High Mobility SiGe/Si n-Type Structures and Field Effect Transistors on Sapphire Substrates

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***Abstract*—SiGe/Si n-type modulation doped field effect transistors (MODFETs) fabricated on sapphire substrates have been characterized at microwave frequencies for the first time. The highest measured room temperature electron mobility is 1380 cm^2/V-sec at a carrier density of $1.8x10^{12}$ cm^{-2} for a MODFET structure, and 900 cm^2/V-sec at a carrier density of $1.3x10^{12}$ cm^{-2} for a phosphorus ion implanted sample. A two finger, 2 X 200 micron gate n-MODFET has a peak transconductance of 37 mS/mm at a drain to source voltage of 2.5 V and a transducer gain of 6.4 dB at 1 GHz.**

***Index Terms*—SiGe, MODFET, sapphire.**

I. INTRODUCTION

SiGe /Si n-type modulation doped field effect transistors (MODFETs) on sapphire have the potential to integrate high speed Si technology with high quality microwave passives on the same substrate. However, while p-type MODFETs on sapphire have been reported, there are no publications on n-MODFETs on sapphire to our knowledge. All Si based devices on sapphire use silicon-on-sapphire (SOS) as a starting substrate, which has the Si layer in compressive strain. While this aids the fabrication of p-MODFETs, which have compressive strained SiGe channels, it complicates the fabrication of n-MODFETs, which require tensile strained Si channels. Here we report, for the first time, a microwave SiGe/Si n-MODFET device on a sapphire substrate.

II. SUMMARY

High mobility n-type SiGe/Si field effect transistors (FET) transistor structures have been fabricated by MBE on sapphire substrates using strained 100 Å thick silicon channels. The strained Si channels are sandwiched between $Si_{0.7}Ge_{0.3}$ layers, which, in turn, are deposited on $Si_{0.7}Ge_{0.3}$ virtual substrates and graded SiGe buffer layers (Fig. 1). The electrons in the strained Si channels are obtained using two methods: modulation doping of the top $Si_{0.7}Ge_{0.3}$ layer using a delta-doped Sb technique (thereafter called the n-MODFET structure), and phosphorous ion implantation followed by post-annealing. The highest room temperature electron mobilities measured are 1380 cm^2/V-sec at a carrier density of $1.8x10^{12}$ cm^{-2} for the n-MODFET structure, and 900 cm^2/V-sec at a carrier density of $1.3x10^{12}$ cm^{-2} for a phosphorous ion implanted sample (Fig. 2). A systematic study of the ion implanted samples showed that the electron concentration appears to be the key factor that determines mobility, with the highest mobility observed for electron densities in the 1 – $2x10^{12}$ cm^{-2} range (Fig. 2). For the n-MODFET structure, mobility above 13,000 is measured at liquid He temperatures accompanied by Shubnikov de-Haas oscillations, showing the existence of a 2DEG and excellent confinement of the electrons (Fig. 3 and Table 1).

n-MODFETs with gate dimensions of 2 X 200, 3 X 200, and 5 X 200 µm were fabricated on the Sb delta-doped material. The IV characteristics of the 2 X 200 µm gate transistor are shown in Figs. 4 and 5. An I_{DS} of 9 mA is obtained by operating the transistor in an enhancement mode (positive V_{GS}) and the maximum transconductance (g_m) is 37 mS/mm at a V_{DS} of 2.5 V. The transducer gain (G_t) is 4.4 dB at 800 MHz and 6.4 dB at 1 GHz for a V_{DS} of 2.5 V and V_{GS}=-0.4 V.

III. CONCLUSION

n-MODFETs fabricated on r-plane sapphire substrates have demonstrated microwave frequency characteristics for the first time, but further development is required to improve the Schottky contacts and increase the carrier density.

REFERENCES

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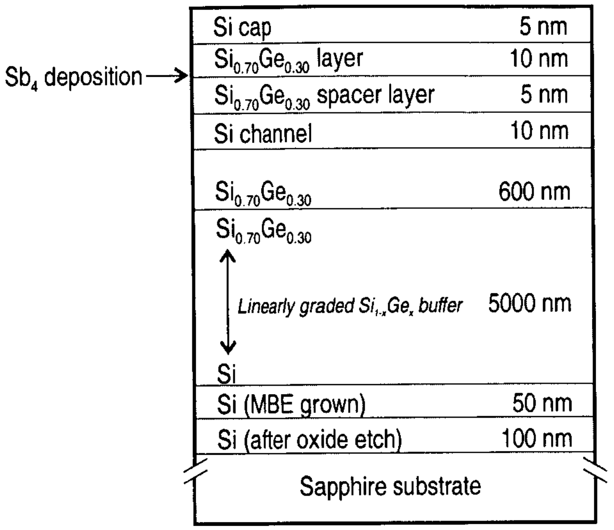

Figure 1: Schematic diagram of buffer layer, virtual substrate, and channel of the n-MODFET SiGe/Si transistor on sapphire substrate.

