Low Contact Resistance on p-SiGe Junctions with B / Ga Implants and Nanosecond Laser Anneal

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Outline

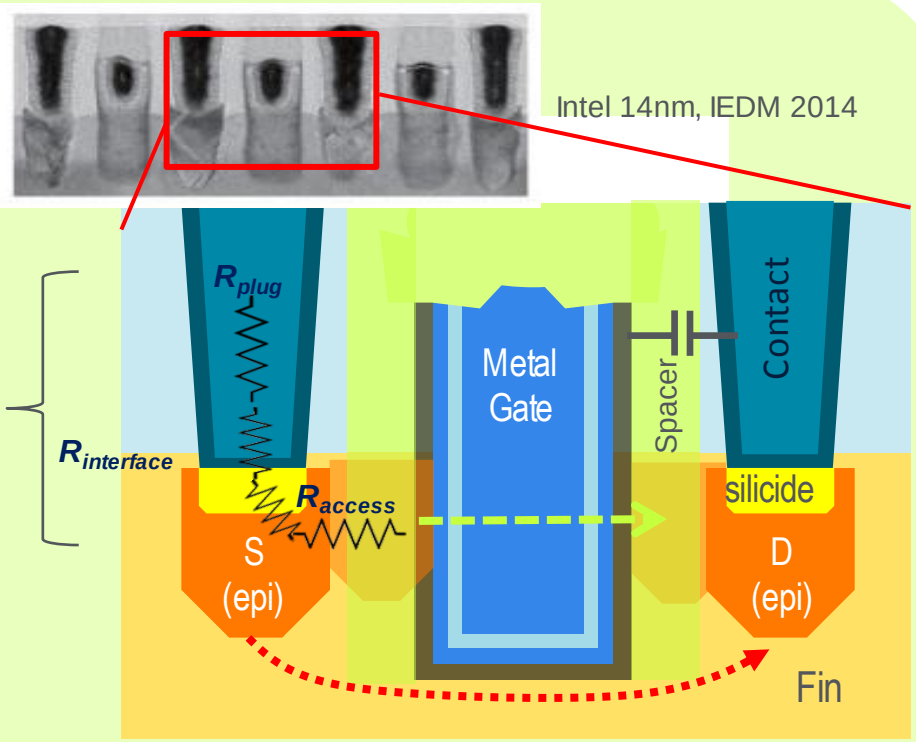
- **Motivation for Contact Resistivity (ρc) Reduction**

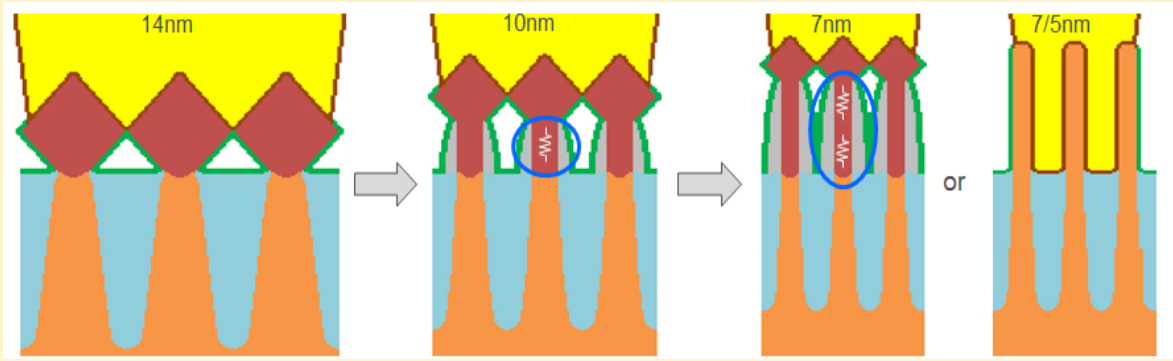
- **$Si_{0.55}Ge_{0.45}$** *(Applied Materials Internal Data)*
  - **Experimental Details**
  - **Results and Discussion**

- **$Si_{0.40}Ge_{0.60}$** *(Applied Materials – IMEC Collaboration)*
  - **Experimental Details**
  - **Results and Discussion**

- **Summary**

Contact Interface Impact to Performance





- Fin pitch scaling reduces contact area ➔ increases Rc
- Tall fin height results in increase of S/D resistance (RSD)
- External resistance is limiting transistor performance

Require Innovative doping and Annealing solutions for NFET & PFET to reduce Rc and RSD

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$Si_{0.55}Ge_{0.45}$ *(Applied Materials Internal Data)*

- **Title:** Ultra-low ($1.2x10^{-9}$ Ωcm^2) p-$Si_{0.55}Ge_{0.45}$ Contact Resistivity (ρ_c) using Nanosecond Laser Anneal for 7nm Node and Beyond

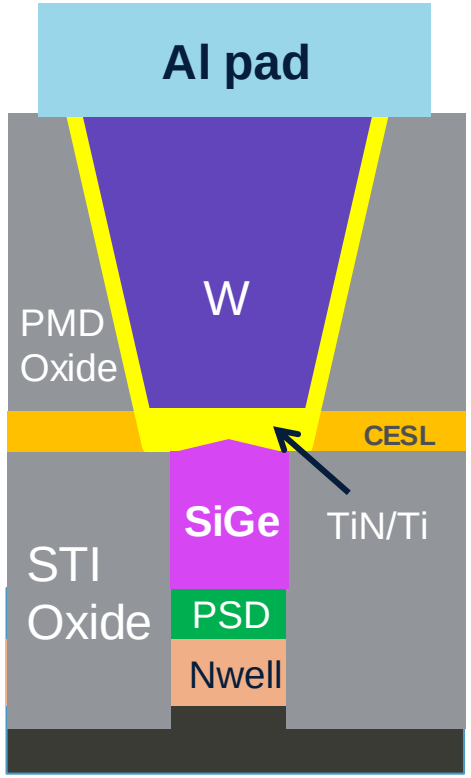
- **Authors:** Chih-Yang Chang, Fareen Adeni Khaja, Kelly E Hollar, K.V. Rao, Christopher Lazik, Miao Jin, Hongwen Zhou, Raymond Hung, Yi-Chiau Huang, Hua Chung, Abhilash Mayur, Namsung Kim

- **Publication:** The 17th International Workshop on Junction Technology (IWJT 2017), Kyoto, Japan

Experimental Details: Process Flow

PMOS Contact Process Flow

- STI
- PMOS junction
- SiGe Epi
- PMD patterning
- Hi-k anneal
- Contact open
- **Contact I/I**
- **Implant anneal**
- Metal dep (*preclean*\Ti\TiN)
- Contact anneal
- W fill / CMP
- Al pad formation
- FGA



