CLUSTER ION IMPLANTATION SYSTEM: CLARIS FOR BEYOND 45NM DEVICE FABRICATION (II)

Masayasu Tanjyo, Nariaki Hamamoto, Tsutomu Nagayama, Sei Umisedo, Yuji Koga, Noriaki Maehara, Hideyasu Une, Takao Matsumoto, Nobuo Nagai, and John O. Borland [a]

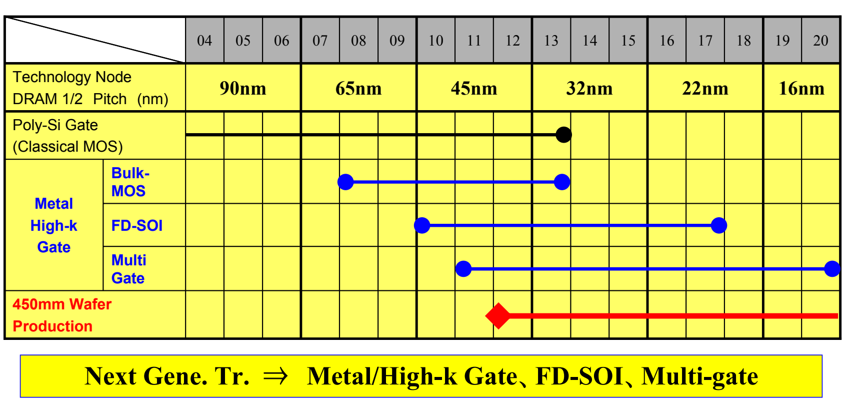
Nissin Ion Equipment Co.,ltd., Kuze-tonoshiro-cho, Minami-ku, Kyoto 601-8205, Japan
[a]JOB Technology, 98-1204 Kuawa St. Aiea, Hl 96701, USA

Newly developed sweep beam Cluster ion implanter: CLARIS with 0.2-7keV energy range for Boron beam and 1-10keV energy range for Carbon beam is introduced. Novel Cluster ion implantation technology is capable for 45nm beyond device requiring USJ formation (<15nm) with high retain dose (>70%) and low sheet resistivity (<1200Ω/sq). Comparison of retain dose and sheet resistivity of B_{18}, BF_2, and B beams with FLA shows the superiority of the B18 implantation for less than 500eV implantation.

INTRODUCTION

In Table 1, it is shown the transition of the transistor structure and material in ITRS2007 [1]. From 2008, the poly-Si gate of classical MOS is transferred to the high-k + metal-gate of new concept transistor. There are some kinds of new configuration devices, but the formation of the ultra-shallow junction (USJ) is continuously the key technology to fabricate next generation devices, as shown in Fig.1. Beyond 45nm node, the USJ for source drain extension is requiring low energy implantation below 0.5 keV. These low energy implantations have severe problems such as energy contamination with decal mode operation and spot beam divergence which is caused from space charge effects. Solving these problems there are three kinds of approaches are known. One is the classical method to improve the deceleration lens, which is more reliable but less attractive. Second is the innovative method called plasma immersion implantation (PIII), which is applicable for low energy ultra-high dose like over 1E16/cm^2, but which is not so easy to answer the requirement of severe beam controllability. [2] Last one is the cluster ion implantation, which is expected to be precise dose, uniformity and beam angle control method. [3], [4], [5]
In this paper Nissin Cluster ion implanter system named CLARIS is introduced, and the characteristics of the Cluster ion implantation technology is explained.

