1998 5TH INTERNATIONAL CONFERENCE ON SOLID-STATE AND INTEGRATED CIRCUIT TECHNOLOGY PROCEEDINGS

October 21—23, 1998
Beijing, China

Editors: Min Zhang
King Ning Tu

Sponsored by:

Chinese Institute of Electronics

Technical co-sponsored by:

IEEE Electron Devices Society

In Cooperation with:

IEEE solid-state Circuits Society
Japan Society of Applied Physics
URSI Commission D
Electronics Division of IEE(U.K.)
Korea Institute of Telematics and Electronics
IEEE Beijing Section

Endorsed by:

Materials Research Society

Supported by:

National Natural Science Foundation of China

IEEE PRESS

電子工業出版社
PUBLISHING HOUSE OF ELECTRONICS INDUSTRY

MICROCAVITY ENGINEERING USING PLASMA IMMERSION ION IMPLANTATION

Paul K. Chu

Dept. of Physics & Materials Science
City University of Hong Kong,
83 Tat·Chee Avenue, Kowloon, Hong Kong

Abstract – Microcavities or bubbles formed by hydrogen and helium plasma immersion ion implantation (PIII) possess intriguing properties. For example, they emit light similar to porous silicon, but because they are buried, the optical properties are not affected by surface conditions such as those encountered by conventional porous silicon materials. These bubbles also form excellent internal gettering sites for metallic impurities and are stable even at high temperature. Last but not least, the ion-cut / bonding technology utilizing the mechanical stress created by these microcavities to achieve thin film transfer is used to fabricate silicon-on-insulator (SOI).

INTRODUCTION

It is well known that implantation of hydrogen and helium into silicon generates bubbles and in a low temperature post-annealing step, they coalesce to form bigger microcavities. High temperature annealing causes the gas to diffuse out of silicon leaving behind the cavities that are stable to at least 800°C [1].

Plasma immersion ion implantation (PIII) is a burgeoning technology for microelectronics processing [2] and excels for large wafers as the implantation time does not depend on sample size. As in to conventional beam-line ion implantation, microcavities can be created by hydrogen or helium PIII. In this paper, we describe three applications of these microcavities: light emission, metallic ion gettering, and thin film transfer using the ion-cut technique.

LIGHT EMISSION

Strong room-temperature light emission from electrochemically etched porous silicon (PS) [3] opens up the possibility of integrating optoelectronic and microelectronic devices on a single Si wafer. Unfortunately, the chemically etched PS process is difficult and not compatible with traditional Si fabrication technology. An alternative way to prepare clean PS is by employing hydrogen PIII. Fig. 1 is a cross-sectional transmission electron microscopy (XTEM) picture showing the innumerable nano-sized bubbles under the surface of a silicon wafer after hydrogen PIII. When the silicon walls between these bubbles are thin enough to allow quantum effects to take place, silicon will be transformed from an indirect bandgap material to a direct bandgap one and emit light at an energy higher than the silicon bandgap. The material is called buried porous silicon (BPS) as its structure is similar to ordinary porous silicon.

The optical emission can be monitored by photoluminescence (PL). The PL spectrum in Fig. 2 is acquired at an excitation wavelength of 514.5 nm. There are two broad fluorescent bands in the as implanted sample: at 1010 nm and 890 nm (curve c in Fig. 2). By comparing to the PL spectrum of pure Si wafer acquired under the same conditions, the 890 nm peak is determined to be instrumental background. The small peak at 1100 nm in the pure Si PL spectrum corresponds to the band to band emission of Si. Its energy is equivalent to the Si indirect bandgap. Thus the band located at 1010 nm is believed to originate from the BPS. The full-width half-maximum (FWHM) of this band is about 0.2 eV. The BPS emission band can still be observed after annealing at

0-7803-4306-9/98/$10.00 © 1998 IEEE

325°C for 1 hour, but almost disappears after annealing at 670°C for 2 hours. This is due to the coarsening of the bubbles during the annealing process as well as the loss of hydrogen from the silicon wafer when the annealing temperature exceeds 400°C [4]. The implanted hydrogen can passivate non-radiative recombination centers stemming from defects and dangling bonds and consequently increase the efficiency of light emission.

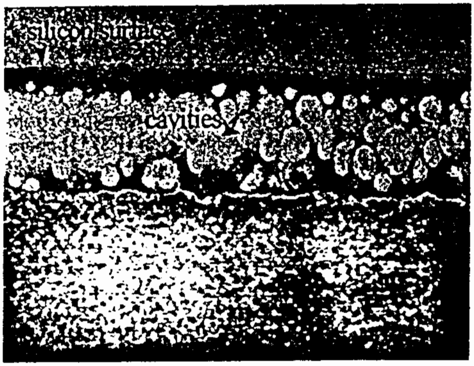

Fig. 1: XTEM micrograph of a silicon wafer implanted with $2x10^{17}$ cm^{-2} He showing the band of helium induced cavities.

