Overview of SOI materials technology in China

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Abstract In recent years, novel structure SOI materials have been fabricated successfully. Also, SiGeOI (SGOI) material, an ideal substrate for realizing strained-silicon structures, has been investigated by modified SIMOX technology. From 2002, the 100 mm, 125 mm and 150 mm SIMOX wafers have been successfully produced by Shanghai Simgui Technology Co. Ltd, a commercial spin-off of Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS), and shipped to the semiconductor industry worldwide. This paper presents an outlook for R & D on SOI technologies, and the recent status and future prospect of SIMOX wafers in China.

Key words Silicon-on-insulator(SOI), Ion implantation, Separation by implanted oxygen (SIMOX)

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1 Introduction

The SOI technology is now moving into commercial product applications, particularly for high performance and low power CMOS circuits, radiation hardness devices and high temperature electronics. Trends in the SOI material initiated a new branch of the silicon based industry.[1,2]

Chinese Silicon-on-Insulator (SOI) work began in the early 1970s with Silicon-on-Sapphire (SOS) devices. From the early 1980s, new technologies of SOI were developed.[3-7] These new technologies include: zone melting recrystallization (ZMR) of polycrystalline or amorphous silicon on insulator by using CW Ar^{+} laser, electron beam and a graphite strip heater; separation by implanted oxygen (SIMOX) and separation by implanted nitrogen (SIMNI); bond and etch-back SOI (BESOI); full isolation by porous oxidized silicon (FIPOS); epitaxial lateral overgrowth (ELO), Smart-cut and epitaxial layer transfer (ELTRAN).

Studies on device physics and device applications of SOI are of current special interest in China, which includes: 1) SOI device physics and modeling of partially depleted and fully depleted SOI MOSFET's, for example, floating body effect, self-heating effect, modeling of the threshold voltage and *I-V* of deep-submicrometer fully depleted SOI MOSFET's, and so on; 2) SOI application for low voltage, low power and high speed CMOS devices, for example, 64K CMOS/SIMOX static RAM's; 3) MEMS, high temperature pressure sensor and SOI optical waveguides; 4) new applications of SOI technology, for example, thin film SOI for high performance system-on-chip application, double gate SOI MOS device.

The SOI group of Shanghai Institute of Microsystem and Information Technology (SIMIT) was established in the beginning of 1980's with its first patent in SOI materials in 1985. Currently, there are two labs involved in SOI technology R&D: Ion Beam Laboratory – the key lab of CAS; and Laboratory of Functional Materials for Informatics– a state key lab.

Shanghai Simgui Technology Co., Ltd. is a high-tech company, which manufactures SOI wafers and markets the wafers to the semiconducter industry worldwide. The company is a commercial spin-off of Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences. Simgui established in Shanghai in July 2001. In December 2001, Ibis 1000 implanter arrived in China, and construction of the Simgui factory began. Simgui com-

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pleted installation of its SIMOX production line, and successfully produced its first batch of SOI wafers in July 2002.

2 SIMOX process optimization

In recent years, there has been a growing interest in low dose (dose<1.0×10^{18}cm^{-2}) separation-by-implantation of oxygen (SIMOX) SOI materials because thin buried oxide (BOX) SIMOX has been shown to improve wafer quality in all aspects as compared with a full dose SIMOX wafer, such as drastically reduced threading dislocation density, metallic contamination, uniformity of SOI and BOX layers, due to the lowered oxygen dose by reducing the implantation time, which simultaneously makes it possible to cut down the production cost. An effort was made to directly fabricate high quality low-dose SIMOX wafers by optimizing the dose energy match. The relationship between the quality of low dose SIMOX wafers and the dose-energy match was investigated.[8-10]

Our study reveals a method to directly form high-quality low-dose SIMOX materials from a good dose-energy match. The higher the oxygen dose, the higher the implanted energy required for the formation of low Si-islands BOX layer. For samples implanted at the energies of 160 keV, 130 keV, 100 keV, and 70 keV, the respective optimum doses are 5.5×10^{17} cm^{-2}, 4.5×10^{17} cm^{-2}, 3.5×10^{17} cm^{-2}, and 2.5×10^{17} cm^{-2}. The effect of dose energy match is due to the oxygen profile in the as-implanted materials, which is optimized by the dose-energy match. Fig.1 plots a series of good matches of dose-energy combination for the formation of high-quality low-dose SIMOX materials. In Fig.1, the solid circles come from present experiments, the solid line is plotted as a guide. It is seen around the solid line, that high-quality SIMOX wafers have been fabricated with fixed cleaning and annealing procedures from a series of good dose-energy matches. This work also indicates a possibility to directly fabricate ultra thin SIMOX materials with ultra thin SOI and BOX layers by selecting an optimum low energy, low-dose implantation.