Table 1. Transition of Transistor Structure in ITRS2007



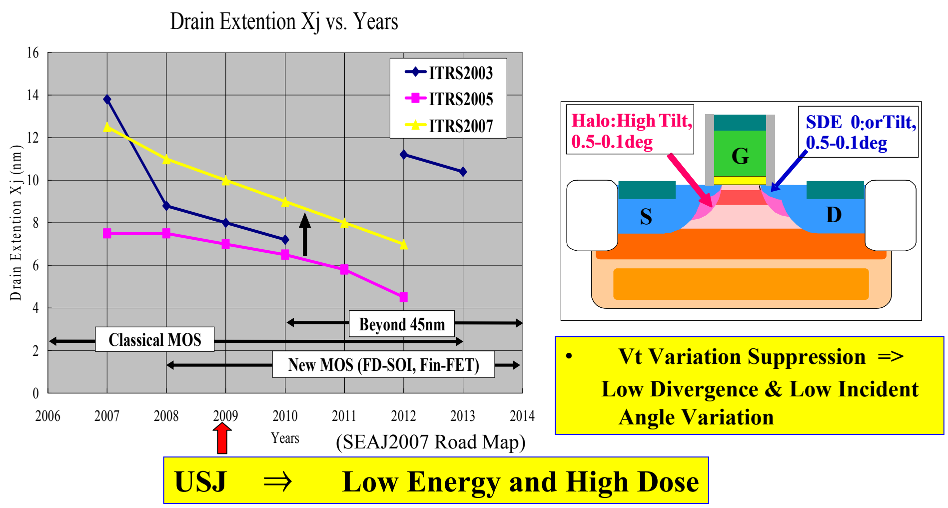


Figure 1. ITRS Road Map ; Transition of Junction Depth Xj

CLUSTER ION IMPLANTATATION SYSTEM: CLARIS

In Fig.2, it is shown the CLARIS layout. Its foot print is almost similar to our medium current ion implanter EXCEED3000AH and the end station is same to it. But, the ion source is developed for Cluster beam production and the beam line is originally designed for high mass number beam transportation.

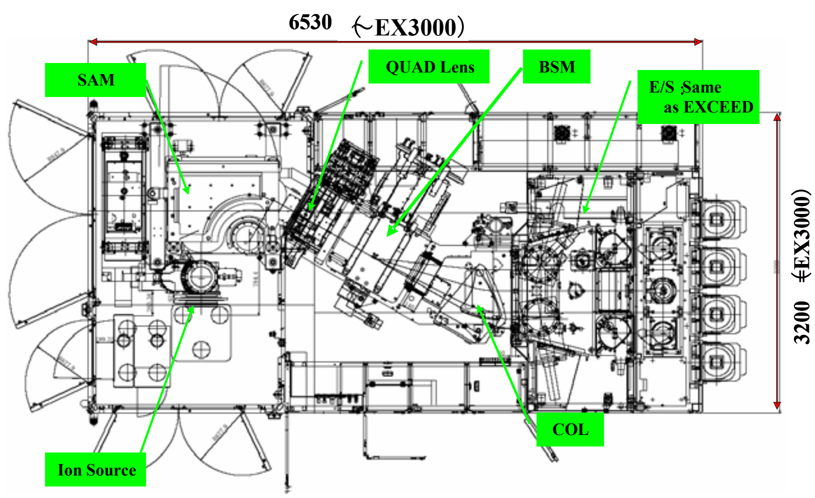


Figure2. CLARIS Layout

Equivalent Energy (keV)	Equivalent Sweep Beam Current (uA)	Ion Species
0.2	1,800	$B_{18}Hx^+$
0.3	4,000	
0.5	8,000	
1	14,400	
3	20,700	
5	15,000	$B_{10}Hx^+$
6	15,000	
7	15,000	

