A Study of the HTS Josephson Junction Formed by a Ga Focused Ion Beam

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Abstract

HTS SQUIDs (High T_C Superconducting Quantum Interference Devices) mainly utilize grain boundary Josephson junctions (G.B.JJ), e.g. a bi-crystal JJ. But bi-crystal JJs have some problems, as the layout and number of JJs are restricted because they must be located along the grain boundary on the substrate. Therefore, the use of Ga Focused Ion Beam (Ga-FIB) irradiation to make nano-brige JJs (which is HTS JJs) was investigated, as it introduced an atomic disorder in the superconducting region.

Before we fabricated the nano-bridge JJs, Au protective layer, which thickness was 20 nm was deposited on a YBCO layer in order to prevent from over dose during SIM (Scanning Ion Microscope) observation.

We observed decrease of I_c of nano-bridge JJs along the fluence; Shapiro steps were observed in 500 nm wide nano-bridge irradiated by the fluence of 2.0 $\times 10^{15}$ ions/cm² under 2.0 GHz microwave irradiation.

1. Background

Problems of HTS G.B.JJ

- The layout and number of JJs are restricted because they must be located along the grain boundary on the substrate.
- Bi-crystal substrate is expensive.

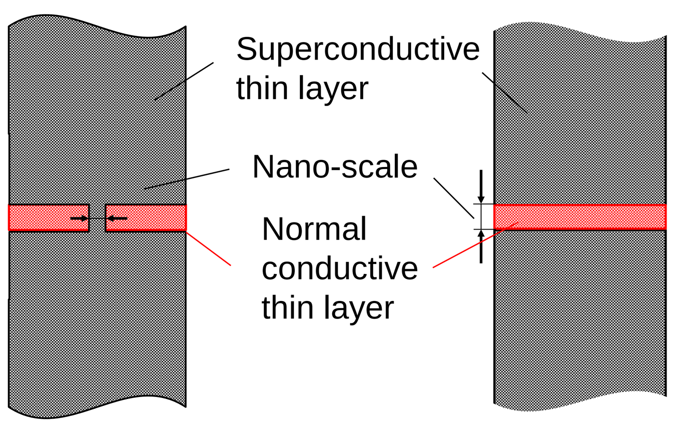
Advantages of nano-bridge JJs by Ga-FIB

- Standard Substrate can be used.
- There is much flexibility in the device design, such as an arrangement and number of JJs.
- Parameters of JJs can be controlled by adjusting irradiation conditions of Ga FIB.

2. Fabrication of nano-bridge JJ by Ga-FIB

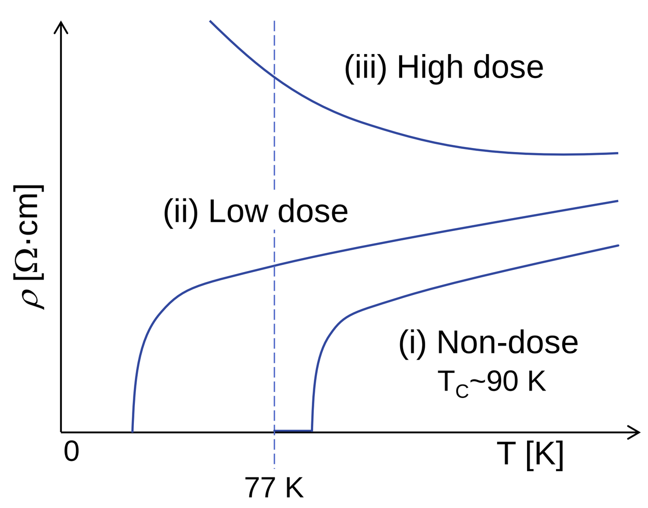
Nano-bridge JJ

- Size : nm order
- Property : SNS
- Substrate : Standard substrate (Non bi-crystal)