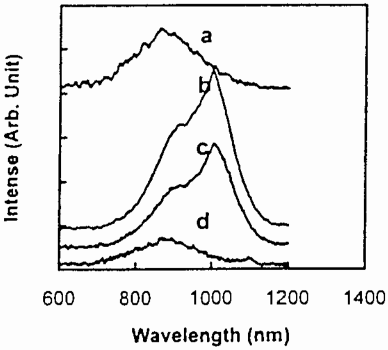

Fig. 2: PL spectra of pure Si (curve d) and hydrogen implanted samples: (a) 670°C, 2 hours annealing, (b) 325°C, 1 hour annealing, and (c) as implanted)

The XTEM image in Fig. 3 reveals a large number of bubbles under the surface. The projected range of BPS is about 50nm deep. The Si absorption coefficient of photons at an energy of 1.5 eV is 0.78 x 10^3 cm^{-1}. Therefore, the emitted light from the underlying BPS layer penetrates the thin overlay unattenuated. Even if the light energy shifts to 2.5 eV (blue), the transmission loss will still be minimal and 91% of the fluorescent light can be transmitted. This has important ramification if indeed both photonic and microelectronic devices can be fabricated in the same substrate. The BPS materials are more stable than the electrochemically etched counterparts as they are protected by the overlayer.

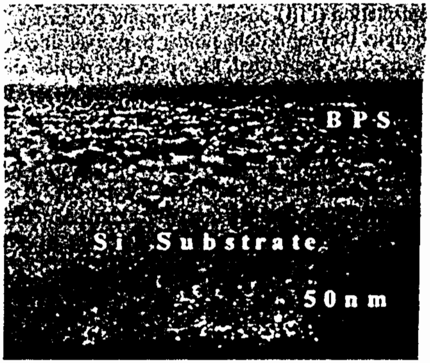

Fig. 3: XTEM micrograph of buried porous silicon

IMPURITY INTERNAL GETTERING

Internal gettering is a process by which metallic impurities are removed from the active regions of devices to favorable trapping or precipitation sites. The traditional internal gettering technique utilizes oxgyen precipitates present in CZ-Si wafers. The highly reactive silicon dangling bonds on the inner surface of microcavities formed by helium PIII can also act as gettering sites. Silicon wafers pre-implanted with $2x10^{17}$ cm^{-2} of helium by PIII are intentionally contaminated by Cu or Au on the backside and annealed to assess the efficiency of microcavity gettering. The composite depth profiles acquired by secondary ion mass spectrometry (SIMS) are displayed in Fig. 4. The sample implanted with He^+ at 20 kV introduces a band of cavities at a depth of 210 nm with a straggle of 105nm, and the peak of the Cu profile in Fig. 4 corresponds well with the microcavity band created by 20 kV He^+. The gold gettered sample is implanted by He^+ at 8 kV. The SIMS depth profile of Au shows a peak at a depth of 95 nm and a band of approximately 110 nm. Our results indicate that the well-defined band of helium-induced cavities act as an effective gettering sink for both Cu and Au. A small peak near the surface in both the Cu and Au profile is seen and is attributable to a SIMS surface artifact. SIMS analysis of annealed samples indicates that these gettering sites are stable during high temperature annealing of 1200°C and PIII is thus well suited for internal gettering of 200-mm or larger silicon wafers because the implantation time does not increase with wafer size.

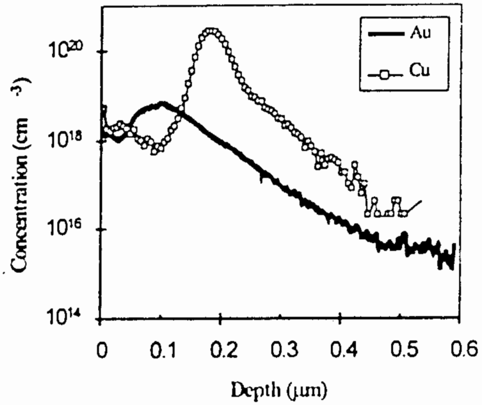

Fig. 4: SIMS depth profiles of Cu and Au showing gettering by helium microcavities.

THIN FILM TRANSFER USING ION-CUT

The technique of ion-cut involves the implantation of hydrogen and helium into a single crystal silicon wafer and uses the stress created by the microcavities to cause cleavage along the implantation plane. If the surface of this donor wafer is bonded to an acceptor wafer, the exfoliated layer becomes a new thin film on the acceptor wafer. Plasma immersion ion implantation again excels due to the high implantation current and because the implantation time is independent of wafer size. The combined PIII / ion-cut technique has been successfully applied to the fabrication of silicon-on-insulator (SOI) when the implantation temperature is controlled to be below a few hundred degrees Centigrade by either sample cooling or pulsed implantation [5,6].

The present understanding of the ion-cut process is shown in Fig. 5. After implantation, the trapped hydrogen atoms combine with silicon atoms forming Si-H complexes. During thermal annealing, the trapped hydrogen atoms diffuse and segregate near the peak implantation region forming microcavities filled with H_2 molecules. Under further annealing, more hydrogen diffuses into these microcavities grow and the high pressure becomes the driving force for their expansion. Eventually, the mechanical stress causes exfoliation. If the donor wafer has been bonded to another wafer, the broken film will be transferred from the donor wafer to the acceptor wafer.