Patterned SOI technology is an attractive approach to solve the floating-body and self-heating effects, which degrade the SOI device performance and reliability. In our work, SIMOX technique was used to fabricate patterned SOI materials. We have studied the effect of process parameters, such as implantation dose and energy on the quality of patterned SOI materials. We have developed an optimized low-dose and low-energy SIMOX process to manufacture patterned SOI materials with improved quality. The patterned SOI materials prepared with this new SIMOX process exhibit high quality, which is indicated by the low defect transition of SOI and bulk silicon region, a high degree of surface planarity and a high-integrity BOX layer without detectable silicon islands. At the same time, the DSOI (drain and source on insulator) device was fabricated by combination of patterned SIMOX and conventional CMOS technologies.

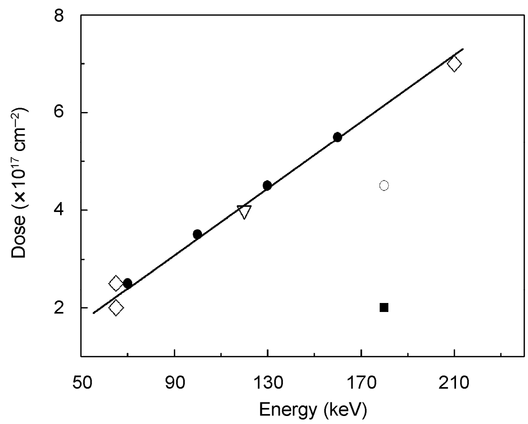

Fig.1 Plot of a series of good dose-energy matches for the formation of high-quality low-dose SIMOX materials.

3 Novel SOI structure

More recently, in most SOI structure, taking SiO_2 as buried layer greatly limited SOI materials in applications to high temperature, high power integrated circuits because of its lower thermal conductivity. In order to resolve the problem and meet the demand of special device/circuit, there has been a strong interest in the development of new SOI structures. Replacement of the buried silicon dioxide by a better thermal conductor could minimize the effect effectively.[11,12]

One of the interesting candidates for such novel buried insulators is aluminum nitride (AlN). The SOI structure with AlN as a buried layer has been fabricated successfully by the Smart-cut process. XTEM micrograph, as shown in Fig.2, confirms the formation of the SOI structure. In addition, the top Si has a good crystal quality and electrical quality indicated by high resolution XTEM image and SRP results.

We have erected the elementary model of temperature distribution and investigated the mechanisms of giving birth to the self-heating effect for SOI device. To suppress the self-heating effect of SOI device effectively, we have proposed some new kinds of SOI structures, such as silicon-on-AlN and sandwiched-layer SOI, which all have the ability to reduce the self-heating effect effectively. Specially, we have taken the lead in bringing forward the sandwiched-layer/SOI, which is a multi-layered structure formed by $SiO_2/Si_3N_4/SiO_2$. We have also simulated the electrical characteristics of all these new kinds of structures and got many results, which could prove that these kinds of SOI structures can reduce the self-heating effect of SOI device availably.

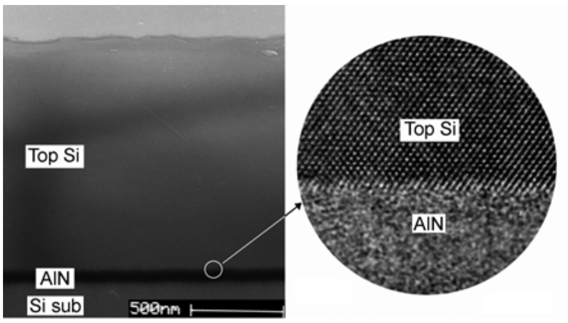

Fig.2 Cross-sectional TEM micrograph of the SOI sample (left) and high-resolution XTEM image of the top Si / buried AlN interface (right).

4 SGOI advanced materials

SiGe-on-insulator (SGOI) technology is one of the most advanced technologies in nowadays microelectronics, which combines advantages of both SiGe and silicon-on-insulator (SOI) technologies. It has a great potential in future applications in high speed, low power and high density integrated circuits, opto-electronics, system-on-chip (SOC) and so on. Particularly, it is almost an ideal substrate material for realizing strained-silicon substrates which are very competing and popular in present silicon technology. Unfortunately, SGOI research is greatly hampered by many difficulties and now is at its very beginning, thus has a long way to go. Thereby, we propose a method to fabricate SGOI novel structure with separation by implantation of oxygen (SIMOX), starting directly from pseudomorphic SiGe thin films.[13,14]

Successful growth of high quality SiGe film on Si substrate has been carried out at an ultra-high vacuum chemical vapor deposition (UHVCVD) system. Various characterizations showed that the SiGe film has a good single-crystal quality, the Ge content in the SiGe layer is uniform and about 14%. It has a strain rate of 95%, thus is almost fully strained.

For the first time, we have realized a SGOI structure with SIMOX process from pseudodomorphic SiGe thin film, abandoning the graded SiGe buffer layer, which is widely used in previous reports. The modified SIMOX process fits well for SGOI fabrication.