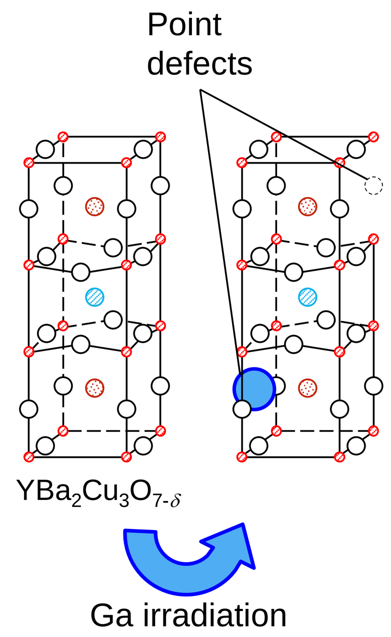


Nano-bridge JJ SNS JJ

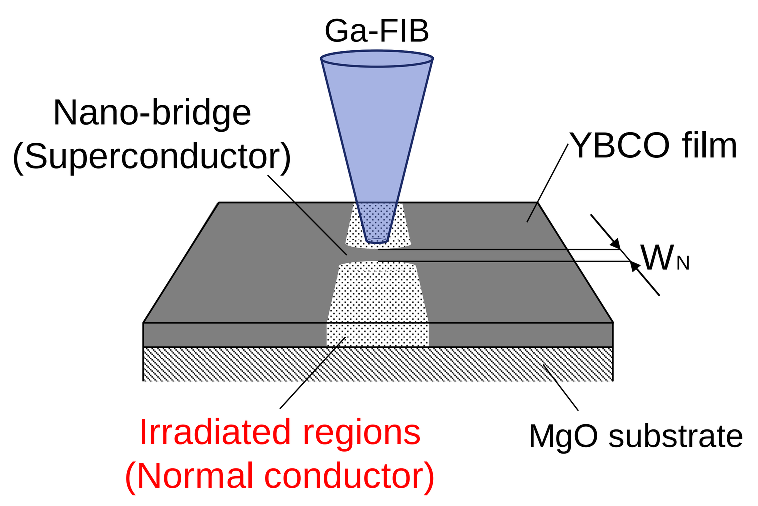
Mechanism of Tc decrease in Ga-FIB process



Schematic of R-T characteristics of irradiated YBCO films



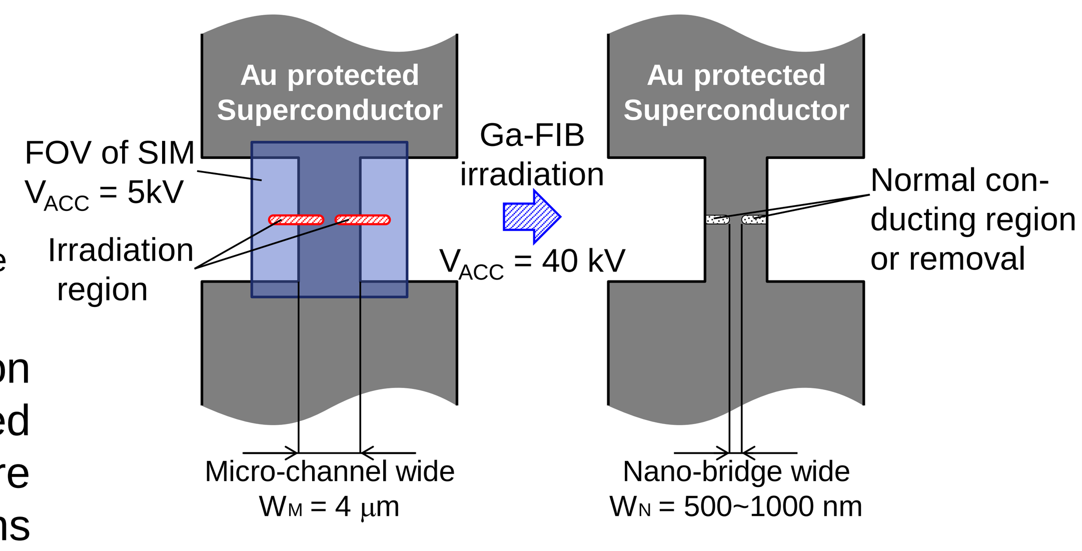
Atomic disorder occurs in YBCO crystal structure by Ga ion irradiation.
Disorder of crystallinity causes decreasing critical temperature(T_C).



To form a nano-bridge, Ga ion beam is irradiated on a selected region of an YBCO thin film, where the superconductivity property turns into normal conductivity.

Thinner YBCO film is required to improve controllability because the distribution of the ion defects is expanded when the film is thick and as a result the ion penetration depth becomes deeper.