Pre-Silicide Contact I/I :

1. Ga^+ ion implant
2. B^+ ion implant

Pre-Silicide Anneal:

1. Nanosecond Laser Anneal (NLA)
2. Millisecond Laser Anneal (Astra™ DSA)

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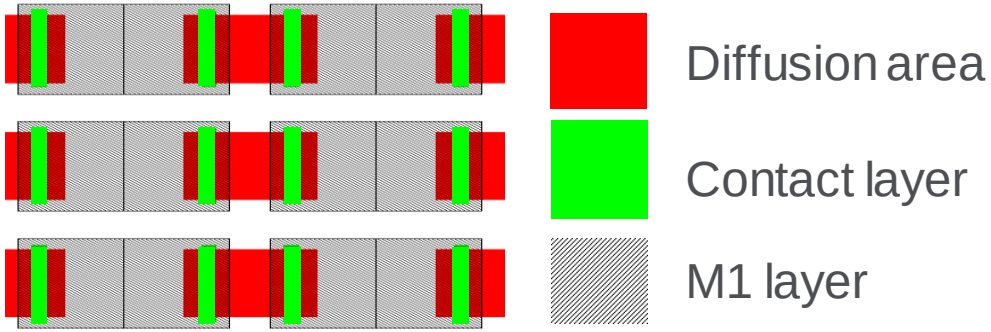
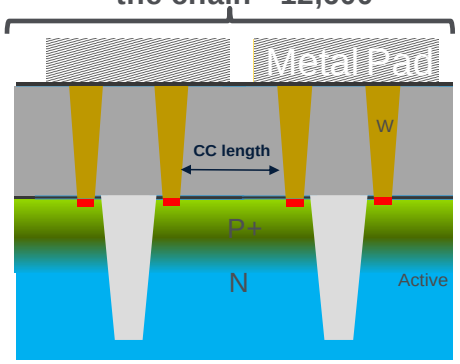
Contact Resistivity Extraction

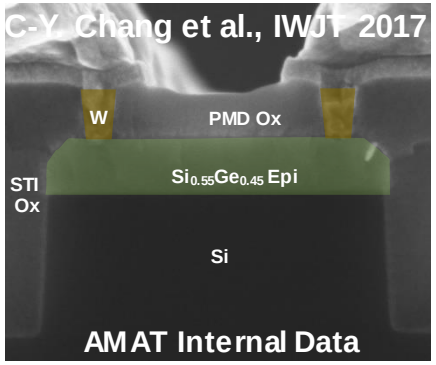
(a) **Top-down Schematics**



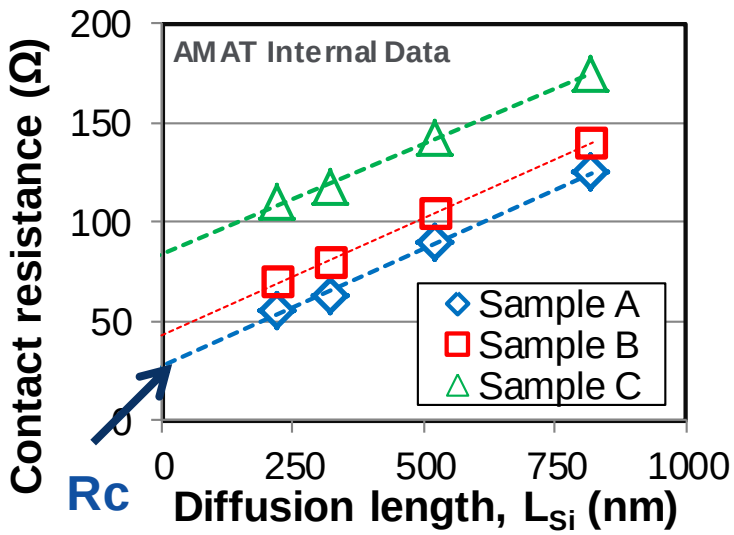
(b) Number of contact holes in the chain ~ 12,600



Cross-sectional SEM



Rc extraction



$$R_{Total} = R_{Metal} + R_{Si} + R_{Plug} + R_C$$

$$= \sum\left(\frac{L_M}{W_M} R_{S\_M} + \frac{L_{Si}}{W_M} R_{S\_Si} + R_{Plug} + R_C\right)$$

$$= L_{Si} \bullet \sum\left(\frac{\alpha}{W_M} R_{S\_M} + \frac{1}{W_M} R_{S\_Si}\right) + \sum\left(R_{Plug} + R_C\right)$$

