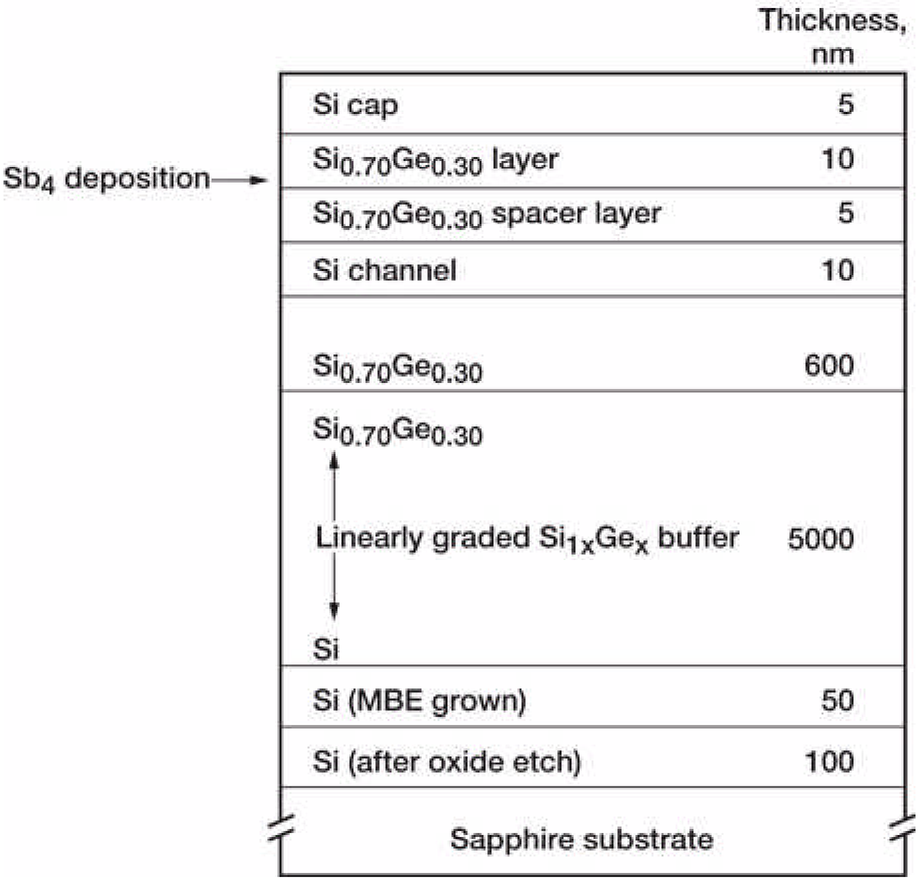
Silicon-Germanium Films Grown on Sapphire for Ka-Band Communications Applications

NASA's vision in the space communications area is to develop a broadband data network in which there is a high degree of interconnectivity among the various satellite systems, ground stations, and wired systems. To accomplish this goal, we will need complex electronic circuits integrating analog and digital data handling at the Ka-band (26 to 40 GHz). The purpose of this project is to show the feasibility of a new technology for Ka-band communications applications, namely silicon germanium (SiGe) on sapphire. This new technology will have several advantages in comparison to the existing silicon-substrate-based circuits. The main advantages are extremely low parasitic reactances that enable much higher quality active and passive components, better device isolation, higher radiation tolerance, and the integration of digital and analog circuitry on a single chip.

Specifically, the purpose of this research was to grow, for the first time, SiGe films on sapphire suitable for electron conduction transistors and to evaluate whether or not the quality of these films will prove adequate for high-frequency applications. To date, these films have not been reported in the literature for SiGe electronic conduction devices at any frequency. All the work except the molecular beam epitaxy (MBE) step was performed at the NASA Glenn Research Center. MBE growth was done at HRL Laboratories LLC.

Actual work included three steps:device modeling, material fabrication, and material characterization. The first step in the work was the modeling of various SiGe film structures and transistors for their Ka-band performance. The results of this step set the starting values for the layer structure needed for the SiGe transistor and the required electron mobility for Ka-band operation, namely a mobility of at least 700 cm^2/V-sec. The fabrication step included substrate preparation and MBE film growth. Researchers started with 4-in. commercial silicon-on-sapphire wafers. Then, the top Si layer on each wafer was amorphized, recrystallized, and thinned down to roughly 100 nm. The MBE growth used several buffer layers and virtual substrates, with one example of a final structure shown in the diagram on the preceding page. Several structures were investigated in this study. In the characterization step, the following techniques were used: Hall effect, high-resolution x-ray diffractometry, secondary ion mass spectroscopy, atomic force microscopy, and transmission electron microscopy. The results showed high-quality crystalline SiGe and strained Si active layers, with the correct dopings and Ge concentrations. Most importantly, measurements at room temperature showed electron mobilities as high as 1300 cm^2/V-sec. This result proved that this material is now ready to be used for SiGe transistors working in the Ka-band and fabricated on sapphire substrates.



Schematic diagram of SiGe transistor structure on a sapphire substrate, including the virtual SiGe substrate, the graded buffer, and the top active channel layers.
Diagram of structure layers with thicknesses, showing (top to bottom) 5-nanometer Si cap, 10-nanometer $Si_{0.70}Ge_{0.30}$ layer, Sb_4 deposition, 5-nanometer $Si_{0.70}Ge_{0.30}$ spacer layer, 10-nanometer Si channel, 600-nanometer $Si_{0.70}Ge_{0.30}$, 5000-nanometer linear gradient from $Si_{0.70}Ge_{0.30}$ to Si, 50-nanometer Si (MBE grown), 100-nanometer Si (after oxide etch), and sapphire substrate.

Bibliography

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