits a smaller Vth-deviation than the undoped substrate. However, it should be emphasized that the Vth-deviation is increasing as the gate length decreases. This is mainly due to the short channel effect in Vth. In order to avoid the additional inhomogeneity, the gate length should be more than 1.5μm. This is also confirmed in Fig.4, where Vth distributions

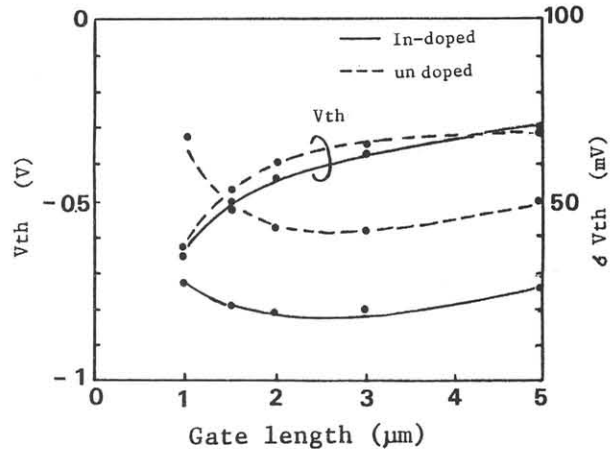

Fig.3 Gate length dependences of Vth and its standard deviation (σVth).

for four FETs fabricated closly to each other but having different gate lengths, showing that the Vth-distribution patterns for FETs with more than 1.5um gate are similar to each other but different from those of 0.5μm and 1.0μm gate FETs. Figure 5 (A) and (B) show the overall Vth-distributions evaluated by using the long gate (Lg=2μm) FETs fabricated on the In-doped (4E19 atoms/cm^3) and the undoped LEC substrates, respectively. The In-doped dislocation-free substrate exhibits a very small Vth-fluctuation not only for the local area but also in the whole wafer. On the other hand, the undoped LEC substrate gives a concentric pattern of Vth-inhomogeneity, maybe reflecting the dislocation density distribution. In Table 1, the mean value and the standard deviation of FET threshold voltage measured in the local area (both center and periphery) and in the whole wafer are summarized for two wafers. σVth value for the In-doped substrate almost remains constant, not depending on both the measuring point and the area.

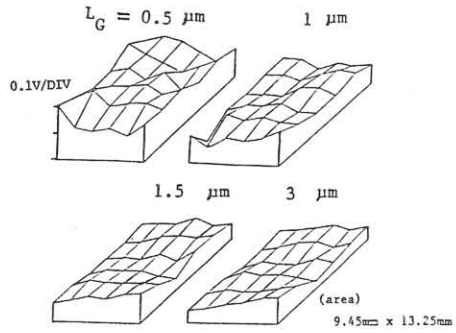

Fig.4 Vth distributions drawings of GaAs MESFETs with four different gate lengths made on 1890μmx2650μm chip area.

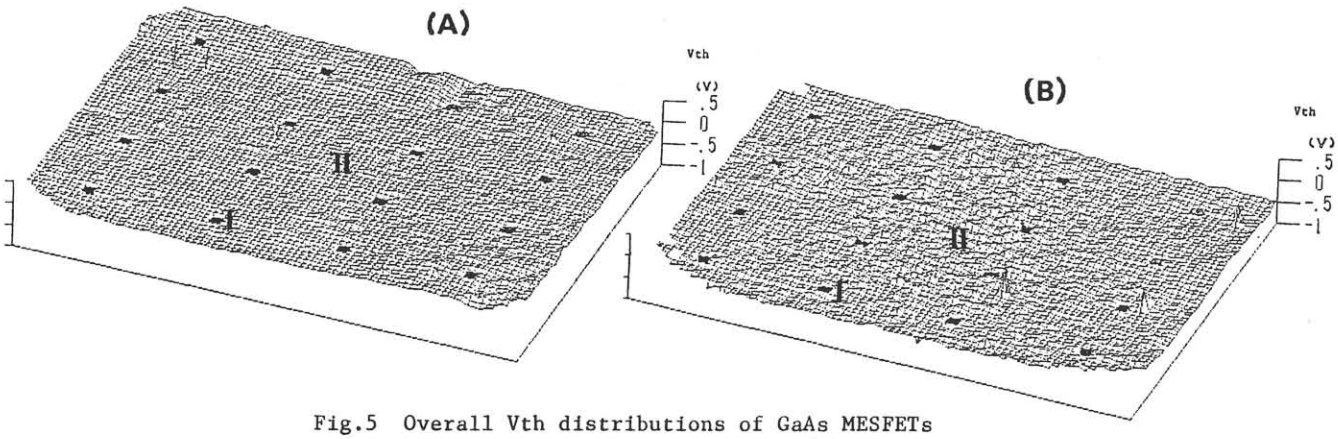

Fig.5 Overall Vth distributions of GaAs MESFETs made on In-doped LEC substrate (A), and on undoped LEC substrate.

σVth of 8mV was achieved in the peripheral area (9.4mm x 9.15mm). Even in the case of the whole wafer, σVth is as small as 19mV. On the other hand, the undoped substrate shows much larger σVth, especially for the central region (51mV). Another important information in Table 1 is the difference in the mean threshold voltages (Vth). In-concentration dependence of Vth was measured more systematically by fabricating FETs on LEC GaAs substrates with different In-concentrations from 6E18 to 9E19 atoms/cm^3, with the other growth conditions unchanged. Experimental results are shown in Fig.6, where measured Vth and σVth are plotted as a function of In-concentration. It can be seen that the Vth value shifts toward a normally-off region under increased indium concentration in spite of the same ion-implantation and annealing conditions. The origin of this outcome is obsure now, but it may be attributable to the stoicheometric problem or the stress filed caused by indium element arising at the implant activation process. Figure 6 also shows that Vth increases drastically by decreasing In-concentration below 2E19 atoms/cm^3. By combining this result and the dislocation density (Fig.1), it can be concluded that the Vth value has a tight correlation with the dislocation density.