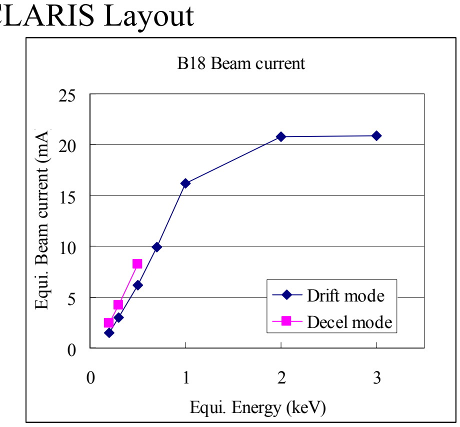


Figure 3. Boron Beam Current Specification

In Fig.3, it shows the Boron beam current specification. For 0.3keV Boron beam of 4mA makes 32 WPH at 1E15/cm^2, which is very difficult with conventional Boron monomer implantation without any energy contamination.
In Fig.4, it shows the Carbon beam current characteristics. For Carbon Cluster beam, $C_{14}H_{14}$ or $C_{16}H_{10}$ are used as source materials. As the $C_{14}H_{14}$ is easily resolved to C_7Hx^+ ions that it is suitable for stress engineering of deep implantation.[6] Contrary, as the $C_{16}H_{10}$ is capable for low energy high beam current, that it is used for Carbon co-implantation with Boron Cluster for suppress the Boron diffusion at annealing. [7]

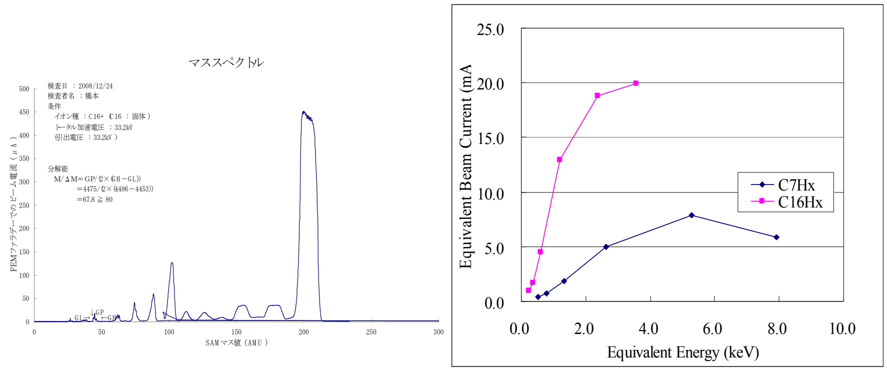


Figure 4. Carbon Beam Current Characteristics

In Table 2, it is summarized CLARIS G1 specification.

Table 2. CLARIS G1 Specification

Tool Size	**3200(W)*6530(L) *3200(H)**
Ion Source	**EB source**
B/L	**Fast magnetic beam scanner & Collimator Hybrid implantation**
E/S	**Same as EXCEED series**
Energy	**$B_{18}H_{22}$; 4~60KeV (B equivalent: 200eV~3keV) $B_{10}H_{14}$*; ~80KeV (B equivalent: ~7keV)**
Dose range	**9E12~3.6E16 atoms/cm2**
Equivalent Energy & Beam Current	**$B_{18}H_{22}$ 200eV : 1.8mA 300eV : 4mA 500eV : 8mA 1 keV : 14.4mA 3keV : 20.7mA $B_{10}H_{14}$* 5keV : 15mA 7keV : 15mA**
Uniformity Repeatability	**<1% (Boron Energy>= 1keV) <1.5% (Boron Energy < 1keV)**
Horizontal Parallelism	**< +- 0.5 degree**
Metal contamination	**Al < 50ppm, others < 10ppm**
Particle	**<30pc (particle size > 0.12um)**

* $B_{10}H_{14}$: Option **Preliminary Specifications. Subject to Change without Notice.**

CLUSTER ION IMPLANTATION TECNOLOGY

In Table 3, it shows the next generation beyond 45nm transistor requirement and the solution of the Cluster ion beam technology.
For the productivity improvement, cluster implantation is capable for the effective energy reduction and the enhance beam current with the molecular atom numbers.
The space charge effect reduction makes low beam divergence and low wafer charging, which will suppress the Vt variation. For example, using Octa-decaborane ($B_{18}H_{22}$), the space charge effect is reduced to $1/N^2$ =324 (N=18).

