TRANSFORMATION OF HYDROGEN TRAPPED ONTO MICROBUBBLES INTO II PLATELET LAYER IN SI

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ABSTRACT

Features of a process of delamination of crystalline silicon layer from silicon wafer along hydrogen platelet layer formed by rf plasma hydrogenation are described. The process involves first making a buried layer of nuclei for hydrogen platelets. Ion implantation of inert or low-soluble gases is used to form the layer. The nuclei are microbubbles that appear along R_P plane of implanted ions. Results for argon are presented. Wafers implanted with a dose of 10^15 cm^-2 are then hydrogenated with an rf plasma. During hydrogenation, an atomic hydrogen diffuses into the silicon wafer and collects onto internal surfaces of the microbubbles. Then the hydrogen increases the internal surface of the microbubbles by growing a platelet type extensions to the microbubbles. The extensions grow preferably along the buried layer plane. A silicon layer above the layer of grown platelets were delaminated through pre-bonding/cut/pos-bonding sequence as in the Smart-cut process. The plasma hydrogenation of the trap layer may be used as a step in a process of fabricating of SOI wafers with a very thin top crystalline silicon layer. Also, implant doses needed to form the microbubble trap layer are much lower than doses of direct implantation of hydrogen in the Smart-cut process. Temperature range of 200°C to 400°C during the hydrogenation process allows effectively grow extended hydrogen platelets from the nuclei. Mechanisms of nucleation of platelets as extenstions of microbubbles are suggested. Control of hydrogen outdiffusion/platelet growth with thermal trajectory during plasma processing is discussed.

INTRODUCTION

The International Technology Roadmap for Semiconductors 2001 [1] projects that the top silicon layer for SOI starting wafers will be 20 to 100 nm in thickness by 2004 to support processing of fully-depleted CMOS circuits. At the present time processes such as Smart-Cut™ provide an inherent silicon film thickness of about 500 nm [2]. The thickness of the delaminated layer in the Smart-Cut process depends on the energy of implantation of hydrogen. When the energy of the hydrogen implant is reduced to levels below 50 keV to achieve thin delaminating thickness problems arise [3–5]. Attempts have been reported to thin the surface silicon layer of Smart-cut processed wafers to obtain SOI wafers with surface films of less than 200 nm thickness. Terreault et al. [3–5] used low energy hydrogen implantation (5 to 8 keV) in a regular Smart-cut and in a double specie (helium+hydrogen) layer transfer process to get a thinner top SOI layer. They report blistering the thin layer, but do not describe the layer transfer. Maleville et al. [6] reports 70 nm top Si SOI using touch polishing of an initial 500 nm layer. Srikrishnan [7] forms an etch stop layer inside of the transferred with Smart-Cut silicon film by implantation into the top silicon layer with a subsequent etching. Popov [8] reports a layer-by-
layer oxidation of the film transferred with Smart cut with subsequent stripping in diluted HF for thinning of the layer. All listed approaches increase SOI wafer production cost and degrade thickness uniformity. Our work here reports a microwave plasma hydrogenation as a post process following a low level implant to create the desired surface layer of thickness less than 100 nm.

EXPERIMENTAL DETAILS

Silicon wafers were ion implanted with argon to form a buried trap layer for hydrogen. After implantation some of wafers were annealed at temperatures 300°C to 700°C. Then the wafers were hydrogenated in an microwave plasma setup Tegal-100 at hydrogen pressures of 0.5 to 10 Torr and an microwave power of 100 to 500 Watts. The microwave plasma processing is performed at 200°C to 400°C. Pre-bonding, cleavage, and post-bonding steps were performed similarly as in the Smart-cut process. The thickness of transferred layers was measured with a Dektak profilometer near wafer edges where the layer transfer fails. Infrared absorption measurements were performed using both transmission and multiple internal reflection geometries [9] to gain access to both bonding and stretching vibrations of trapped hydrogen. Some wafers were annealed in nitrogen atmosphere after hydrogenation step to reveal surface blistering. Those wafers were than analyzed with optical and with atomic force microscopy.

RESULTS

The layer transfer occurs in cases of proper selection of implantation conditions, post-implantation anneal, and plasma hydrogenation conditions. A typical edge profile of the transferred layer is shown on Fig.1. The thickness of the transferred layer is about 70 nm.