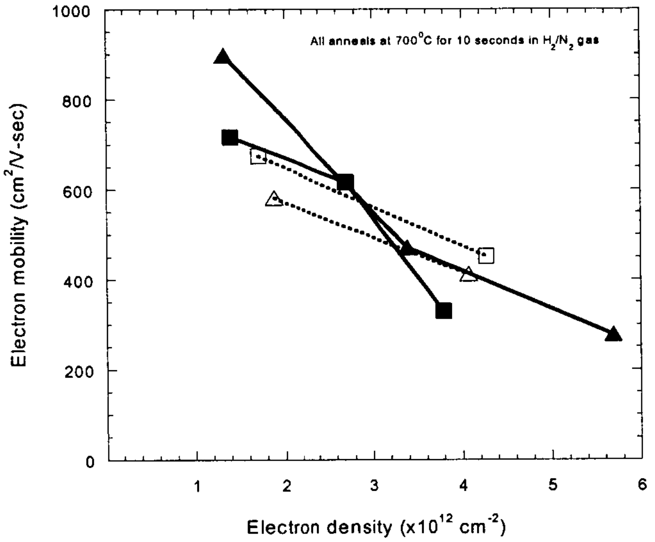

Figure 2: Room temperature mobility versus electron density for the high mobility phosphorous ion implanted SiGe/Si structures with different buffers and surface-to-channel distances.

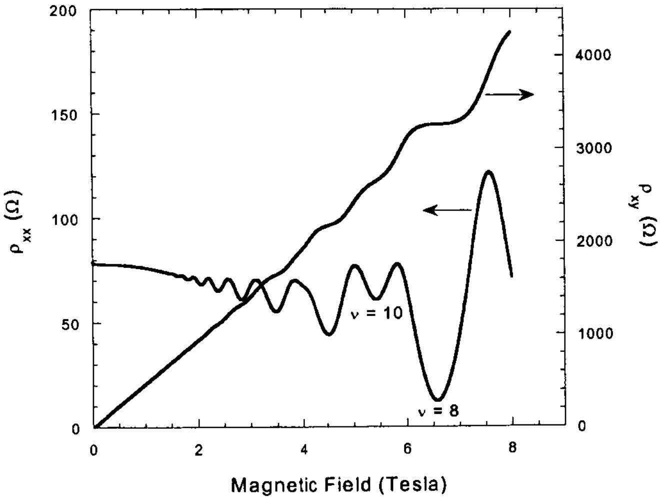

Figure 3: Longitudinal (ρ_{xx}) and Hall (ρ_{xy}) resistivity versus magnetic field for the n-MODFET SiGe/Si structures. Data taken at 0.25K.

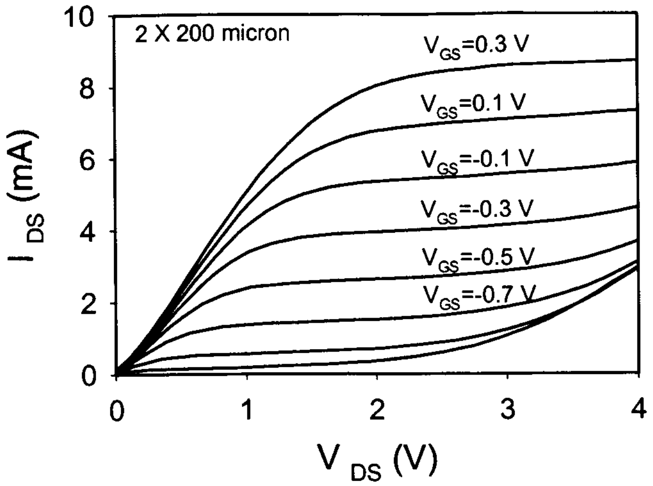

Figure 4: Measured IV characteristics of 2 X 200 micron n-MODFET.

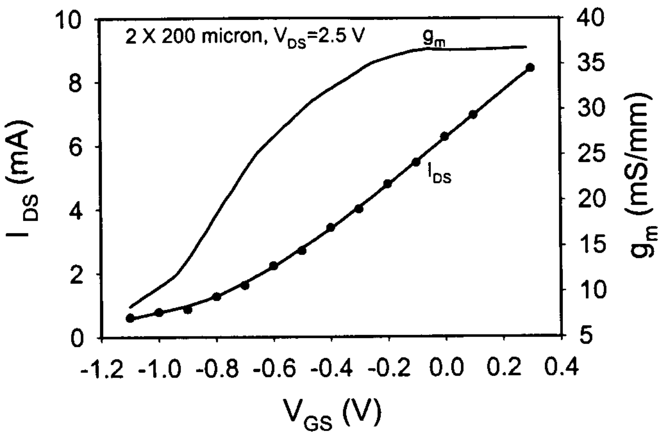

Figure 5: Measured transconductance of 2 X 200 micron n-MODFET.

Table 1: Summary of electron mobility, electron concentration, and sheet resistance at 0.25 and 300 K for n-MODFET SiGe/Si transistors.

Temperature (K)	Electron Concentration ($\times10^{12}$ cm^{-2})	Hall Mobility (cm^2/V-sec)	Sheet Resistance (Ω/sq.)
300	1.6	1271	3073
0.25	1.33	13,313	352