Cluster Ion Implantation for beyond 45nm node novel device applications

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Abstract

This paper describes the applications of Cluster Ion Implantation for beyond 45nm node novel devices.

A) Metal/High-k MOSFET: A flash lamp annealing (FLA) has advantage of dopant diffusion-less characteristics, but it requires suitable angle control for optimum gate overlap length. Cluster boron implantation with tilted SDE implantation for p-FETs has superiority over monomer boron implantation with Ge PAI (pre-amorphous implantation) in terms of VTH roll-off's and Ion-Ioff's if FLA is used as activation anneal. Full-metal-gate HfSiON transistors whose gate length is less than 50nm are fabricated with superior electrical characteristics.

B) n-MOS Stress engineering: Si:C formation with high carbon substitution has been obtained using Cluster Carbon implantation and msec annealing which leads to higher stress in the channel region.

C) Fin-FET: High tilt angle with low energy boron cluster ion implantation is found to improve the retained dose compared to monomer boron. It is suitable for Fin-FET implantation applications.

1. Introduction

Recently, the Cluster ion implantation like $B_{18}H_x^+$ or As_4^+ is regarded as one of the important technologies to form Ultra Shallow Junction (USJ) beyond 45nm node semiconductor devices [1,2]. To commercialize this technology, we are developing the cluster ion implanter with the fast magnetic beam scanning capability, which can control the implantation quality precisely. This system is tested for SDE, SD, Halo, and poly-Gate process applications and has advantageous results [3,4]. We think the preciseness of the process is even more important for non-classical devices beyond 45nm node, such as Metal/High-k devices, FD-SOI devices, Fin-FET device, and Stress Engineering processes. We introduce the initial results of these applications.

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2. Cluster Implantation Equipment Characteristics

In Fig.1, it is shown the cluster ion implanter layout [5]. SemEquip's ClusterIon™ source, which has a large source aperture to extract high current ion beam, is installed and typically more than 30mA @ 1keV equivalent in case of $B_{18}H_x^+$ is extracted and 4mA @0.3keV on a wafer [6]. Source material vapor delivery system and in-situ deposition cleaning system are located below the ion source.

Experimental result of beam divergence is shown in Fig.2. These data are taken from 2keV to 0.2keV boron cluster beam divergence and the parallelism on a wafer, which shows less than 0.5deg values are achieved. This exceptional beam quality is due to the medium current ion implanter-base hybrid scan beam control system.

3. Beyond 45nm node novel device applications

A. Bulk Metal/High-k MOSFET

Metal/High-k MOSFET are near the mass production stage, but W full metal Gate FET less than 45nm are under development [7]. It is difficult to achieve 10nm USJ and get practical Ion-Ioff characteristics simultaneously. To solve the problem, we adopted tilted $B_{18}H_x^+$ implantation for p-MOS SDE formation with flash lamp annealing (FLA) for activation. In Fig.3, SIMS depth profiles of p-MOS and n-MOS are shown. By optimizing the tilt angle for suitable gate overlap length, Full-metal-gate HfSiON transistors whose gate length is less than 50nm are fabricated with superior electrical characteristics.

Fig.4 shows the roll-off characteristics of p-MOS for implantation, anneal conditions, and tilt angle, with both Cluster and monomer implantation having good roll-off characteristics. Fig 5, shows the Ion-Ioff's characteristics, For tilted implants cluster implantation shows a 20% improvement in I_{ON} current compared to monomer boron implantation with PAI implant.

(by SELETE & NIC)

B. n-MOS Stress Engineering

The active method to enhance the I_{ON} in the channel region is through stress engineering. For p-MOS, SiGe epi-layer is the candidate for the solution, however, for n-MOS there is no practical solution. We propose carbon cluster implantation and msec annealing for Si:C formation, which makes higher carbon substitution. This results in a higher stress on channel region [8]. Fig. 6 shows the ClusterCarbon^{TM} mass spectrum $(C_7H_7^+)$ from $C_{14}H_{14}$ source material. The HRXRD measurement data of the stress induced lattice layer are shown in Fig.7. The implantation conditions and the anneal conditions also affect the carbon substitution ratio and the stress value. This method has a possibility to reduce the process steps and cost compared to the SiC epi-process.

(by SemEquip & NIC)

C. Fin-FET

The Fin-FET is another structure of the next generation MOS-FET [9]. It requires conformal doping characteristics or high tilted ultra low energy implantation. In Fig.8, shows the SIMS data for the tilt angle with low energy Cluster Ion Implantation. The data in Table 1, clearly shows that the retained dose of the high tilt angle low energy Cluster implantation is improved compared to monomer Boron and BF2 implantation. Precise analysis is presented at the conference.