Table 3. Next Generation Transistor Requirement & Cluster Technology

No.	Requirement	Measure	Method
1	USJ	Low-E High-Current	B_{18},As_4
2	Suppression for Vt variation	Low-div. angle, low injection angle variation	Low space charge
3	Low thermal budget	High-activation	Self-amorphization &re-crystallization
4	Increase on-current	Stress engineering, Multi-gate	C_7H_7-Si:C、 High angle I/I

In Fig.5, it shows TW and Rs uniformity at B, 0.6keV and SIMS depth profile at B, 0.3keV, respectively. It is recognized that at these low energy condition the uniformity and energy contamination are no problem.

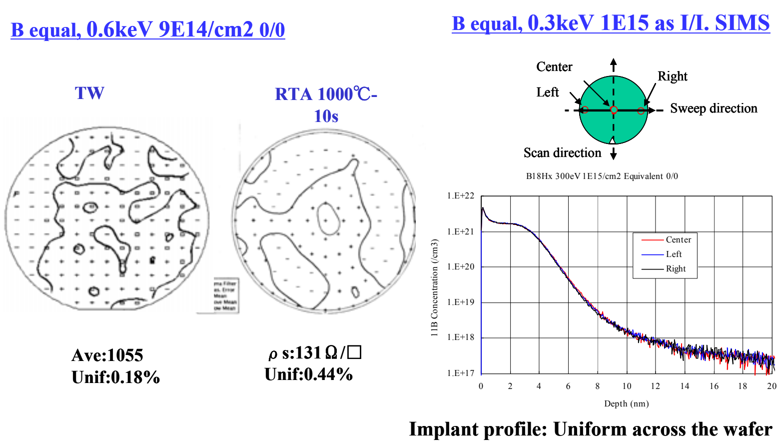


Figure 5. TW/Rs Uniformity & SIMS Profile

Ion species [B_{18}, B_{36}]
B 100eV 1E15/cm2 0/0deg
as I/I SIMS Profile

Retain Dose

ion	Ge-PAI,Dcc	D(/cm^2)
B18$^+$	w/o, Dcc	7.7E14
B18$^+$	with, Dcc	7.5E14
B36$^+$	with, Drift	7.3E14

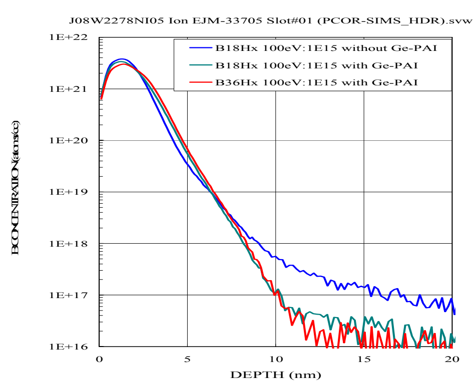


Figure 6. Ultra-low Energy B 100eV: $B_{18}Hx^+$ & $B_{36}Hx^+$ SIMS Profile

In Fig.6, it shows the SIMS profile of $B_{18}Hx^+$ and $B_{36}Hx^+$ implantation at B, 100eV energy. With Ge-PAI condition it shows no energy contamination that the B_{18}^+ w/o Ge-PAI profile shows channeling effect, which is almost less than 1E18/cm^3 level. It also shows the retain doses by integrating the B profiles, which are around 70 – 80 % with tilt 0deg twist 0deg implantation condition.

For the evaluation of the retain dose and the sheet resistivity characteristics, it was done the comparison of the $B_{18}Hx^+$, BF_2^+, B^+ implantation with flash lamp anneal (FLA). Wafer tilt angle is also changed from 0 to 60 degree. Figure 7 shows the Rs and TW of tilt angle dependency. At this evaluation, beam energy is controlled for same projection depth that is for 0deg-tilt with 0.4keV and 60deg-tilt with 0.8keV. [8]
It is shown that the tilt angle dependency is almost flat except BF_2^+ which is machine energy resolution problem, that Rs is almost follows to cosine low. As the B+ energy is slight higher, that values of Rs are $B_{18}Hx^+ < B^+ < BF_2^+$, contrary values of TW are $B_{18}Hx^+ < BF_2^+ < B^+$. For $B_{18}Hx^+$, values of Rs and TW are both almost half to B^+ and BF_2^+.