![Figure 1 Profile near the edge of transferred layer.](image)

Figure 2 omitted!
DISCUSSION

Our previous work [10] we reported thin layer transfer with a cut plane formed with platelets that are nucleated on post-implantation defects and thin grown due to atomic hydrogen diffusion from microwave plasma source. Here we present results for thin layer transfer using gas microbubbles as the platelet nuclei.

Hydrogen in atomic form is known for its high diffusivity in silicon and its ability to combine with many types of defects in crystalline silicon. It has been known since 1987 that plasma hydrogenation of single crystalline silicon can result in the formation of hydrogen platelets [11,12]. Because of the lack of platelet nuclei in silicon bulk and low hydrogen solubility in silicon, the platelets in [11,12] are found in near-surface defect-rich regions only. To control the process of hydrogen platelet distribution in silicon, an additional step in the formation of the trap layer is needed. To accumulate hydrogen in the desired part of the wafer we need to pre-form nuclei for hydrogen platelets. We supposed that low soluble gases implanted into Si might work as a platelet nuclei layer at desired depth under the surface.

An inherent delaminating thickness for either Smart-cut or the trap-filling processes is controlled by implantation depths [3, 6, 8]. For Smart-cut the depth is between $R_p/2$ and $R_p$ of hydrogen while for the growth-on-nuclei process is between $R_p/2$ and $R_p$ for nuclei forming (heavier) ions. Correspondingly, the layer transfer depths are 200-2000 nm, and 20-200 nm. Therefore, the growth-on-nuclei process is advantageous for making thin SOI.

During the plasma hydrogenation, atomic hydrogen diffuses through silicon and attaches to strained edges on the inner walls of the gas microbubbles [11] thus gradually transforming the gas microbubbles into hydrogen platelets. Further hydrogenation increases the platelet size. Increased temperature during the hydrogenation is needed to allow Oswald ripening during which time bigger platelets grow at the expense of smaller ones [12].

![Figure 3](image_url). Surface relief developed on argon-implanted silicon wafer after plasma hydrogenation. (optical microscope, X1000).
Experiments with blistering were widely used elsewhere to understand phenomena involved in the Smart-cut [3, 9, 13] process. At the level of hydrogen implantation required in Smart-cut (i.e. about $4 \times 10^{16}$ cm$^{-2}$), the silicon surface easily blisters during implantation, even without an additional annealing. The silicon wafer surface can be also blistered after microwave plasma hydrogenation. An interesting feature is that the minimum hydrogenation time in microwave plasma required for blistering is several times longer, than the time required for successful layer transfer. Typical blistering picture after microwave plasma hydrogenation and subsequent 500°C anneal is shown on Fig.3. In a regular Smart-cut [6] it was found that the hydrogen implantation dose needed for blistering is about the same as the dose required for layer transfer (for the same annealing temperatures). We suppose, that in our case there is much higher hydrogen loss due to out-diffusion than for the case of blistering caused by high dose hydrogen implantation. These hydrogen losses may be due to the proximity of surface. When the hydrogen-rich layer (either obtained by platelet growth on nuclei or by direct implantation) evolves into a quasi-continuous cleavage plane, the hydrogen atoms or ions de-traps from one defect, diffuse to another defect with higher bonding energy, and get trapped again. In a case of high dose hydrogen implantation the higher mechanical stress is expected, so we expect more weakened silicon bonds, and higher bonding energy for hydrogen attaching to those sites.

Figure 3 shows the surface of a wafer processed with platelet nuclei formation + platelet growth upon hydrogenation. The surface is covered with features with lateral dimensions about 1 micron. Atomic force microscopy reveals the vertical dimension of those features is about 10 nanometers. Infrared measurements show high hydrogen peak.

The microwave plasma causes a platelet nucleation and growth along a layer at a depth of about Rp of the gas microbubble implants. The surface features of Fig.3 show smaller features by a factor of 10x and 100x for lateral and vertical dimensions, respectively, compared with laboratory results [2,3] obtained with heavy hydrogen implants.

CONCLUSION:

An rf plasma hydrogenation of a layer of platelet nuclei formed with low dose ion implantation of inert gases has been demonstrated for forming SOI with a thin top silicon layer. Experiments described here indicate that the platelet growth process can provide a 10X reduction in SOI top layer thickness.

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