In Proceedings of Symposium on Ion-Solid Interactions for Materials Modification, Boston, Massachusetts, November 27-December 1, 1995, Volume 396. D. B. Poker, D. Ila, Y.-T. Cheng, L. R. Harriott, and T. W. Sigmon, Editors, Materials Research Society, Pittsburgh, PA, 1996.

PROPERTIES OF SILICON-ON-DEFECT-LAYER MATERIAL

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ABSTRACT

A new silicon material, silicon-on-defect-layer (SODL), has been measured by secondary ion mass spectrometry (SIMS) and spreading resistivity (SR) measurements. SIMS data show that the buried defect-layer in SODL consists of silicon oxide due to the gettering of intrinsic oxygen by proton-implanted damage. Furthermore, SODL procedure makes a silicon wafer contain much fewer oxygen in surface-layer on the defect-layer, resulting in a purified surface-layer. Measurements of SR indicate that the surface-layer of n-type silicon wafer was converted to p-type silicon after SODL procedure. A metal oxide semiconductor (MOS) device with a value of the electron mobility in the inversion mode of $714 \text{ cm}^2/(\text{V} \cdot \text{s})$ was fabricated on SODL material. Like isolation function of a well in a complementary MOS (CMOS) device, the p-n junction in SODL material could play a role of isolation between the surface-layer and bulk. In addition, by reducing the implantation energy, SODL technology for making p-n junction, in which built-in field separates light-generated electrons and holes, is a candidate to make cheap solar cells by using low-quality low-cost silicon.

INTRODUCTION

A novel silicon structure consisting of silicon-on-defect-layer (SODL), with a thermally stable buried defect layer (DL) beneath the surface, has been produced¹⁻³ which may have properties similar to silicon-on-insulator (SOI) material.⁴ The purpose of this letter is to report new measurements on SODL that verify its application potential.

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The next generation of very-large-scale-integration (VLSI) circuits fabricated on surface regions of the silicon wafers will require wafers with fewer impurities at the surface; but conventional gettering treatments, which create gettering centers (defect regions) at the center or backside of wafers, are not effective for SOI devices. Thus, enhancement of the gettering efficiency by placing the gettering centers closer to the active area of the device, as in the SODL process, offers a significant advantage for fabricating selectively a high-purity surface layer.

SOI materials are currently produced using separation by implanted oxygen (SIMOX). In this case, high density dislocations are produced in the surface region and high oxygen doses are needed to form the buried isolation layer. Therefore, SODL produced using hydrogen beams may be a useful improvement to this approach since it can be produced with lower doses and has fewer defects at the surface. SODL provides a major cost reduction factor.

EXPERIMENT

The SODL material was produced following the procedures originally described by Li.¹⁻³ The silicon wafer was n-type (100) Czochralski (CZ) with a resistivity of about 40 $\Omega\text{-cm}$ cut 0° off axis. The implantation was carried out with H^+ ion beams at an energy of 180 keV. The beam currents were 120 μA . The beam size was approximately 5 mm, and the dose was 3×10^{16} protons/cm². The wafers were then annealed at 900°C for 10 seconds and 1180°C for 20 minutes. A metal oxide semiconductor field effect transistor (MOSFET) was fabricated on the SODL material. Al was evaporated for the source and drain contacts. $\text{SiO} + \text{O}_2$ (1×10^{-4} Torr) and Cr were evaporated for the gate oxide and gate metal, respectively.

RESULTS

Spreading resistivity measurements were made after the two annealing steps to define the electrical characteristics of the material. The results, as shown in Fig. 1, indicate that the resistivity of the surface layer has been substantially lowered compared to the value for the bulk material. The maximum of the resistance at the defect layer is estimated to be in the neighborhood of $10^8 \Omega$. The results corroborate the numerical values given by Li.¹⁻³ In addition, note that the implantation causes a change from n-type to p-type material in the surface layer. Although this transformation has been observed previously,⁵⁻¹⁰ conversion to p-type material is reported here for the first time for SODL material after two annealing steps.

The SIMS measurements shown in Figs. 2 and 3 were done to determine the depth distribution of hydrogen and oxygen in the implanted material. Initial hydrogen distributions were consistent with the predictions

FIG. 1. Spreading resistivity determination on SODL material produced as described in the text. Resistivity values and type of silicon (p-or n-type) are shown as a function of depth below the surface.

FIG. 2. SIMS measurement showing depth distribution of hydrogen in hydrogen-implanted silicon after the first (L4) and second (L2) annealing steps described in the text.

FIG. 3. SIMS measurement showing depth distribution of oxygen in hydrogen-implanted silicon after the first (L4) and second (L2) annealing steps described in the text.

of the TRIM 92 code of Ziegler *et al.*¹¹ It was found that the hydrogen concentration was essentially eliminated following the second annealing procedure, but the peak in spreading resistivity indicated that the defect layer was still present. Furthermore, the oxygen distribution in the surface layer is decreased by about one order of magnitude after the second annealing procedure, apparently by gettering of the impurities by the defect layer. The distribution observed indicates the defect layer comprises a silicon oxide (SiO_x) component. Also, we found that the width of the SiO_x is about 200 nm.

Measurements of mobility and channel mobilities in the MOSFET were also performed. The gate threshold voltage was 2V, transconductance 1.25×10^{-4} mhos, and the calculated field effect electron mobility $714 \text{ cm}^2/(\text{V} \cdot \text{s})$. The average carrier concentration and mobility were also determined for the surface p-layer by determination of the Hall mobility. It was assumed that the n-substrate did not contribute to conduction because of its isolation from the p-n junction and because of its much higher resistivity. An average value of $200 \text{ cm}^2/(\text{V} \cdot \text{s})$ was found for the hole mobility at room temperature—which is slightly less than the accepted value of $250 \text{ cm}^2/(\text{V} \cdot \text{s})$ for silicon of this resistivity.

CONCLUSIONS

The experimental results we have obtained verify the earlier results obtained in Beijing for the existence of a high resistivity region in the hydrogen implanted silicon. The SIMS measurements demonstrate the gettering of oxygen by the defect region and also show that little hydrogen is left after the second annealing step. The mobility values, reported here for the first time, show that the material may be suitable as the starting point for VLSI CMOS device production and the selective transformation of n-type to p-type Si in the surface layers provides an opportunity for improved architecture. Thus it is concluded from this comparison that the performance achieved in the SODI material at the present time makes it worthy of consideration for further developments and for use in production of semiconductor devices.

ACKNOWLEDGMENTS

This work was supported in part by a Cooperative Research and Development Agreement, BNL-C-92-02, between Brookhaven National Laboratory and Plasma Physics Corporation, and the U. S. Department of Energy under Contract No. DE-AC02-76CH00016. This work was done in the period from 1992 to 1994. The spreading resistivity measurements were done by the Solecon Labs, San Jose, CA 95131; the SIMS measurements by Charles D. Evans Associates, Redwood City, CA 94063.

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