Patterned by Ga-FIB

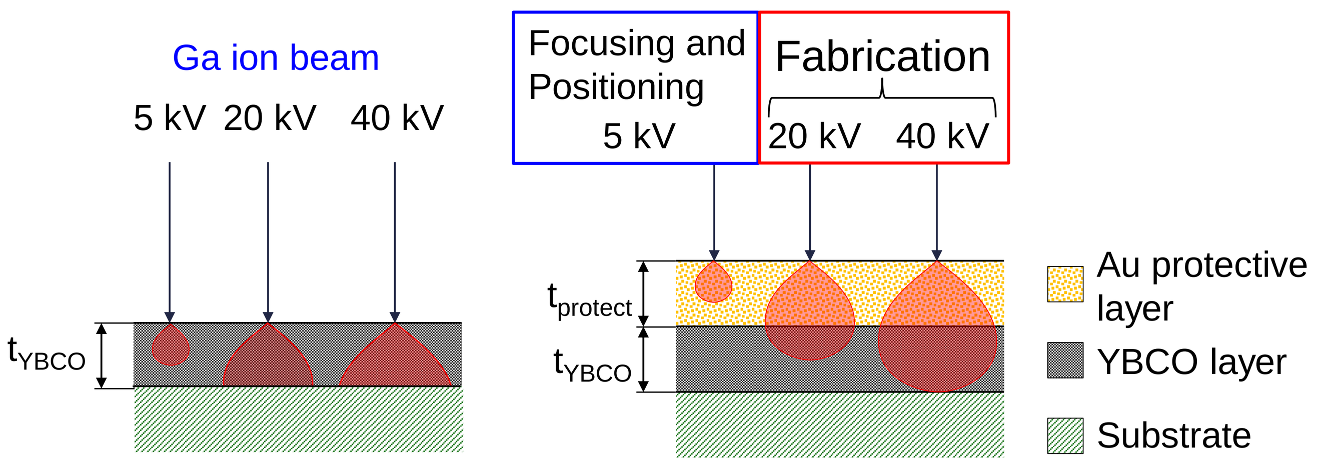


Problem

During a SIM (Scanning Ion Microscope) observation, which is required for a focusing and a positioning process, an over dose amount is given in the field of view (FOV), resulting in excess defects.

3. Prevention from over dose by Au protective layer

No protected YBCO Protected YBCO

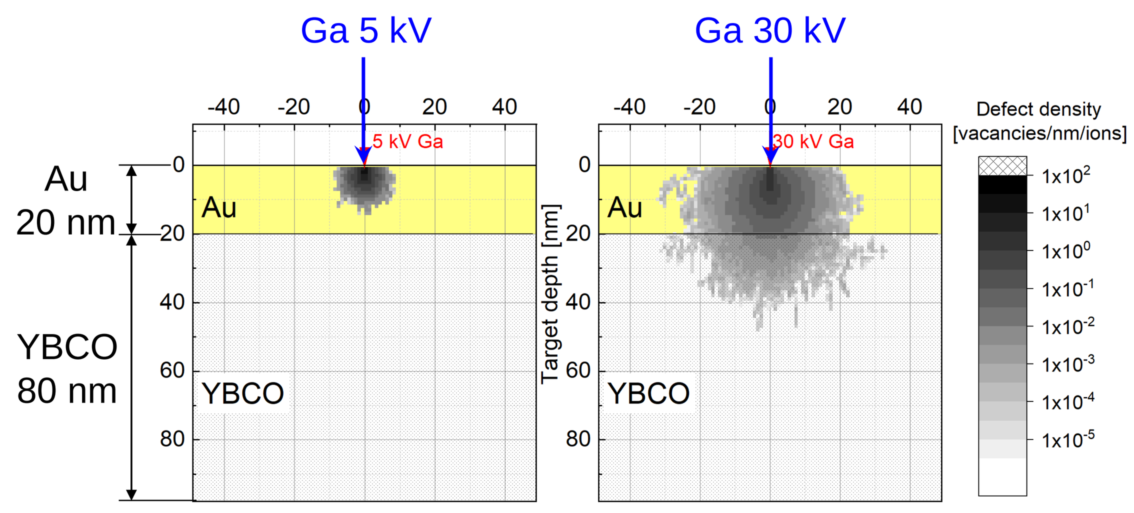


An YBCO film is damaged by irradiation even at low acceleration voltage (V_{Acc}). But by giving an Au protective layer on YBCO thin film, damage of the YBCO layer can be suppressed under irradiation at low V_{Acc}. In addition, defects can be introduced into the YBCO thin film through the Au protective layer at high V_{Acc}.

