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The reduction of critical H implantation dose for ion cut by incorporating B-doped SiGe/Si superlattice into Si substrate

Zhongying Xue[a,*], Da Chen[b], Pengfei Jia[a], Xing Wei[a], Zengfeng Di[a], Miao Zhang[a,*]

[a] State Key Laboratory of Functional Materials for Informatics, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, 865 Changning Road, Shanghai, 200050, China
[b] Department of Microelectronic Science and Engineering, Ningbo University, Ningbo 315211, China

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ABSTRACT

An approach to achieve Si or SiGe film exfoliation with as low as $3 \times 10^{16}/cm^2$ H implantation dose was investigated. Two intrinsic $Si_{0.75}Ge_{0.25}$/Si samples, merged with B-doped $Si_{0.75}Ge_{0.25}$ layer and B-doped $Si_{0.75}Ge_{0.25}$/Si superlattice (SL) layer respectively, were used to study the formation of crack after $3 \times 10^{16}/cm^2$ H implantation and annealing. For the sample into which B doped $Si_{0.75}Ge_{0.25}$ layer is incorporated, only few discrete cracks are observed along both sides of the B doped $Si_{0.75}Ge_{0.25}$ layer; on the contrary, a continuous (100) oriented crack is formed in the B-doped $Si_{0.75}Ge_{0.25}$/Si SL layer, which means ion cut can be achieved using this material with $3 \times 10^{16}/cm^2$ H implantation. As the SIMS profiles confirm that hydrogen tends to be trapped at B-doped SiGe/Si interface, the formation of continuous crack in SL layer can be ascribed to the more efficient hydrogen trapping by the multiple B-doped SiGe/Si interfaces.

1. Introduction

As a well known technique, ion cut process based on H implantation and wafer bonding has been employed to manufacture commercial silicon-on-insulator (SOI). Recently, ion cut technique has also been applied to fabricate SiGe-on-insulator (SGOI) and Germanium-on-insulator (GOI) [1–3]. SGOI and GOI materials, excelling in carrier mobility and having such advantages inherent to "on-insulator" structures as low parasitic capacitance, low leakage current and immunity to short channel effects, have been considered to be prospective channel materials for high performance Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) in future technology nodes. However, due to the high stopping power of Ge atoms and the low mobility of point defects within the collision cascades, Ge is more likely to become amorphous than Si under ion implantation [4], which hampers the application of SGOI and GOI in IC industry. Therefore, developing a novel H implantation technique or considerably reducing the H implantation fluence becomes a big challenge to make high quality SGOI and GOI by ion cut technique.

Utilizing plasma hydrogenation technique replacing conventional H implantation has been proposed to facilitate ion cut process with lower radiation damage. In these approaches, different H trapping centers such as B-doped Si [5], Sb-doped Si [6] or strained SiGe [7] were merged to capture H efficiently. However, plasma hydrogenation is a thermal process that triggers the simultaneous occurrence of surface blistering, which, in turn, impedes the subsequent bonding process. On the contrary, conventional H implantation combined with high efficiency H trapping center may achieve ion cut with a prominently decreased H implantation dose. Recently, we have demonstrated an approach to create SGOI with half of typical H implantation fluence by inserting between $Si_{0.75}Ge_{0.25}$ epitaxial layer and Si substrate a B doped $Si_{0.70}Ge_{0.30}$ layer as a trapping center [8]. However, in order to trap sufficient H to form continuous cracking, the B doping concentration should be as high as $2 \times 10^{19}/cm^3$. In this work, we present a modified method to produce SGOI with $3 \times 10^{16}/cm^2$ H fluence by combining B doped SiGe/Si superlattice (SL) with substrate, where the B concentration could dwindle to $8 \times 10^{18}/cm^3$.

2. Experimental

Two SiGe heterostructures were epitaxially grown on p-type 8-inch Si (100) substrates in a commercial reduced pressure chemical vapor deposition (RPCVD) system. Before deposition was carried out, Si substrates were cleaned in the standard RCA-1 and RCA-2 solutions and rinsed in deionized water. After a Si wafer was loaded into the chamber, in-situ bake in H_2 was performed to

* Corresponding authors.
E-mail addresses: simsnow@mail.sim.ac.cn (Z. Xue), mzhang@mail.sim.ac.cn (M. Zhang).

