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Patterned Ion-cut Transfer of Si Layer

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INTRODUCTION

It is apparent that as the density of microelectronic and photoelectronic devices increases to the lithography-imposed limits, 3-D integration is a promising direction for the future [1,2]. The process of ion induced exfoliation can be an enabling technology to achieve 3-D integration. Transfer of capacitor patterns (passive devices) through ion-cut process has already been reported [3]. For active device layer transfer, however, the large ion dose required to achieve exfoliation could cause damage to the devices fabricated on the silicon prior to the implantation. For instance, the thin gate oxide of MOS devices may be damaged during the through-device implant. One way to circumvent this obstacle is to implant H in the passive regions only. Si layer transfer by patterned H implantation was already demonstrated and it was found that hydrogen-induced silicon surface layer cleavage could propagate through 16 μm _ 16 μm of non-implanted material with implanted regions only 4 μm wide [4].

RESUTLS AND DISCUSSIONS

In the first set of experiments of this work, the transfer results of Si (100) and (111) orientated wafers were compared. The starting silicon wafer was patterned with a 4 _m thick photoresist ion mask in the shape of square and line patterns, followed by implanting 5 5 10^{16} H^+ ions/cm^2 at 150 KeV. The hydrogen ions were implanted only in the opening area, which was confirmed by the blistering experiments of un-bonded samples. After ion mask removal, the wafer was bonded to a receptor Si wafer through low temperature hydrophilic wafer bonding. Finally, the bonded pair was annealed, typically around 550°C, to achieve Si layer transfer. The transferred Si layer was studied by both SEM and AFM. For (100) orientated wafer, the exfoliation propagation direction appears to favor (111) plane at the border of non-implanted region, causing the uneven morphologies of the non-implanted region. For (111) orientated wafer, however, the exfoliation direction favors the (111) plane, resulting in a flat cut across the non-implanted area.

A theoretical model, based on linear elasticity theory, was formed to explain the various morphologies of the transferred layer. In this simplified model, the patterned ion-cut process is viewed as propagation of microcrack under the internal loading provided by hydrogen gas pressure inside the microcrack. It was proposed that two main factors determine the exfoliation direction: (1). The angular stress field distribution around crack-tip and (2). The surface energy anisotropy of Si single crystal. The surface energy anisotropy of Si crystal favors (111) plane as the crack propagation direction, while the stress field factor favors the original crack propagation direction, which is determined by the wafer orientation. For Si (100) wafers, the two factors are in conflict, and the competition results in (111) being the favored propagation direction. For Si (111) wafers, both factors favor the (111) plane. This analytical result agrees with experimental observation.

In the second set of experiments of this work, a two-step sequential H implantation was performed on Si (100) wafers. Before ion-mask fabrication, Si wafers were pre-implanted with 150 keV H with doses of 1, 2, 3, and 4 5 10^{16} /cm^2. The wafers were then patterned with 4 μm photoresist ion mask, followed by patterned 150 keV H implant with doses of 4, 3, 2, and 1 5 10^{16} /cm^2. The H dose in the opening regions were kept at a constant value of 5 5 10^{16} /cm^2. Transfer results showed that H pre-implantation has a significant effect on lowering the surface energy of (100) planes. For samples pre-implanted with 2 5 10^{16} /cm^2 H, the majority of the transferred patterns are cut flat along (100) plane, indicating the favored exfoliation propagation direction is (100), not (111) plane. For samples pre-implanted with 3 5 10^{16} /cm^2 H, all the transferred patterns are flat along (100) plane. AFM scan over the transferred layer showed the surface height variation is around 20 nm.

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