(by NIC)

4. Summary

A Cluster Ion Implantation system has been developing for mass production tools not only for todays IC fabrication but also 45nm novel device fabrication. Beyond the 45nm node bulk Metal/High-k transistor will be mass produced with Stress Engineering for I_{ON} enhancement. Fin-FETs will be used beyond 32nm. This ion implantation system will provide solutions for doping and stress engineering work for more than 10 years solving critical issues for all applications listed above.

Acknowledgements

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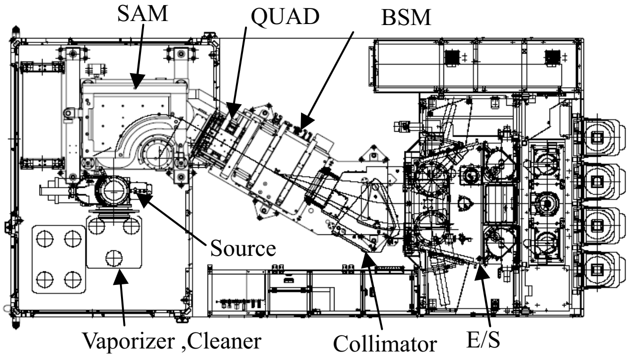


Fig.1. Schematic of the system

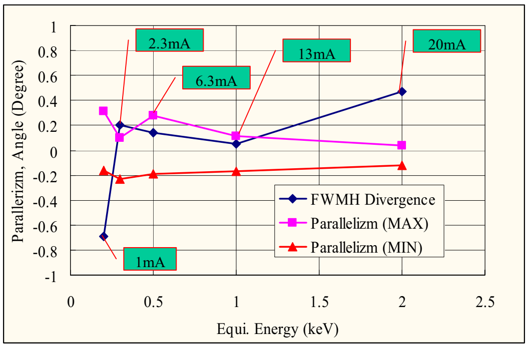
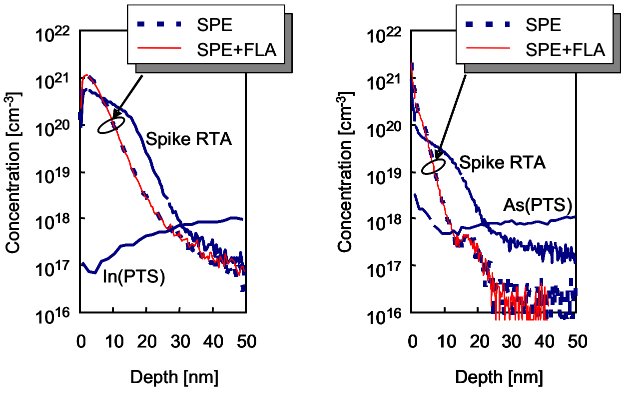


Fig.2. Beam angle quality vs. B_{18} energy and current



(a) Arsenic extension for n-ch.

(b) Boron extension for p-ch.

Fig.3. Dopant profile at S/D extension region. FLA does not affect the junction profiles fabricated by SPE growth alone. Junction depth is 26nm and 13nm for n-channel (a), and p-channel (b), respectively, in the case of SPE + FLA process

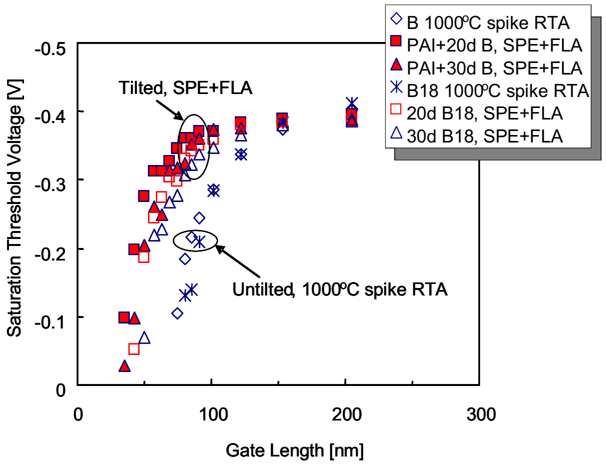


Fig.4. Saturation threshold-voltage roll-off of pFETs for the case of W/WFM/HfSiON gate when extension tilt-angles and activation conditions are varied. Threshold voltage roll-off is improved by tilted extension combined with SPE+FLA.

