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Oxygen-related activity and other specific electrical properties of SIMOX

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Electrical measurements in SIMOX films which explore the activation of oxygen donors, the origin of unintentional impurities and the transport properties at low temperature are reported. Thermal donors and new donors are reviewed in terms of generation rate, energy level, temperature range, kinetics and annihilation. The influence of the parameters used in the synthesis of various SIMOX substrates is emphasized. Several sources of contamination (implantation, capping layer, annealing ambient) are identified by the Hall effect and MOS device characterization. The region with lower crystallinity situated near the buried interface is found to dominate photo-transport properties at very low temperatures. Enhanced performance of integrated circuits is obtained by lowering the temperature, in particular in totally depleted thin film transistors.

1. Introduction

A vigorous research programme in the last five years has promoted SIMOX to a privileged material for the future of microelectronics. SIMOX technology today provides the fastest components ever integrated in Si-based substrates. Nevertheless, this exciting performance should not mask the fact that the characterization work is lagging behind the technological progress. Indeed, the adaptation of structural and electrical methods of inspection in very thin and multilayered materials is rather difficult[1]. This explains why a number of basic aspects are not fully understood and the fabrication parameters not yet optimized. It is accepted that a reasonably good material is obtained by (1) implanting 1.4–1.8×10^{18} O cm^{-2} with 200 keV at about 600°C and (2) annealing at high temperature for several hours[2,3]. These parameters should, however, be more carefully scanned before establishing a suitable 'standard' of SIMOX. Controversial aspects are still related to the origin of dislocations, their electrical influence, annealing ambient and process-induced contamination.

The aim of this paper is to present and discuss a number of specific electrical properties of SIMOX which have not been explored intensively until now. The main section is devoted to the activation of oxygen donors and their impact on integrated circuits. The consequences of post-implantation anneals in low and high temperatures are compared. Experimental data and preliminary models describing the origin, kinetics and annihilation of both thermal donors and new donors are proposed. In Section 3, various sources of contamination of SIMOX are identified and evaluated. The final section presents transport features in low temperature, with distinction being made between the volume properties in as-grown material and performance improvement in MOS devices.

2. Oxygen donors

2.1. Influence on integrated circuits. It is well known that oxygen can be electrically activated in Si by annealing at 400–800°C and that it generates a variety of donor species. The resulting free electrons remain mobile even after cooling down at room temperature. Oxygen donors are therefore able to modify the intentional doping level and to degrade the basic parameters of MOS transistors (threshold voltage, transconductance, subthreshold swing). This problem is tremendously important since the final anneal during the processing of integrated circuits is for metallization sintering at about 450°C, i.e. exactly in the region of intensive generation of donors.

The fundamental and technological aspects related to the formation and annihilation of oxygen donors in Si have received attention for many years[4]. It was demonstrated that the major parameter is the residual concentration of oxygen (C_{ox}): the initial generation rate of oxygen donors is proportional to $(C_{ox})^4$ and their total number is proportional to $(C_{ox})^3$. In this respect, oxygen donors are a priori even more prejudicial in SIMOX due to the very high dose of oxygen received.

A practical example is considered in Figure 1. During oxygen implantation the beam-induced temperature of the wafer is higher in the centre than on the edges, leading to a higher residual concentration of oxygen and to a more active generation of donors in the centre[5]. Not only the threshold voltage but also the transistor transconductance are modified *non-uniformly* across the wafer. The transconductance variation was explained by the 'doping-induced channel length modulation'[6]: the effective doping governs the extension of source and drain depletion regions and thus controls the channel length and transconductance. The calculations of Figure 1 were performed using this simple model and without knowledge of the full set of processing parameters. However, the results are very similar to those obtained experimentally by Davis *et al*[5] as they both show opposite behaviours for n-channel and p-channel MOSFETs. In p-channel transistors, the effective doping (sum of intentional donors and oxygen donors) decreases from the centre of the wafer to the edges and makes the threshold voltage less negative. Simultaneously, the channel length is progressively reduced and the transconductance increased. In n-channel transistors, the effective doping is given by the difference between intentional acceptors and oxygen