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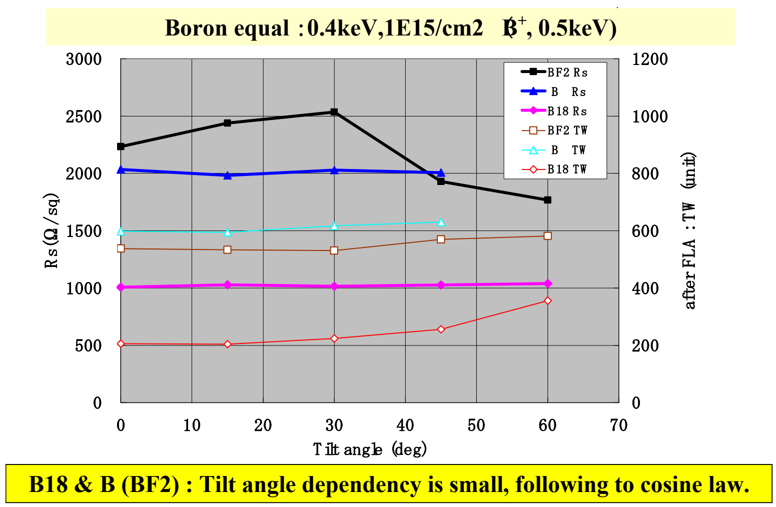


Figure 7. After FLA, Rs & TW Tilt Angle Dependency; B_{18}^+, BF_2^+, B^+

In Fig.8, it shows (a)as I/I and (b)after FLA SIMS profiles with different ion spices and tilt angles. In both (a) and (b) cases, B_{18}^+ shows most abrupt profile and shallow junction.

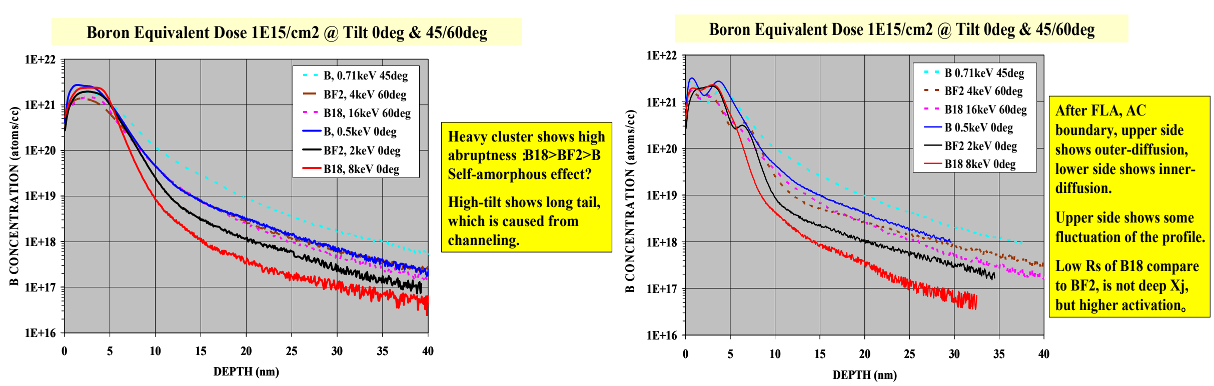
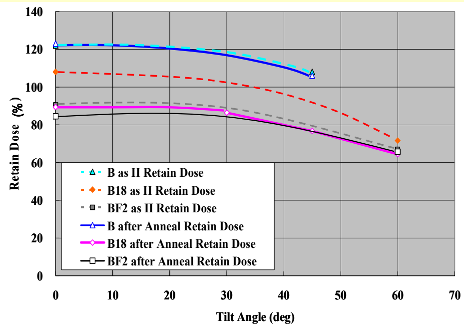