Fig.3 depicts the elemental depth profile acquired by Auger electron spectroscopy (AES) of the sample annealed at 800℃+1350℃. A good SiO_2/SiGe/SiO_2/Si structure is revealed. The surface oxide that is about 48 nm originates from oxidation during high temperature annealing (1350℃), indicating that the top Si cap layer has been completely oxidized and a small thickness of SiGe has been consumed. The remaining SiGe layer is about 70 nm thick with a Ge content of about 8%. It is smaller than the original Ge content due to Ge penetration through the buried oxide layer during high temperature annealing. We will later show that the heat treatment step at a moderate temperature reduces Ge loss. The buried oxide is about 32 nm thick and the original SiGe/Si interface has been substituted by this buried oxide layer. Particularly, the upper interface of the buried oxide (SiGe/SiO_2) is extremely steep. The Ge signals in the surface oxide and buried oxide layer are negligible because of Ge rejection during surface oxidation and buried oxide formation.

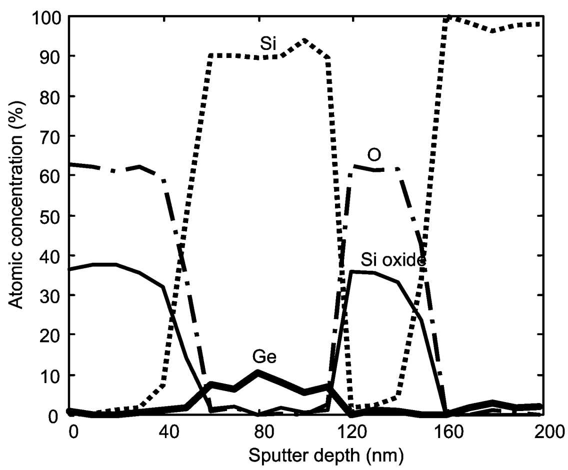

Fig.3 Elemental depth profiles acquired using sputtering Auger electron spectroscopy (AES) from the sample annealed at 800℃+1350℃.

5 SIMOX wafers produced in China

Studies on SOI materials and SOI devices are of current special interest in China. More than 10 institutions are working on SOI materials and their applications. For example, the high-current oxygen ion implanter and its application for SIMOX material processing are investigated in the 48th Research Institute of China Electronics Technology Group Corporation, Changsha. The CMOS/SOI technology in sub-100nm regime is investigated in Peking University, Tsinghua University, Institute of Microelectronics, Chinese Academy of Sciences, and so on. The technology of bond and etch-back SOI (BESOI) and its application for MEMS are developed in Southeast University and the 24th Research Institute of China Electronics Technology Group Corporation, Chongqing.

Simgui specializes in the production of 100 mm, 125 mm and 150 mm SIMOX wafers. The company also has the capability to produce 200 mm wafers. The optimum thickness of the top silicon layer (above the buried oxide layer) will vary depending on your applications. With the aid of precision equipment and in-house epi-facilities, Simgui can produce wafers with a top layer as thin as 50 nanometers, or as thick as 10 micrometers or more. A thicker top layer is especially important for optical communication and MEMS devices. High resistivity is necessary for wafers used in radio frequency devices. Simgui has the capability to fabricate wafers with resistivity up to 1,000 ohm·cm. Simgui understands the need for flexibility. Whether your demand is large or small, Simgui can and will meet it.

Simgui wafers are guaranteed to meet the international semiconductor standard, and satisfy the demands of today's mainstream IC fabrication lines. Every product, every process and every facility is constantly monitored with the aid of advanced quality characterizing tools and a statistical process control system. Meanwhile, regular inspection and training of all engineers and operators ensures that the human side of the operation is running smoothly.

Simgui is a young company with a long history. Twenty percent of its personnel have earned their PhDs through research into SOI technology. The research institute (SIMIT), several of whose members formed the core of Simgui, continues to support the company in its R&D projects. Through SIMIT Simgui enjoys the technical backing of the Chinese Academy of Sciences.

Though Simgui's profound understanding of SOI technology is at the heart of its success, the company is not purely reliant on technical expertise. A team of highly professional and dynamic managers, and a small body of hand-picked, highly skilled engineers and operators contribute their rich practical experience to the company.

Simgui's mission is quite simply to become a major player in the global SOI wafer industry. Far from satisfied with its leading position in China's IC industry, the company is constantly expanding its capability and capacity in order to meet fresh challenges. It has already considerable local and overseas investment, and shows potential for rapid and sustainable growth.

This expansion is closely guided, however, by a highly qualified R&D team dedicated to explore new possibilities in the field of SOI technology. Simgui is currently engaged in several large-scale research projects, which aim to supply the future needs of emerging industrial applications. The company's aim is not just to keep up with developments in silicon wafer technology, but to lead them.

Simgui's vision is of growing together with its customers, employees and suppliers. To its customers, Simgui promises to improve their performance, meet their needs and give them the very best solutions SOI technology can offer. To its employees, Simgui will provide an exciting and supportive work environment, ongoing training and the opportunity to participate in groundbreaking projects. Last but not least, Simgui will maintain and build on its partnerships with its suppliers to reach ever higher levels of technological achievement.

There is a Chinese saying that "the longest journey begins with just one step." For Simgui, that journey has only just begun.

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