$R_{plug} << R_C$

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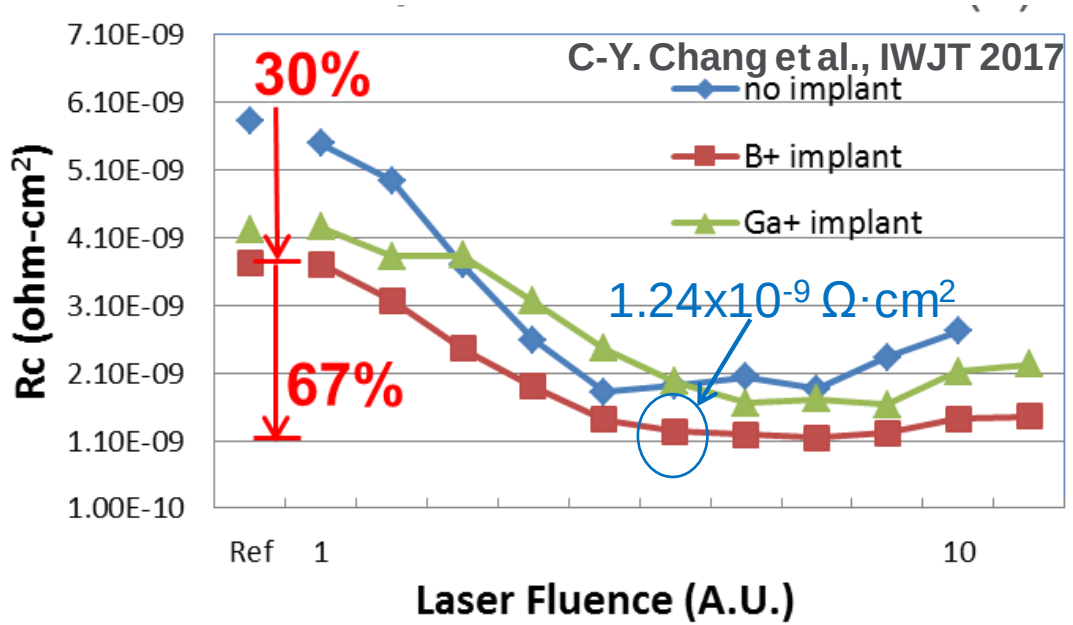
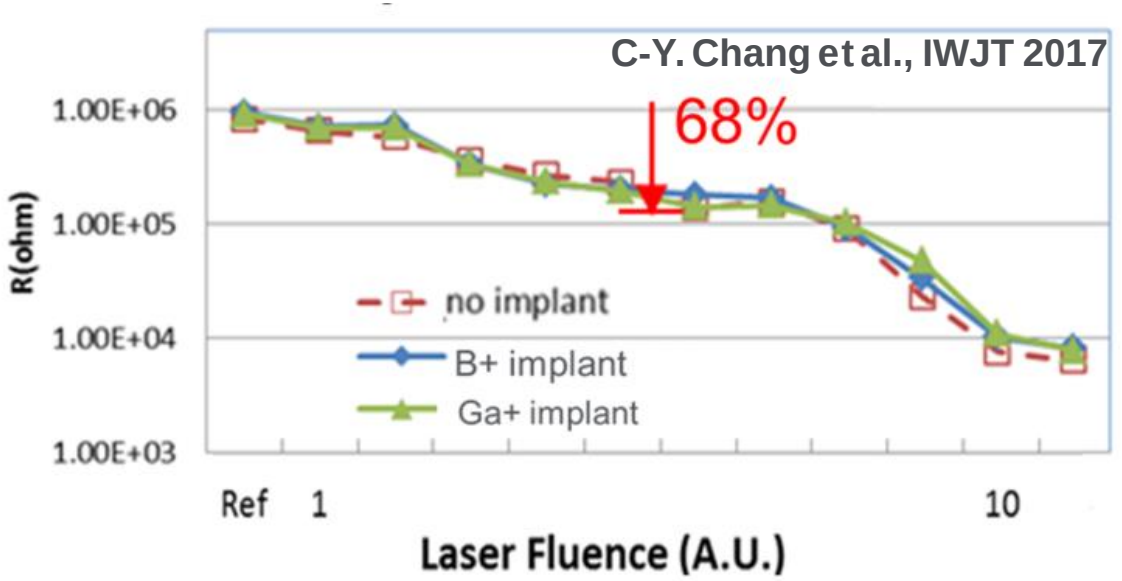
Nanosecond Laser Anneal Result of Contact Chains

$Si_{0.55}Ge_{0.45}$:B Epi–Contact Chains



- By adding I/I obtain 30% ρ_c reduction and NLA can have 67% further ρ_c reduction

$Si_{0.55}Ge_{0.45}$:B Epi-85 nm diffusion line

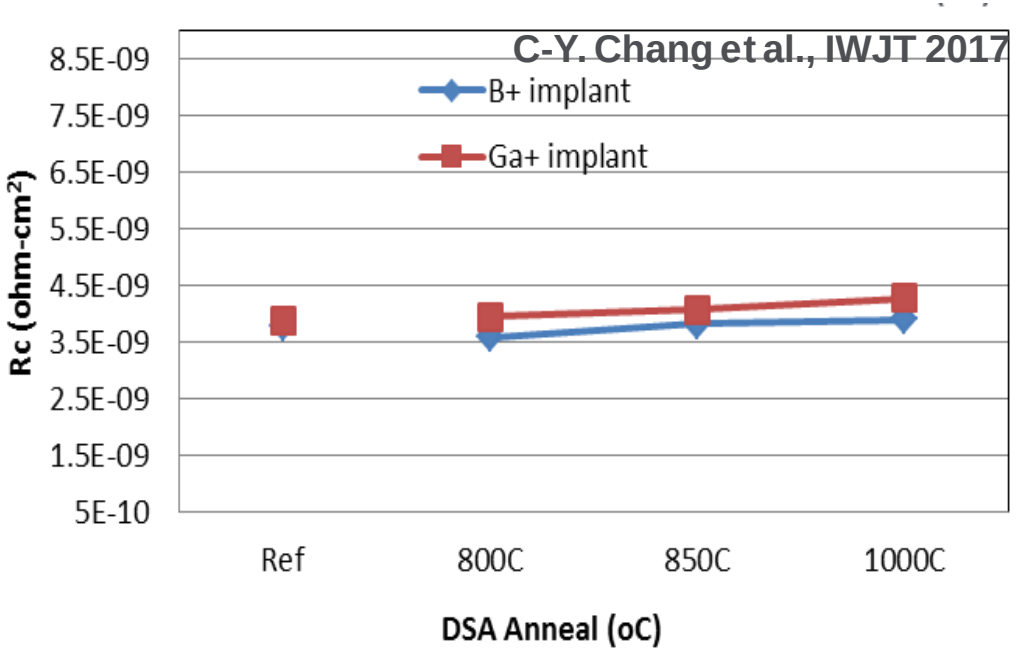


- Significant improvement in diffusion line resistance

NLA enables super-activation of implanted dopants and dopants in the Epi film

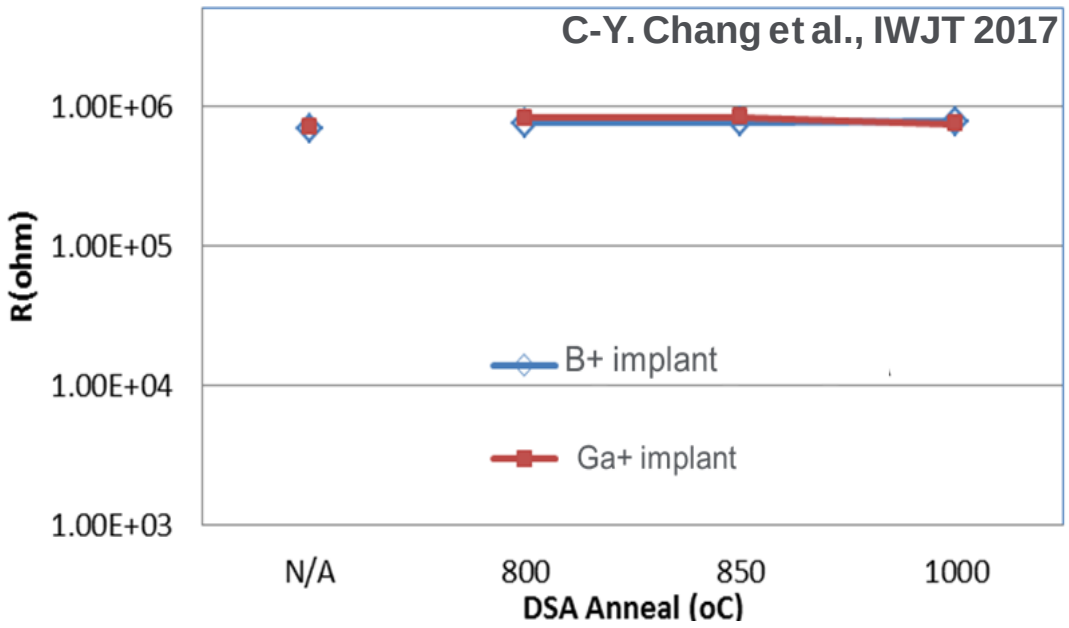
DSA Millisecond Laser Anneal Result of Contact Chains