Table 1. Summary of the mean threshold voltage ($\overline{Vth}$) and the standard deviation (σVth).

Measured Region	In-doped Sub.		Undoped Sub.	
	$\overline{Vth}$	σVth	$\overline{Vth}$	σVth
PART I * (Periphery)	0.034V	8 mV	-0.42V	30.6mV
PART II * (center)	0.009V	14mV	-0.35V	51.0mV
Whole wafer+	0.016V	19mV	-0.43V	45.0mV

* (area) 9.4mm x 9.15mm + (area) 37.6mm x 36.6mm

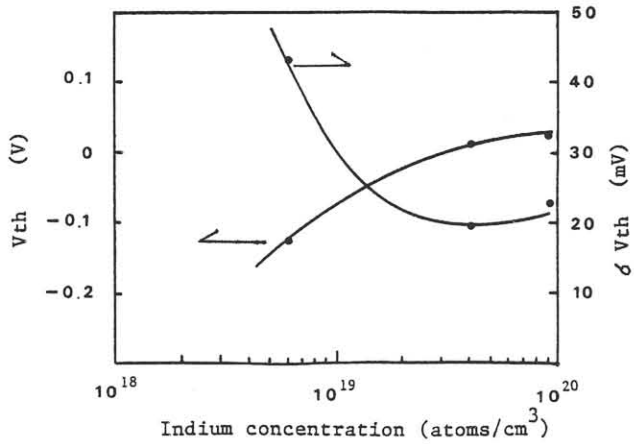

Fig.6 Indium concentration dependences of Vth and its standard deviation (σVth).

Another important point of view which has to be focused in evaluating the substrate is GaAs MESFET performance itself. Figure 7 shows the Ids-Vds characteristics of FET made on the In-doped (4E19 atoms/cm^3) GaAs substrate. Transconductance (Gm) of as high as 260 mS/mm was obtained for Lg of 1μm, which is comparable to that of FETs made on the undoped substrate. The sub-threshold characteristcs should also be focused, because it is directly influenced by the substrate quality such as resistivity, deep level concentration and thermal conversion. Figure 8 shows the gate vol-

tage (Vgs) versus drain current (Ids) characteristics for the In-doped and the undoped LEC substrates. The sub-threshold current is below 2E-08 (A) for 10μm wide GaAs FETs, for both substrates. From Fig's 7 and 8, it can be concluded that the doped In has no serious influence on GaAs MESFET performance itself.

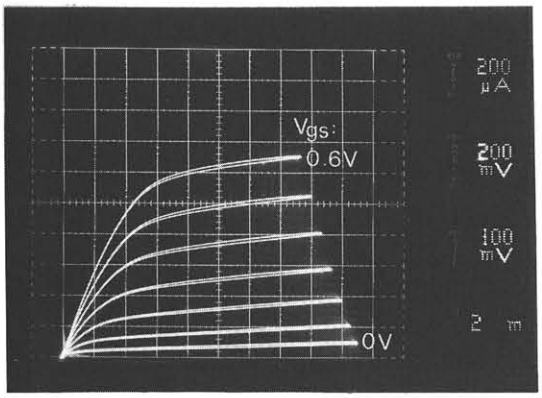

Fig.7 I-V caracteristic of GaAs MESFET fabricated on In-doped LEC substrate. (Lg=1μm, Wg=10μm)

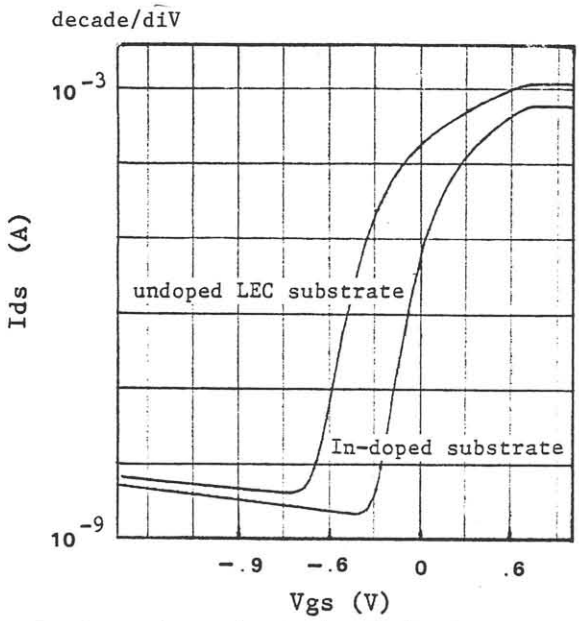

Fig.8 Comparison of sub-threshold characteristics of fabricated LEC substrate.

CONCLUSIONS

The In-doped dislocation-free GaAs substrate has been evaluated from view point of the application to GaAs LSI fabrication. It was demonstrated that the In-doped substrate exhibits a good Vth uniformity for whole wafer (2 inchϕ) as well as for the local area, and that there are no serious obstacles for its application to the GaAs LSI fabrication.

The authors would like to express their thanks to Messrs. T. Nozaki, K.Uetake, I. Sakuma and Dr. J. Matsui for their valuable discussions and to Dr. Y. Takayama and Mr. M. Ohta for their encouragements during the cource of this study.

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