Positive charge compensation with interface HfO_2 layer in SOS structures formed by silicon layer transfer on c-sapphire

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The well known problems of heterointegration of mismatched materials for post-Moore law electronics were solved for silicon-on-sapphire (SOS) structures using hydrogen induced transfer of thin SiO_2Si heterolayers on Si substrate [1], or by direct bonding of silicon-on insulator (SOI) wafer with sapphire wafer and followed etching of sacrificial silicon substrate from SOI wafer [2]. Earlier we have suggested using for mass SOI production more simple hydrogen induced transfer of only Si layers from hydrogen irradiated silicon wafer without the additional SiO_2 layer. Such approach allows avoiding at hydrogen irradiation the mobile positive charge and scattering center formation in the future buried oxide (BOX), which degrade charge carrier mobilities in the upper Si layer on BOX [3].

The same method was useful also in the case of hydrogen induced Si layer transfer during hot bonding of silicon and sapphire wafers [4]. The transfer of monocrystalline layer of silicon on sapphire wafers treated by O_2 plasma provides the full integrity at the interfaces. Si films with thickness 0.1-2.0 μm were successfully formed in SOS structures with electronic properties very similar the same in SOI wafers. But high temperature annealing at 800-1100°C needed for SOS wafers leads to an introduction of high effective positive charge $Q_i \sim +3x10^{12}$ см$^{-2}$ (or oriented dipoles) at the interface between silicon and sapphire and strong conductivity in Si film due to an electron accumulation. CV measured flat band voltages V_{FB} were observed below -4 kV even for 70 μm thickness of sapphire. Usual method to avoid this charge accumulation is using a stack of different high-k dielectrics with opposite sign of charges in the stack [5]. According to the literature the negative charge at SiO_2/ALD Al_2O_3 stack can be compensated by positive charge in HfO_2. We used in our work similar 10-20 nm PEALD HfO_2 interface layer despite of another sign of the interface charge at the monocrystalline surface of Al_2O_3 c-sapphire.

Cross-section HREM investigation shown us a complete recrystallization of PEALD HfO_2 layers in tetragonal or cubic phases after annealing at 1100°C. Pseudo-MOS measurements revealed remarkable compensation of positive charge to $Q_i \sim +1.4x10^{12}$ см$^{-2}$ and V_{FB} = -1.54 kV. Moreover we observed a clear evidence of ferroelectric FET operation mode with strong repeatability in such structures.

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