$Si_{0.55}Ge_{0.45}$:B Epi–Contact Chains



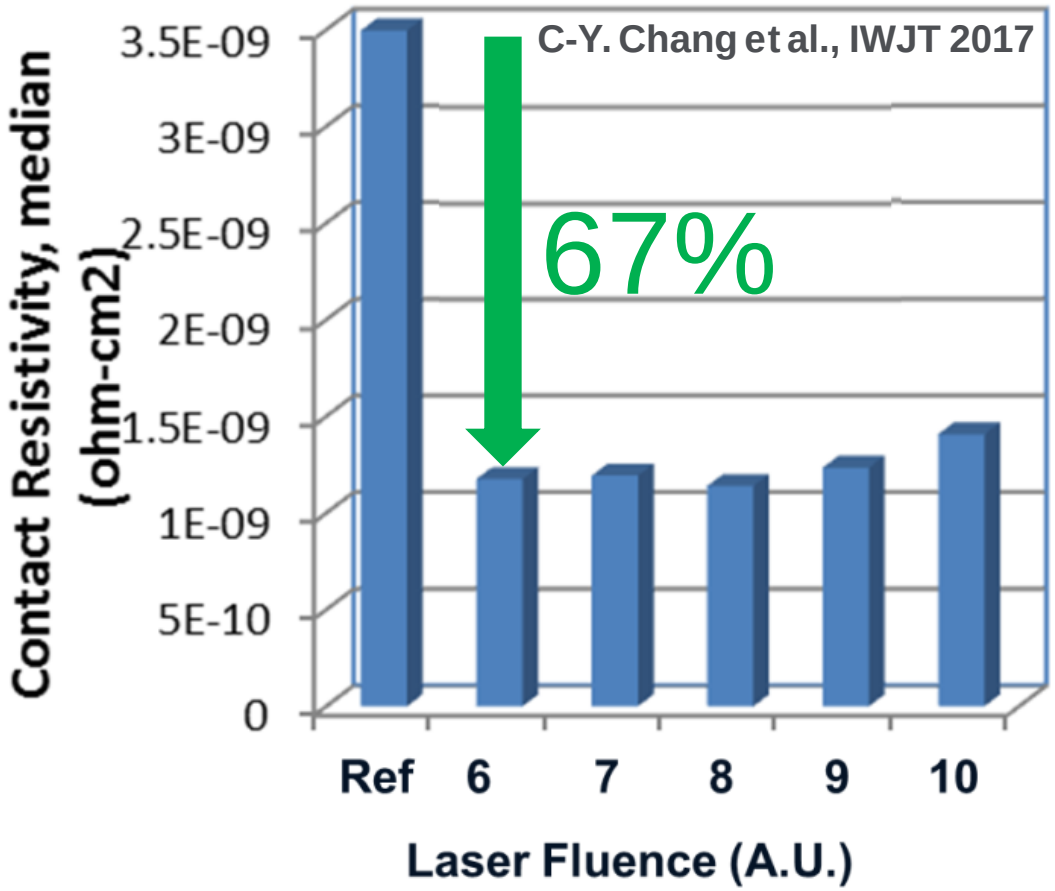
- Similar ρ_c observed with B and Ga implant post DSA 1000°C anneal

$Si_{0.55}Ge_{0.45}$:B Epi-85 nm diffusion line



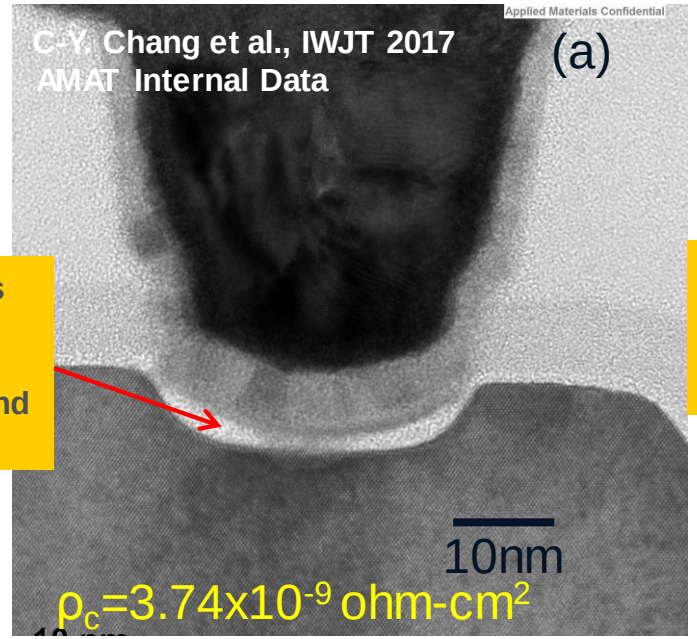
- No change in resistance of 85 nm diffusion line

Contact Chain's Median Contact Resistivity vs. NLA Fluence

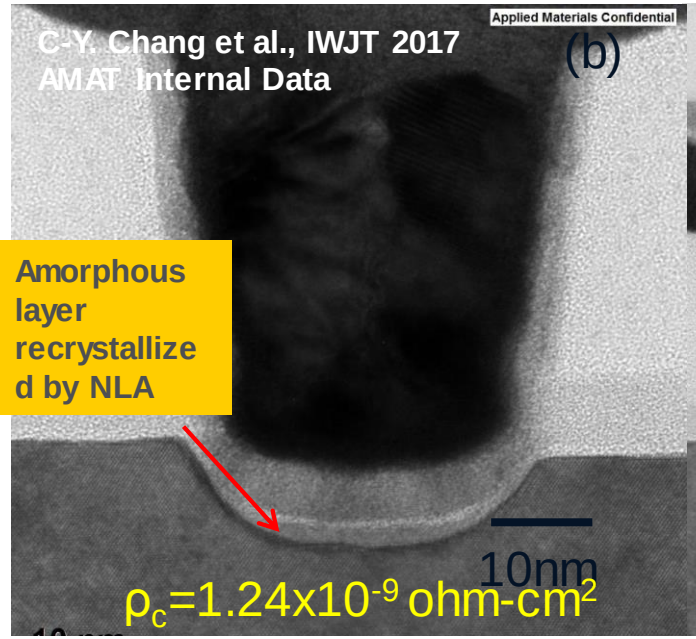


NLA demonstrated 67% ρ_c improvement (3.4×10^{-9} ➔ 1.2×10^{-9} ohm-cm^2)