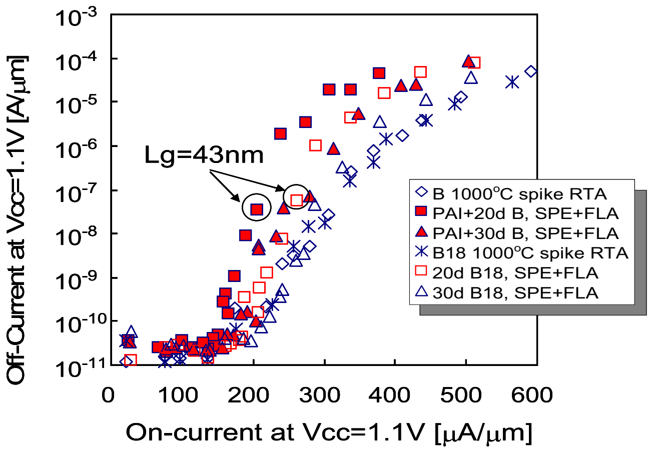


Fig.5. Ion-Ioff of pFETs for the case of W/WFM/HfSiON gate when extension tilt-angles and activation conditions are varied, using B18 and B implantation to fabricate drain extensions.

Mass Spectrum

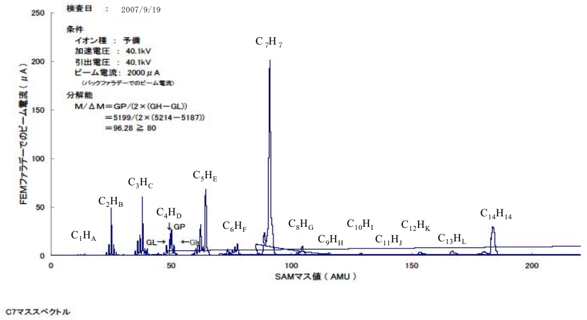


Fig.6. Mass spectrum of Carbon Cluster ion beam (C_7H_7) produced by $C_{14}H_{14}$

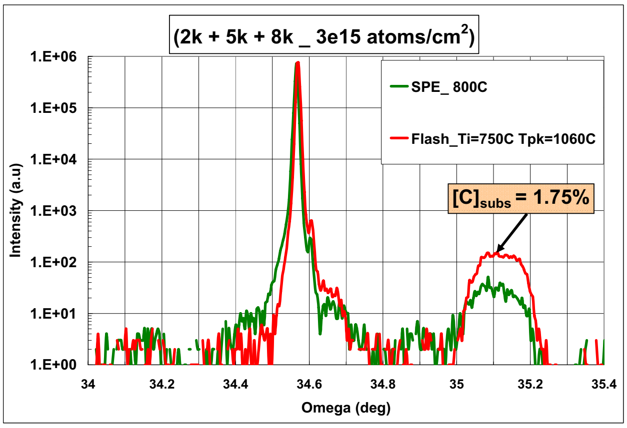


Fig.7. SiC substitution ratio: Chained or Multiple implant HRXRD = Flash Anneal (2keV + 5keV + 8keV) @ 3e15/cm^2

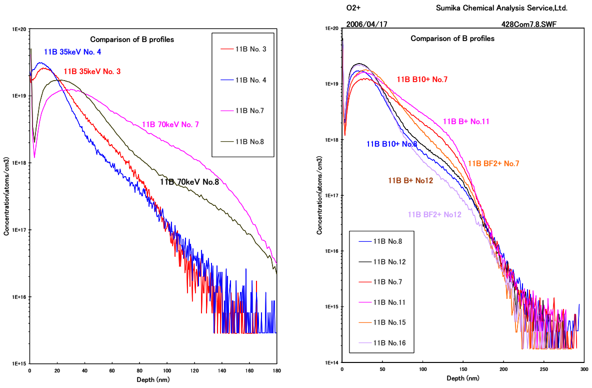


Fig.8. SIMS depth profile for Tilt Angle Dose Evaluation: B18Hx, B, BF2

Tilt Angle Dose Effect

Item No.	Specie	Energy	Total Dose at B	Tilt	Twist	Step	10B Dose	11B Dose	Total-B Dose	DoseRatio(%) 30deg/0deg
3	B10H14	35keV	1E14/cm2	0	0	quad	1.8E+13	7.0E+13	8.8E+13	97.2%
4	B10H14	35keV	1E14/cm2	30	0	quad	1.9E+13	6.7E+13	8.6E+13	
7	B10H14	70keV	1E14/cm2	0	0	quad	1.7E+13	6.8E+13	8.5E+13	91.6%
8	B10H14	70keV	1E14/cm2	30	0	quad	1.5E+13	6.3E+13	7.8E+13	
11	B	6.5keV	1E14/cm2	0	0	quad	N.D	9.0E+13	9.0E+13	91.4%
12	B	6.5keV	1E14/cm2	30	0	quad	N.D	8.2E+13	8.2E+13	
15	BF2	30keV	1E14/cm2	0	0	quad	N.D	8.4E+13	8.4E+13	88.3%
16	BF2	30keV	1E14/cm2	30	0	quad	N.D	7.4E+13	7.4E+13	

Table 1. Tilt Angle Dose Effect