Focusing and positioning at low V_{Acc}
→ Fabrication at high V_{Acc}

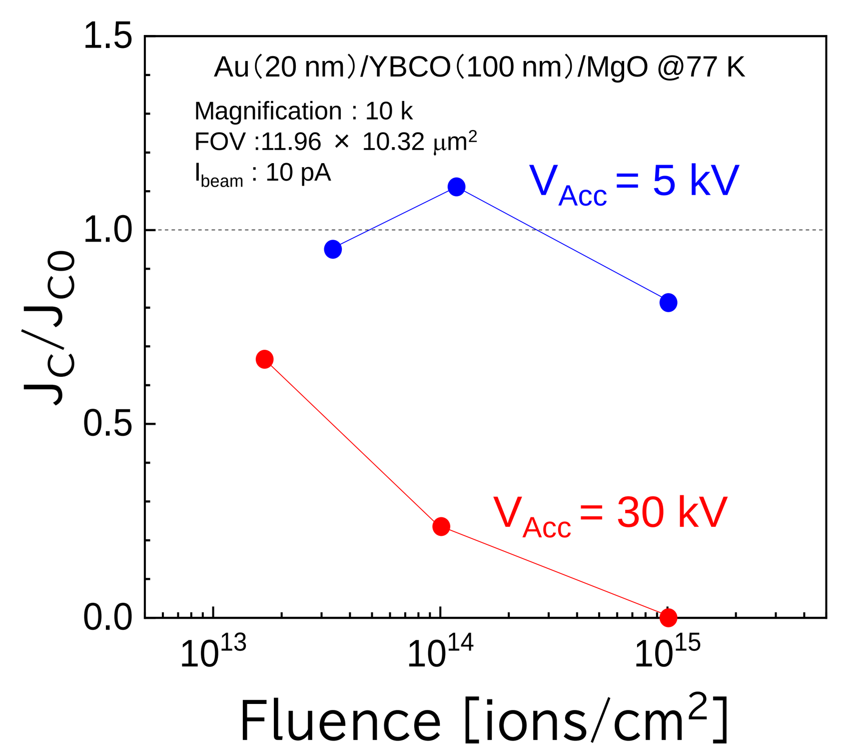
Simulation of defects formation

SRIM program was used to simulate binary collision model.



We simulated the defect distribution in the film when Ga ion number of 10000 were irradiated. At low V_{Acc} of 5 kV, Ga ions didn't reach the YBCO film. But when the V_{Acc} was 30 kV, the number of defects enough to change the properties was introduced into the YBCO thin film though the Au protective layer. Optimizing the thickness of Au layer, we determined the Au thickness of 20 nm.

Experimental Result

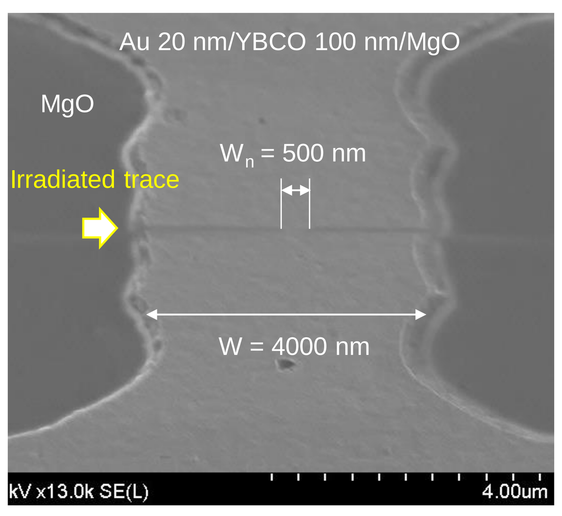


Decrease of J_c along the fluence was not observed at V_{Acc} of 5 kV. In contrast, the J_c was decreased with an increase of the fluence at V_{Acc} of 30 kV.