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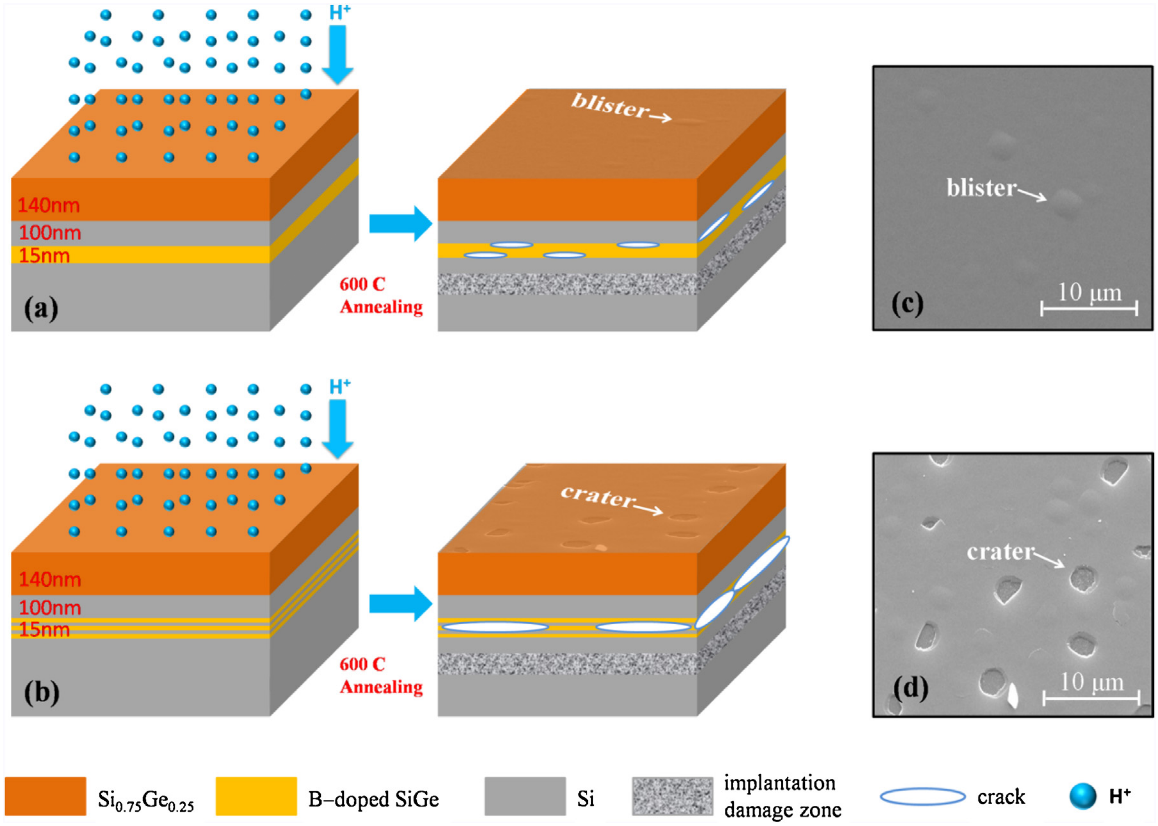

Fig. 1. The sample schematic structures and the SEM micrographs after H ions implantation and annealing process. (a) schematic structure of sample A and process flow; (b) schematic structure of sample B and process flow; (c) SEM micrograph of sample A; (d) SEM micrograph of sample B.

remove any remaining oxide, and then SiGe heterostructure was deposited. As schematically shown by Fig. 1(a) and (b), the first SiGe heterostructure (sample A) comprises a 140 nm $Si_{0.75}Ge_{0.25}$ layer, a 100 nm Si layer, a 15 nm B-doped $Si_{0.75}Ge_{0.25}$ layer and Si substrate; the second sample (sample B) keeps a similar structure with sample A except that the 15 nm B-doped $Si_{0.75}Ge_{0.25}$ layer is replaced by a 15 nm B-doped $Si_{0.75}Ge_{0.25}$/Si SL (three periods of 3 nm $Si_{0.75}Ge_{0.25}$/2 nm Si). For both samples, the B concentration of 15 nm interlayer is about $8 \times 10^{18}/cm^3$. The Ge compositions and B distributions are measured by SIMS and presented in supplementary information (Fig. S1). The purpose of inserting 100 nm Si layer is to block doped B diffusing into top 140 nm SiGe layer during the subsequent annealing process. What's more, if the 140 nm SiGe/100 nm Si dual layers are transferred onto a SiO_2/Si handle wafer, the 100 nm Si layer can be taken as an etch sacrifice layer to achieve SGOI [9,10].

Both of the samples were implanted by 26 keV H^+ ions with the dose of $3 \times 10^{16}/cm^2$ and annealed at 600 °C for 0.5 h in N_2 atmosphere. Afterwards, the surface topographies of the samples were characterized by scanning electron microscope (SEM) and atomic force microscope (AFM), the microstructures of the heterostructures were observed by transmission electron microscopy (TEM), and the depth profiles of H were measured via secondary ion mass spectrometry (SIMS).

3. Results and discussion

Fig. 1(c) and (d) shows the SEM micrographs of sample A and B, respectively. Although the H ions implantation and annealing process are virtually identical for both samples, the SEM images indicate the striking dissimilarity in the results. For sample A, only a few unruptured blisters, approximately 3 μm in diameter, have developed due to the low H ions implantation dose, whereas the blister quantities of sample B increase. Further, besides unruptured blisters, a considerable number of large craters (exfoliated blisters), basically 3–4 μm in diameter, are observed in sample B, which means layer transfer would be achieved if a handle wafer was bonded [11]. Although doped B elements and stress between SiGe/Si play essential roles in the formation and expansion of blisters [5,8,12–15], considering the almost identical B doping concentration and Ge content in both samples, the low dose H implantation inducing blister rupturing in sample B should be ascribed to the more efficient hydrogen trapping by the SiGe/Si SL structure.

Because most of the blisters' heights fall into the range of several nanometers to tens of nanometers, hardly observable under SEM, AFM images were taken to identify them further, as shown by Fig. 2. In order to compare sample A and B, the measurement area of Fig. 2(b) is selected carefully to exclude ruptured blisters. Fig. 2(a) and (b) compared, it can be found that the blister density of sample A is slightly higher than that of sample B and the average blister size in sample A is smaller than that in sample B. The section analyses (demonstrated by white curves) reveal that for sample A, in the view range, the average blister height is no more than 7 nm, the maximum being 18 nm; for sample B, the blister height averages about 12 nm, maximum 50 nm. All of these suggest that more hydrogen were trapped in sample B and filled into microcavities, which, consequently, leads up to blisters expanding, even rupturing [16–18]. Fig. 2(c) shows some deep pits (ruptured blisters) of sample B, the section analysis suggests that the depth of the pit is about 240 nm, consistent with the total thickness of the 140 nm $Si_{0.75}Ge_{0.25}$ and 100 nm Si, manifesting the film splitting occurs in SL layer instead of in the implantation range. As the color scale of Fig. 2(c) is 450 nm, significantly larger than that of Fig. 2(b), the