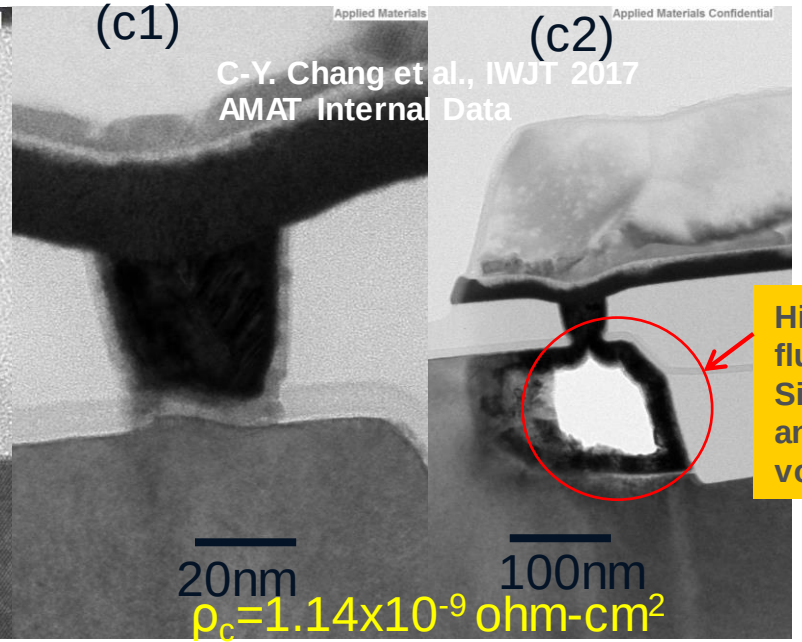
TEM images of contact chain with NLA



Amorphous layer between SiGe Epi and Ti layer



Amorphous layer recrystallized by NLA



Higher fluence melt SiGe Epi film and create a void.

No Anneal

Optimal Laser Fluence

Higher Laser Fluence

Optimal laser fluence is critical for recrystallization without void formation

Summary of ρ_c for the p-$Si_{0.55}Ge_{0.45}$ wafer splits

Anneal	Implant	ρ_c (ohm-cm^2)
None	B implant	3.74×10^{-9}
None	Ga implant	4.21×10^{-9}
NLA	B implant	1.24×10^{-9}
NLA	Ga implant	1.63×10^{-9}
DSA	B implant	3.59×10^{-9}
DSA	Ga implant	3.95×10^{-9}

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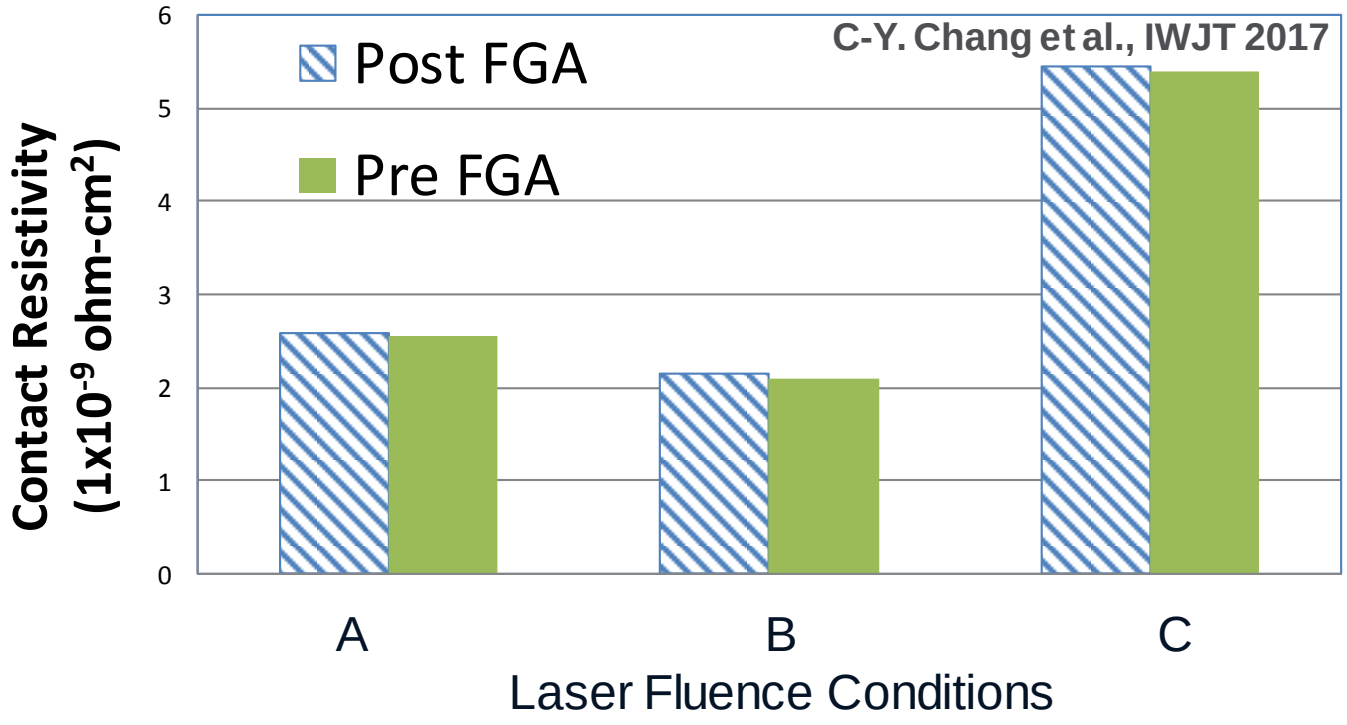
R_c Comparison between Pre and Post Forming Gas Anneal for 55nm Kelvin contact with B implant and NLA



No significant change in ρc post FGA ➔ No deactivation after FGA

$Si_{0.55}Ge_{0.45}$ Summary

- We demonstrated ultra-low ($1.2x10^{-9}$ ohm-cm^2) p-$Si_{0.55}Ge_{0.45}$ contact ρ_c by using cold implant and advanced NLA on contact chain structures.

- Implant and Anneal Optimization is required for achieving low ρ_c.

