EFFECT OF STRESS ON ACCUMULATION OF HYDROGEN AND MICROSTRUCTURE OF SILICON CO - IMPLANTED WITH HYDROGEN AND HELIUM

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INTRODUCTION

Enhanced hydrostatic pressure (HP) at annealing (HT-HP treatment) of hydrogen-implanted oxygen-containing Czochralski silicon (Cz-Si:H, widely applied in microelectronics) exerts pronounced effect on H_2 out-diffusion (reduced at HP). Shear stress at the H_2-filled bubble / Si matrix boundary is tuned; numerous but small crystallographic defects are created under HP [1]. Contrary to the case of annealing at 10^5Pa, oxygen accumulation in the disturbed areas of Cz-Si:H is markedly reduced at ≤ 650°C-HP [2, 3] (for implantation done at ≤100°C [3]).

The HT-HP effect on hydrogen accumulation and microstructure of Cz-Si co-implanted with H and He, Cz-Si:H,He (He affects the properties of Si:H [2, 3]) as well as on the reference Cz-Si:H samples is investigated in the present work.

EXPERIMENTAL

The Cz-Si:H,He samples were prepared at T≤100°C by co-implantation of Cz-Si (oxygen concentration c_o=8x10^{17}cm^{-3}) with H_2^+ (E=135 keV, dose D=5x10^{16} cm^{-2} and He^+ (E=150 keV, D=5x10^{16} cm^{-2}), while the reference Cz-Si:H samples – by H_2^+ implantation at T = 50-250°C (D=4-6x10^{16}cm^{-2}, E=130-135 keV).The samples were subjected to HT-HP treatments at up to 800°C and 1.2 GPa, for up to 10 h, and their microstructure was determined by TEM while the hydrogen (oxygen) profiles - by SIMS.

RESULTS AND DISCUSSION

The reference Cz-Si:H samples treated at 450°C-HP, for up to 10 h, indicate the peak H concentration growing with HP [1], confirming the HP-mediated out-diffusion of H_2. Retarded hydrogen out-diffusion at HP was still detectable for Cz-Si:H treated at 650°C (Fig. 1, for the microstructure of HT-HP treated Si:H see [1, 3]).

The Cz-Si:H,He samples subjected to similar HT-HP treatments indicate the presence of well-defined areas with H_2 (He) filled bubbles (Fig. 2).

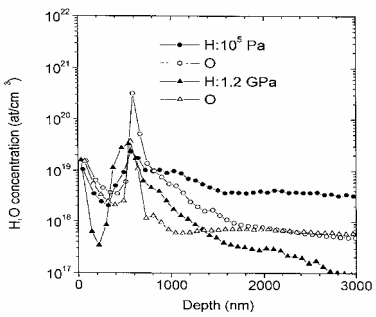

Fig. 1. H and O concentration profiles in Cz-Si:H samples (T≤250°C, D=6x10^{16}cm^{-2}, E=135 keV) treated at 650°C for 10 h at 10^5 Pa and 1.2 GPa.

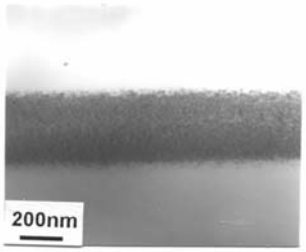

Fig. 2. TEM image of Cz-Si:H,He sample treated at 650°C – 1.1 GPa for 1 h.

The Cz-Si:H,He sample treated at 800°C-10^7 Pa for 5 h indicates the presence of strongly dislocated areas near the H_2^+ and He^+ ion ranges, R_p, of 700 nm and 880 nm, respectively, with some dislocations reaching the sample surface (Fig. 3), as well as of dislocation loops present at up to about 10 μm depth.

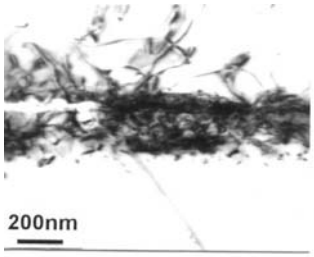

Fig. 3. TEM image of Cz-Si:H,He sample treated at 800°C - 10^7 Pa for 5 h.

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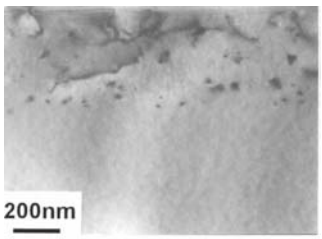

Fig. 4. TEM image of Cz-Si:H,He sample treated at 800°C – 1 GPa for 5 h.

The treatment at 800°C - 1 GPa produced much less numerous dislocations and other defects in the implantation–disturbed and deeper areas, while small (of about 20 nm diameter) cavities and dislocation loops were detected in the near-surface areas, contrary to effect of the treatment under 10^7 Pa (compare Figs 3 and 4).

The hydrogen concentration peak in the as-implanted sample reaches maximum at about 650 nm depth (Fig. 5), close to the projected H_2^+ ion range ($R_{pH} \approx 700$ nm). Annealing at 510°C-10^5Pa for 1 h resulted in the decreased hydrogen concentration maximum (for about 4 times) and in the additional c_H maximum at about 900 nm, practically at the same position as R_{pHe} (≈ 880 nm). It means that part of hydrogen diffused at 510°C to the areas disturbed by He^+ implantation as well as to the deeper sample areas (more extended $_{cH}$ tail) while most of it out-diffused through the sample surface. Contrary to above, the HT – HP treatments at 510°C / 800°C resulted in the hydrogen concentration peaking at much shallower areas (at about 0.5 μm depth) while the total hydrogen concentration decreased with temperature of the treatment (Fig. 5).

As it follows from Fig. 5 and contrary to the case of Cz-Si:H (Fig. 1, [1,3], hydrogen out-diffusion from the Si:H samples was more pronounced under HP than at 10^5Pa. This effect can be related to an influence of He on creation of Si-H bonds [4], dependent on HP-affected diffusion of He atoms to the sample surface through shallower ($R_{pH} \approx 700$ nm) originally H_2-filled bubbles (He out-diffusion is expected to be slower at HT-HP).

CONCLUSIONS

The presence of (implanted) helium in hydrogen-implanted silicon exerts marked effect on its microstructure and hydrogen out-diffusion at enhanced temperatures-pressures. Detailed explanation of this effect (of importance for microelectronics) deserves future research.

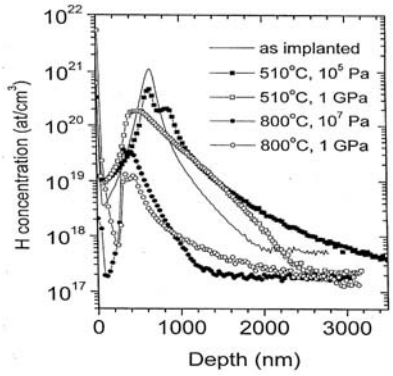

Fig. 5. Hydrogen concentration profiles in Cz-Si:H,He samples (D_H = 5x10^{16}cm^{-2}, D_{He} = 5x10^{16}cm^{-2}, E_H = 135 keV, E_{He} = 150 keV), as-implanted ($T \leq 100$°C} and annealed / HT- HP treated at 510°C for 1 h, under 10^5Pa and 1 GPa, and at 800°C for 5 h, under 10^7 Pa and 1 GPa.

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