

Epitaxial growth of nitrides on germanium

Summary

The interesting physical properties of III-Nitrides allow the fabrication of many devices such as high electron mobility transistors (HEMTs) and blue light emitting diodes (LEDs). The lack of suitable substrates forces nitrides growth on foreign substrates. Sapphire, SiC and Si are most commonly used. In this work the growth of GaN on Ge(111) by molecular beam epitaxy is investigated for the first time. In spite of the huge lattice mismatch between GaN and Ge(111) of more than -20 %, the GaN crystal quality turns out surprisingly good. It is shown that the quality of InN improves significantly when using a thin GaN interlayer in comparison with direct growth on Ge. Structural investigations show the existence of misoriented GaN domains, rotated in the plane of growth. The use of off axis Ge(111) substrates circumvents the formation of domains with 2 different orientations and leads to GaN of one orientation. The excellent results of GaN on Ge(111) are explained by the formation of a thin crystalline Ge_3N_4 layer just before the growth, which accommodates for the lattice mismatch and prevents mixed polarity in the GaN film by making the surface polar.

In 1930 germanium nitride was synthesized for the first time. Different methods have been used since this date to obtain GeN. Renewed interest in Ge complementary metal-oxide-semiconductor (CMOS) has led to the search of an appropriate germanium passivation material. Only amorphous and poly crystalline GeN layers had been obtained so far. Resulting from the work on GaN growth on Ge(111), a method to obtain single crystalline Ge_3N_4 on Ge(111) is developed. The exposure of Ge(111) to a nitrogen plasma at temperatures above which Ge_3N_4 is thermally stable leads to the formation of a thin, mono crystalline Ge_3N_4 layer. At these temperatures, equilibrium is established between the formation and dissociation of Ge_3N_4 , limiting its thickness to 0.7 nm at 800 °C. The thermal stability of a crystalline Ge_3N_4 layer is comparable to an amorphous one. It starts to evaporate at temperatures above 600 °C. The passivation properties of this Ge_3N_4 are investigated by CV measurements.

Severe Fermi level pinning at the interface between n-Ge and a metal leads to the formation of a Schottky barrier, almost independent on the metal work function. Therefore, it seems impossible to form metal Ohmic contacts on moderately, n-type doped Ge layers. For p-type Ge, the Fermi level pinning works opposite: all metal contacts show Ohmic behaviour. This work presents a simple but effective way to alter this fixed behaviour, namely the introduction of a thin Ge_3N_4 layer. Ge_3N_4 seems effective in reducing Fermi level pinning and, therefore, allows the formation of Ohmic contacts on n-type Ge and rectifying contacts on p-type Ge.

Heteroepitaxy of germanium on silicon is a research topic of significant technological importance, because of the potential of Ge devices and compatibility with Si based technology. The large lattice mismatch between Ge and Si of 4 % makes it difficult to obtain high quality crystalline Ge on Si substrates. The lattice mismatch leads to a high surface roughness due to island growth and high

densities of threading dislocations in the Ge epilayers. A new approach to obtain crystalline Ge on Si is investigated in this work. Crystallization of amorphous hydrogenated germanium is proven to work well on Si(111). Smooth surfaces and 100 % crystalline layers were obtained. An annealing temperature of 400 °C is sufficient for crystallization. The presented approach is a cheap and simple way to obtain crystalline germanium on silicon. Twins are however observed in the Ge layer. Avoiding these twins is necessary to improve the crystal quality further.