- No dopant deactivation was observed after forming gas anneal (FGA) for 30min at 400^{o}C.

- These new process technologies provide a pathway to achieve the target ρ_c required for transistor performance in advanced logic devices for 7 nm and beyond.

C-Y. Chang et al., IWJT 2017

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- **Summary**

$Si_{0.40}Ge_{0.60}$ (*Applied Materials – IMEC Collaboration*)

- **Title:** Sub-10^{-9} $\Omega.cm^2$ Contact Resistivity on p-SiGe Achieved by Ga Doping and Nanosecond Laser Activation

- **Authors:** J-L. Everaert[1], M. Schaekers[1] , H. Yu[1,2], L.-L. Wang[1,2,3], A. Hikavyy[1], L. Date[4], J. del Agua Borniquel[4], K. Hollar[4], F. A. Khaja[4], W. Aderhold[4], A. J. Mayur[4], J.Y. Lee[5], H. van Meer[5], Y.-L. Jiang[3], K. De Meyer[1,2], D. Mocuta[1], N. Horiguchi[1]

[1]IMEC, Leuven, Belgium ; [2]KULeuven, Leuven, Belgium ; [3]Fudan University, Shanghai, China ; [4]Applied Materials, Sunnyvale, USA ; [5]Applied Materials, Gloucester, USA

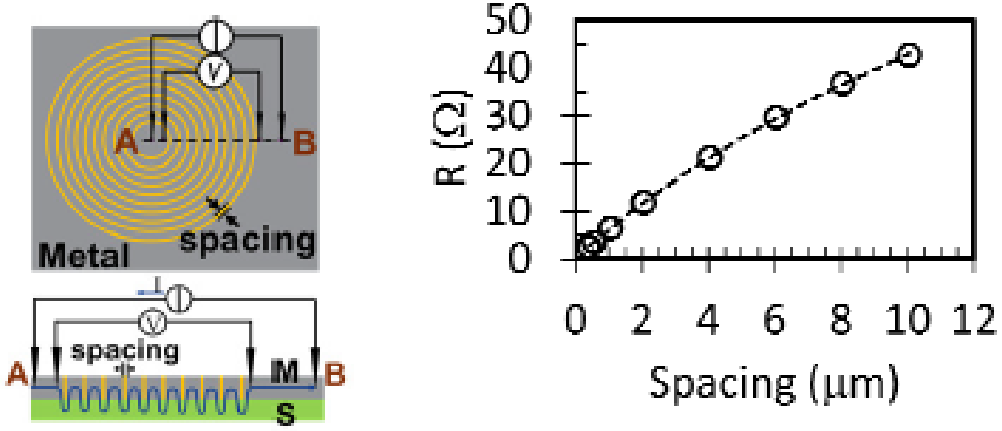
- **Publication:** 2017 Symposia on VLSI Technology and Circuits (VLSI 2017), Kyoto, Japan

Experimental Details

IMEC CTLM Process Flow

- 300mm lightly doped S wafer
- n-well formation
- SiGe epitaxy
- Ga ion implant
- Anneal : spike or scanning laser or pulsed laser
- MR-CTLM patterning : dielectric deposition, lithography, etching.
- Contact metallization :Ti/TiN deposition
- Cu barrier deposition
- Cu plating and CMP

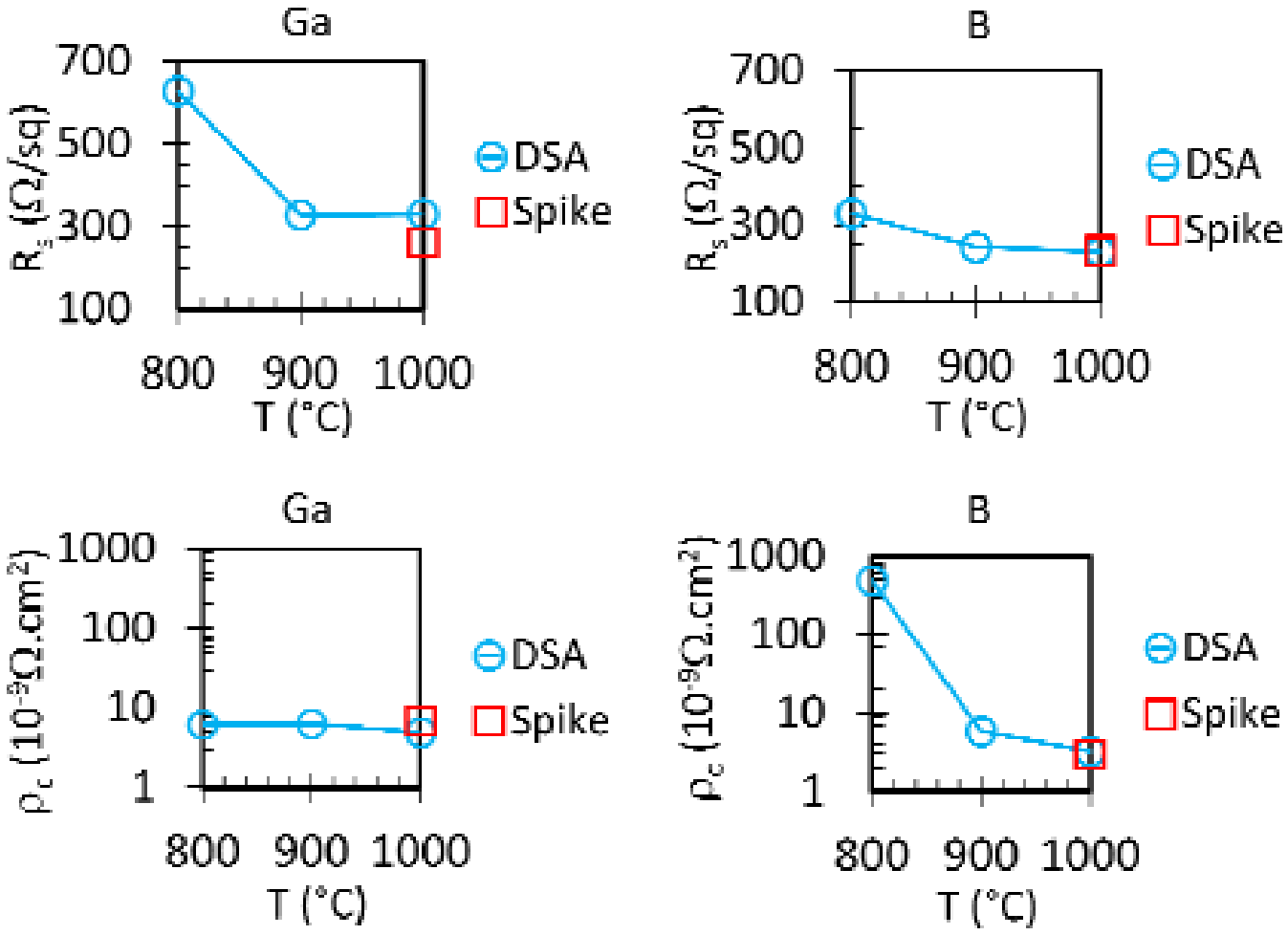
IMEC CTLM Test Structures



- Resistance (R) of the CTLM structure is measured using 4PP
- By fitting R as function of spacing of different structures, R_s and ρ_c are obtained