Figure 8. (a) as I/I & (b) after FLA SIMS Profile; B_{18}^+, BF_2^+, B^+

In Fig. 9, it shows (a) tilt angle and (b) energy dependency at high tilt of retain dose and Rs with different ion spices and tilt angles.
In Fig.9(a), values of retain dose of as I/I are $BF_2^+ < B_{18}^+ < B^+$, and values of retain dose of after FLA are $BF_2^+ \sim B_{18}^+ < B^+$. That is, B_{18}^+ is smaller loss for implantation but larger loss for annealing than those of BF_2^+. It is supposed that the shallower profile makes larger out diffusion at annealing. For high tilt condition the retain dose decreases 20-30%.
In Fig.9(b), values of retain dose of lower energy at 0.4keV are $BF_2^+ < B_{18}^+ < B^+$, and values of retain dose of higher energy at 1.6keV are $BF_2^+ \sim B_{18}^+ < B^+$. Values of Rs are also abruptly increases for low energy BF_2^+. That is, the retain dose of B_{18}^+ and BF_2^+ are

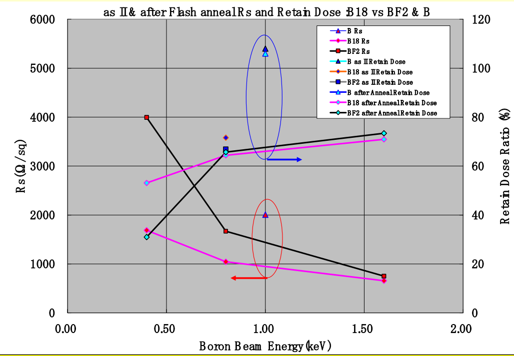
almost same but dopant activation ratio should be much difference. And as the energy is decreased the loss of BF_2^+ is enhanced and Rs is decreasing than that of B_{18}^+.
For B^+, it shows minimum loss for both implantation and annealing but activation ratio is least of the three, because of the deepest dopant profile.

as II & after FLA Retain Dose :B18 vs BF2 & B @B Energy(B_{18}&BF_2)0.8keV/(B)1keV



Tilt angle :0→60deg, retain dose decreases 20～30% which caused from spattering. B18 shows, retain dose of after FLA is decreased much, which caused from outer-diffusion at FLA because of shallow profile.

Boron Equivalent Dose 1E15/cm2 @ Tilt (B_{18}&BF_2)60deg/(B)45deg



At low energy :Retain dose of BF2 shows smaller than that of B18, which caused from F-induced diffusion.

Figure 9. (a) Tilt Angle & (b) Energy Dependency of Retain Dose and Rs; B_{18}^+, BF_2^+, B^+

SUMMARY

1. Nissin Cluster Ion Implantation System: CLARIS for beyond 45nm node transistor mass-production is developed and Boron version: G1 is released.
2. Practical use of Carbon Cluster beam is under developing, and $C_7H_x^+$ and $C_{16}H_x^+$ ion beam current characteristics are evaluated. It is applied to co-implantation of P-and N-MOSFET and Stress engineering of N-MOSFET.
3. Boron Cluster beam shows superiors for retain dose that even at B 100eV 0deg-tilt condition, >70% retain dose is founded.
4. Comparison of B_{18}^+, BF_2^+, B^+ beams, it is confirmed that B_{18}^+ beam is capable of high sheet resistivity, which is caused from high activation than BF_2^+, B^+ beams.
5. For beyond 45nm node transistor mass-production, it is required the break-through technologies, that CLARIS is a candidate of those technologies.

Acknowledgments

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