4. Properties of nano-bridge JJ

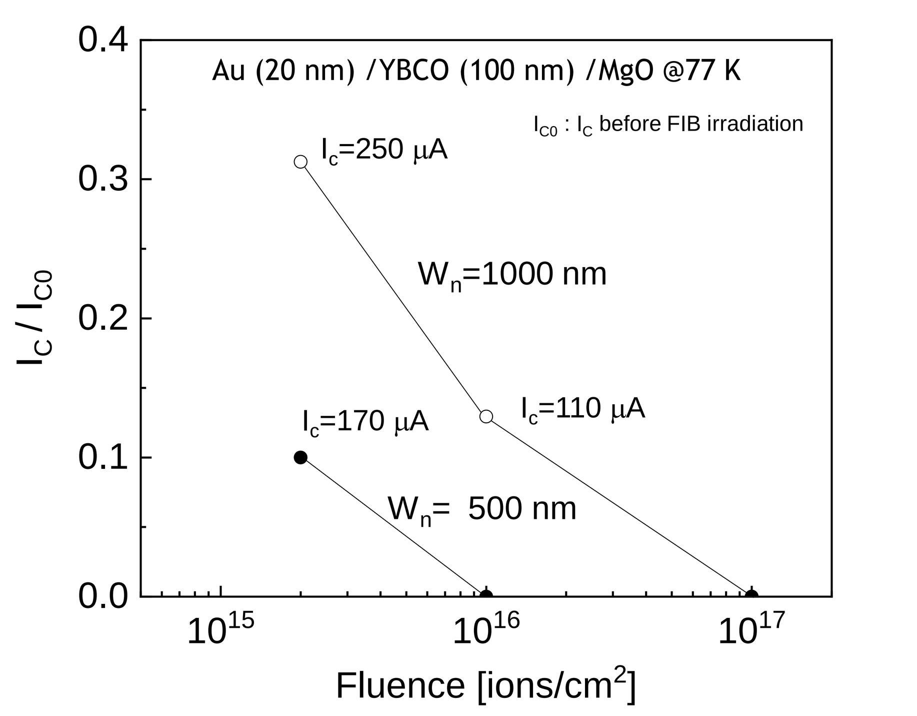
Irradiation condition

Magnification		11 k
SIM observation	I_{Beam}	0.12 nA
	V_{Acc}	5 kV
FIB processing	I_{Beam}	0.07 nA
	V_{Acc}	40 kV



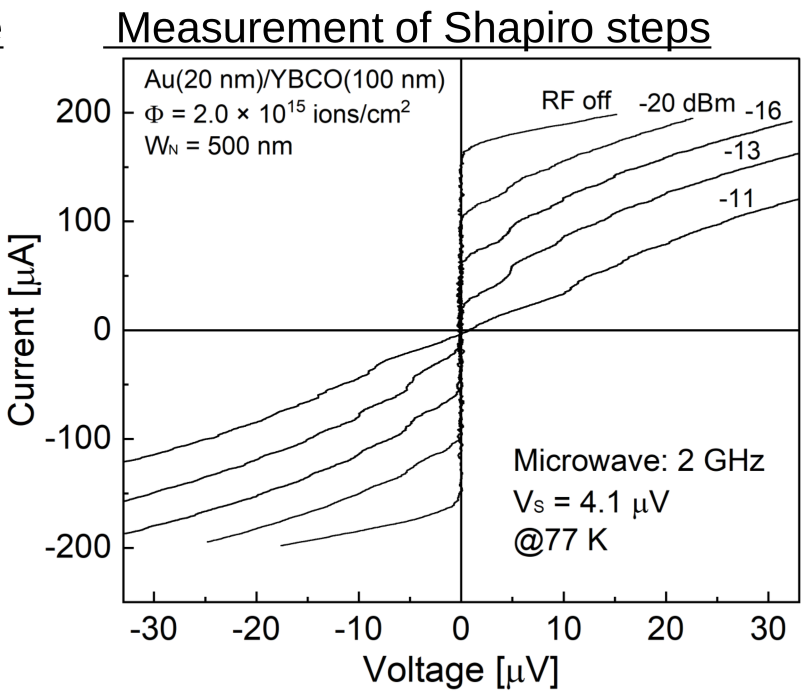
SEM observation at W_n = 500 nm, 2.0 × 10^{15} ions/cm² (Mag. 11 k)

Dependence of I_c on bridge width and fluence



I_c decreased with an increase of the fluence in each nano-bridge with different width. I_c for W_n =500 nm disappeared at 10^{16} ions/cm², and that for W_n =1000 nm disappeared at 10^{17} ions/cm².

Measurement of Shapiro steps



This shows IV-characteristic of a 500 nm wide nano-bridge irradiated by the fluence of 2.0 $\times 10^{15}$ ions/cm² under 2.0 GHz microwave irradiation.

Under microwave irradiation, clear Shapiro steps were observed.

We confirmed that the nano-bridge fabricated by Ga-FIB irradiation shows Josephson-like behavior.

5. Conclusions

1. We investigated properties of nano-bridge JJ irradiated by Ga-FIB introducing an atomic disorder in the superconducting region.
2. By giving a 20 nm thick Au protective layer on YBCO layer, we could prevent from over dose during SIM observation at V_{Acc} of 5 kV. And we confirmed that the Jc was decreased with an increase of the fluence at V_{Acc} of 30 kV for JJ fabrication.
3. We observed decrease of I_c of nano-bridge JJs along the fluence; Shapiro steps were observed at a 500 nm wide nano-bridge fabricated by the fluence of 2.0 $\times 10^{15}$ ions/cm² under 2.0 GHz microwave irradiation.

[1] K. Hayashi, T. Ueda and S. Tanaka, Extended Abstracts of HTSFF2018, 56-57, 2018.

[2] K. Hayashi, T. Ueda, R. Ohtani, and S. Tanaka, ISS2019, EDP1-1, 2019.