J-L. Everaert et al., VLSI 2017

Comparison of R_s & ρ_c for Ga vs. B in $Si_{0.40}Ge_{0.60}$: Spike anneal vs. DSA



Based on SIMS, T>800°C causes strong diffusion for Ga

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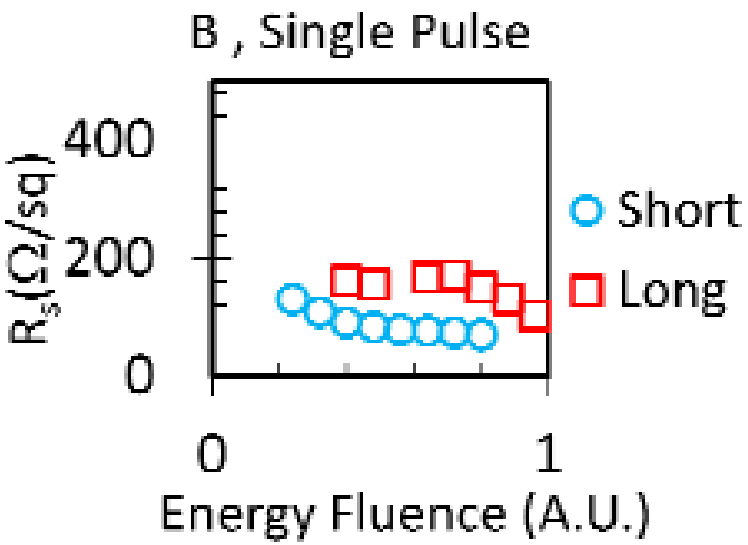
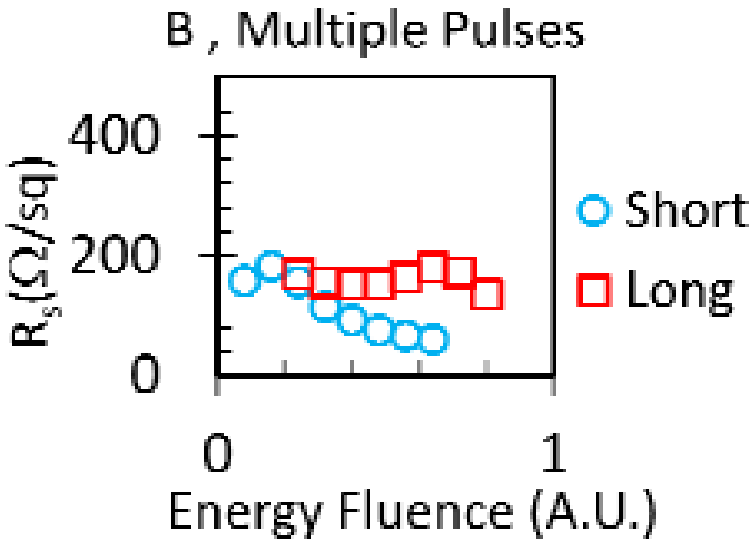
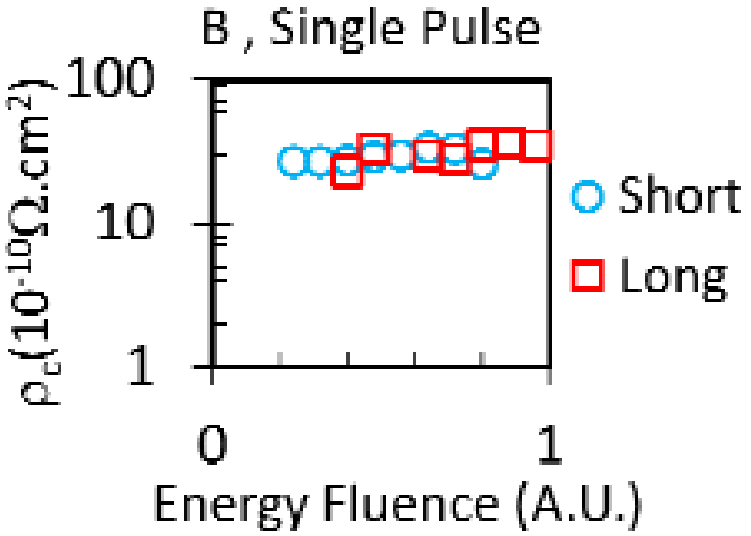
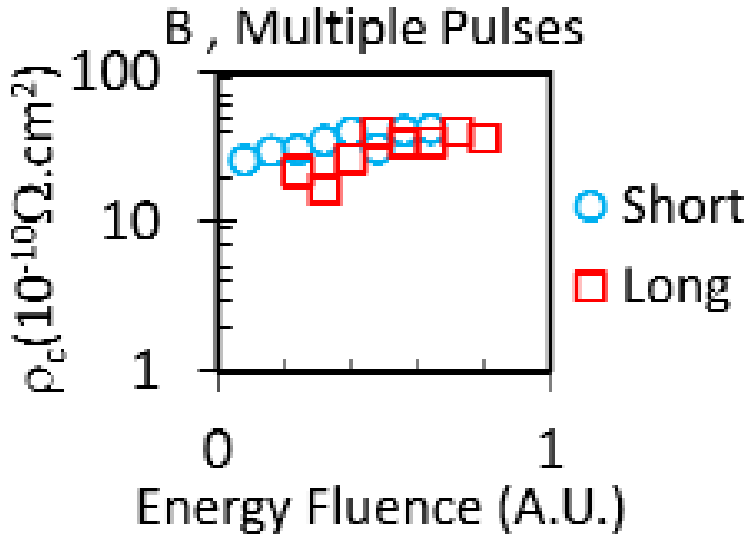
Comparison of R_s & ρ_c for B implant in $Si_{0.40}Ge_{0.60}$ with NLA