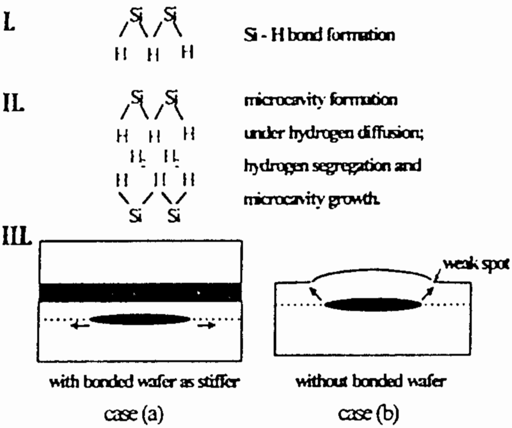

Fig. 5: Schematic picture of current understanding of the silicon cleavage and ion-cut process.

Fig. 6 depicts the XTEM micrograph of a bonded SOI structure using hydrogen PIII and ion-cut. The original bonded surface is hardly noticeable in the picture. Fig. 7 shows the XTEM picture of an SOI test structure formed by He^+ plasma immersion ion implantation and wafer bonding. Helium PIII (1 x 10^{17} cm^{-2} dose) at 33 kV is first carried out. The implanted wafer is then base-bathed and hydrophilically bonded with an oxide or nitride coated substrate at room temperature. The implanted wafer cracks along the implanted helium peak region by annealing at 500°C, and the SOI structure is finally annealed at 1100°C for 60 minutes to solidify the bonding. Our results thus demonstrate that the PIII / ion-cut method is suitable for SOI fabrication.

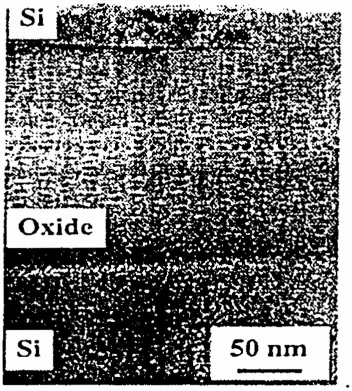

Fig. 6: XTEM micrograph of Si/oxide/Si structure formed using hydrogen PIII and ion-cut. The top silicon wafer is implanted using a hydrogen plasma at 40 kV and a dose of 1 x 10^{17} atoms-cm^{-2}. The dotted line indicates the bonded oxide / oxide interface.

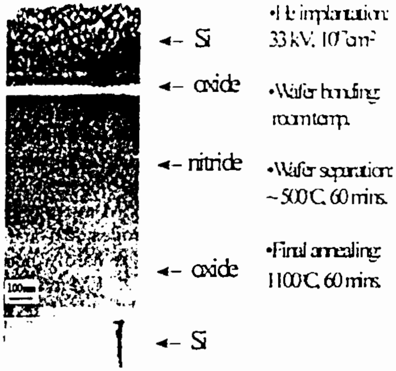

Fig. 7: XTEM picture of Si/oxide/Si_3N_4/oxide/Si structure synthesized using helium PIII and ion-cut. The bonded interface is between the top oxide and nitride layers.

CONCLUSION

Microcavities created by hydrogen or helium plasma immersion ion implantation possess very interesting properties. The unique optical properties may enable the integration of photonic devices into integrated circuits. Impurity internal gettering by microcavities is quite effective and stable up to 1200°C. The PIII/ion-cut technology is a breakthrough as an economical thin film transfer technique and has great potential in SOI fabrication.

ACKNOWLEDGMENTS

The work is financially supported by City University of Hong Kong Strategic Research Grant 7000730 and Hong Kong Research Grants Council Earmarked Grants 9040220 and 9040332.

REFERENCES

[1] J. Min, P. K. Chu, X. Lu, S. S. K. Iyer, and N. W. Cheung, *Thin Solid Films*, 300, 64 (1997).

[2] P. K. Chu, S. Qin, C. Chan, N. W. Cheung, and L. A. Larson, *Mat. Sci. Eng Reports*, R17(6-7), 207 (1996).

[3] L. T. Canham, M. R. Houlton, W. Y. Leong, C. Pickering, and M. J. Keen, *J. Appl. Phys.*, 70, 422 (1992).

[4] D. Bisero, F. Corni, C. Nobili, R. Tonini, G. Ottaviani, C. Mazzoleni, and L. Pavesi, *Appl. Phys. Lett.*, 67, 3447 (1995).

[5] P. K. Chu, X. Lu, S. S. K. Iyer, and N. W. Cheung, *Solid State Technol.*, 40(5), S9 (1997).

[6] X. Lu, S. S. K. Iyer, C. M. Hu, N. W. Cheung, J. Min, F. Z. Fan, and P. K. Chu, *Appl. Phys. Lett.*, 71(19), 2767 (1997).