- R_s is lower than with Spike / DSA
- ρ_c is similar as with Spike / DSA

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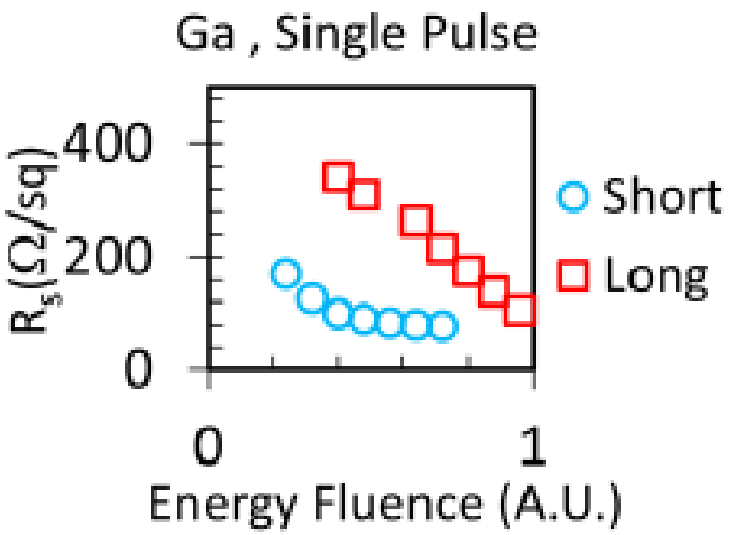
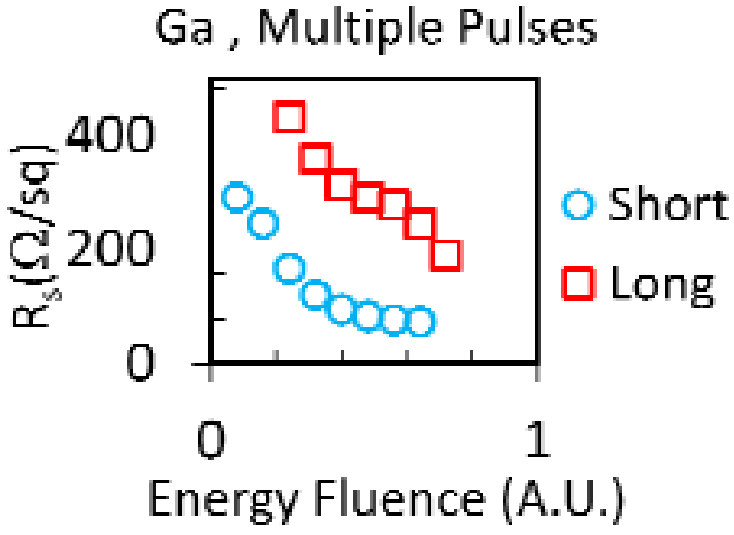
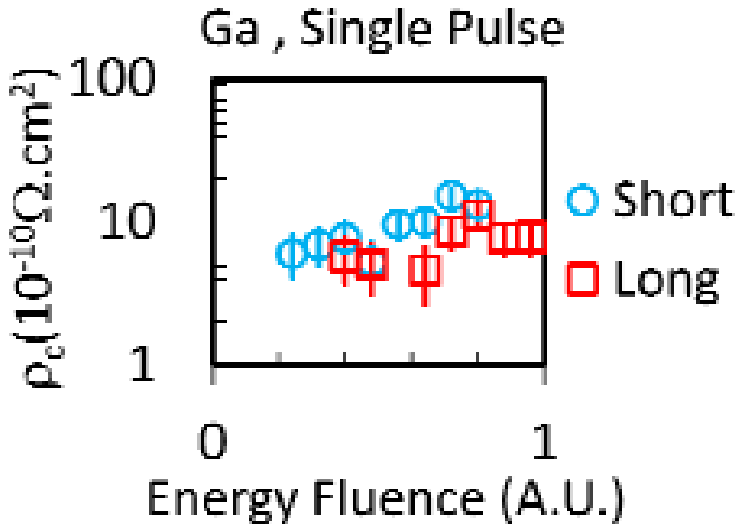
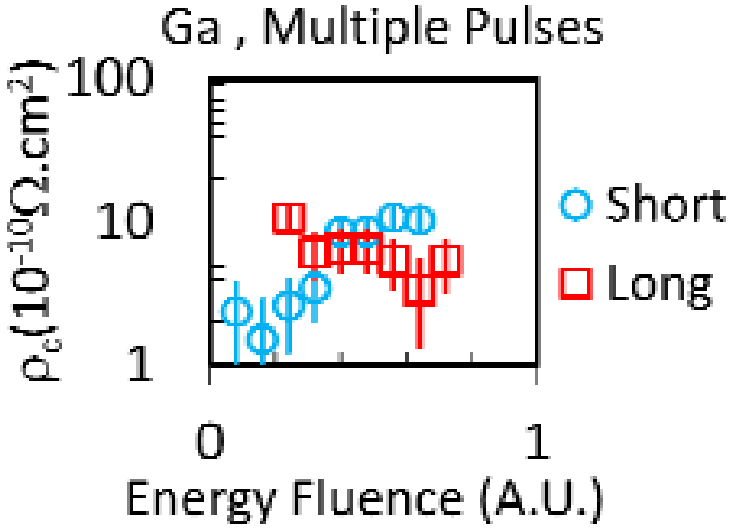
Comparison of R_s & ρ_c for Ga implant in $Si_{0.40}Ge_{0.60}$ with NLA









- Rs decreasing & saturating ⇒ melt
- Rs is lower than with Spike / DSA
- $\rho_c < 10^{-9}\Omega.cm^2$ corresponding with decreasing slope of Rs

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Summary of Results

OVERVIEW OF NLA CONDITIONS WITH EDS AND ELECTRICAL RESULTS

Sample#	Pulse Length	Energy Fluence (A.U.)	# Pulses	Melt Depth (nm)	%Ga	R_s (Ω/sq)	ρ_c ($10^{-10}\Omega.cm^2$)
1	short	0.16	Multiple	15	11.6	246	1.3
2	short	0.48	Multiple	55	5.1	84	8.4
3	long	0.32	Multiple	13	8.3	360	6.1
4	long	0.64	Single	13	7.1	264	4.7
5	long	0.64	Multiple	15	7.7	246	3.4

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$Si_{0.40}Ge_{0.60}$ Summary

- Ga I/I & NLA results in sub-10^{-9} $\Omega.cm^2$ ρ_c
- SiGe:Ga has lower melt laser onset energy than SiGe:B
- Melt laser on SiGe induces Ge segregation towards the surface
- Ti/Ge intermix at the Ti/SiGe interface
- Ga conc. peaks at the Ti/SiGe interface
- Higher Ga conc. at the Ti/SiGe interface lowers the ρ_c

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Thank you


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