# Fabrication of swelling structure on SiC surface by using multi-charged Ar beam

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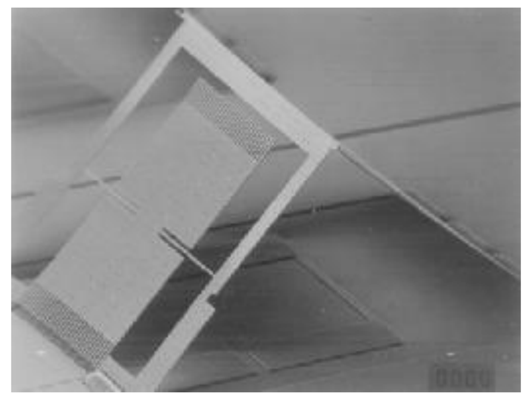
## Abstract :

Silicon carbide (SiC) crystal, which has good mechanical and electric properties, is one of hopeful materials. Owing to its ultrahigh-hardness and chemical stability, it is difficult to fabricate structures in micro-nano meter scale by means of conventional fabrication processes. In previous experiments, a swelling structure, which is fabricated by means of ion-beam induced expansion effect, has been observed for SiC crystal ([1], [2]). The object of the present study is to show a feasibility of ion-beam induced swelling effect as a fabrication method for SiC crystal. Based on the experimental results, a fabrication of multi-step structure on SiC crystal has been demonstrated.

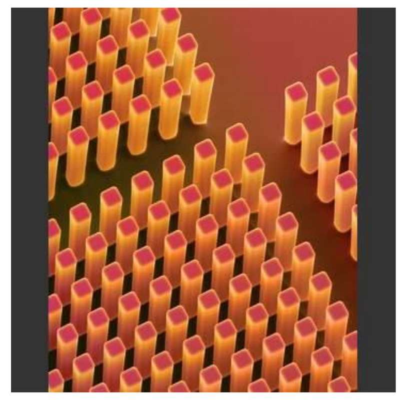
Ar-beam, which was prepared by ECR ion source (10GHz-NANOGAN), was irradiated on 6H-SiC crystal and a swelling height was observed. By using $Ar^{7+}$ beam with 700 keV, the maximum height of 100nm was obtained. Based on those results, two-step structure has been successfully fabricated by the two-step irradiation. In order to confirm the possibility of the swelling structure as mechanical devices, irradiation-induced modification of mechanical properties of SiC crystal was evaluated by means of nano-indentation method. No serious deteriorations have been observed under the present irradiation conditions.

## Expanding application of 3D structure in micro-nano meter scale

MEMS
Linear rack gear reduction drive[3)]



Optoelectronics
Self-Assembled Electrostatic Torsion Mirror Microscanners[4)]



Biomedial
DNA purification microchip[5)]

Fig. 1 Examples of products with 3D structure in micro-nano meter scale

## Advantages of SiC crystal

• High-power devices available at high temperature

• High mechanical strength
Hardness : 55 GPa / Young's modulus 600~620 GPa[6)]

• Price is decreasing
Development of synthesis process for mass production of high-power semiconductor devices would reduce in price.

| Properties | Si | 4H-SiC | GaAs | GaN |
|---|---|---|---|---|
| Crystal Structure | Diamond | Hexagonal | Zincblende | Hexagonal |
| Energy Gap : $E_G$ (eV) | 1.12 | 3.26 | 1.43 | 3.5 |
| Electron Mobility : $\mu_n$ (cm$^2$/Vs) | 1400 | 900 | 8500 | 1250 |
| Hole Mobility : $\mu_p$ (cm$^2$/Vs) | 600 | 100 | 400 | 200 |
| Breakdown Field : $E_B$ (V/cm) X10$^6$ | 0.3 | 3 | 0.4 | 3 |
| Thermal Conductivity (W/cm℃) | 1.5 | 4.9 | 0.5 | 1.3 |
| Saturation Drift Velocity : $v_s$ (cm/s) X10$^7$ | 1 | 2.7 | 2 | 2.7 |

http://rohmfs.rohm.com/en/products/databook/applinote/discrete/sic/common/sic_appli-e.pdf

IB-induced swelling structure caused by volume expansion

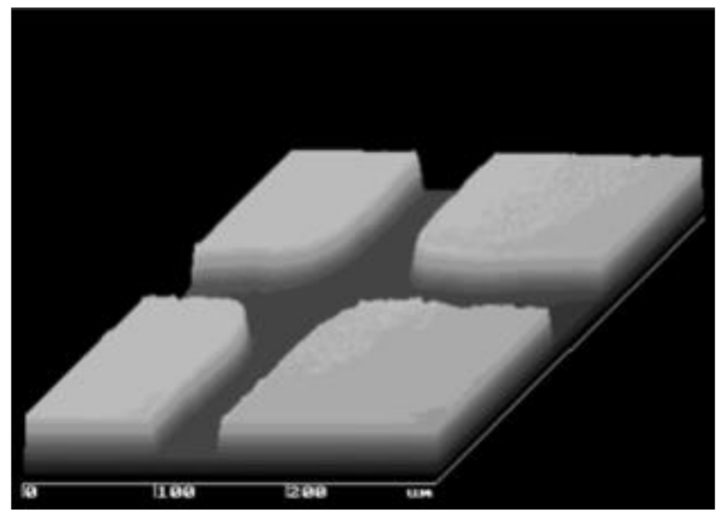


Fig. 2 Swelling structures formed on beta-SiC irradiated by Ni (4 MeV) [7)]

Large volume swelling : Max. 8~20% [8)]

## Highly charged ion beam facility @ KUT

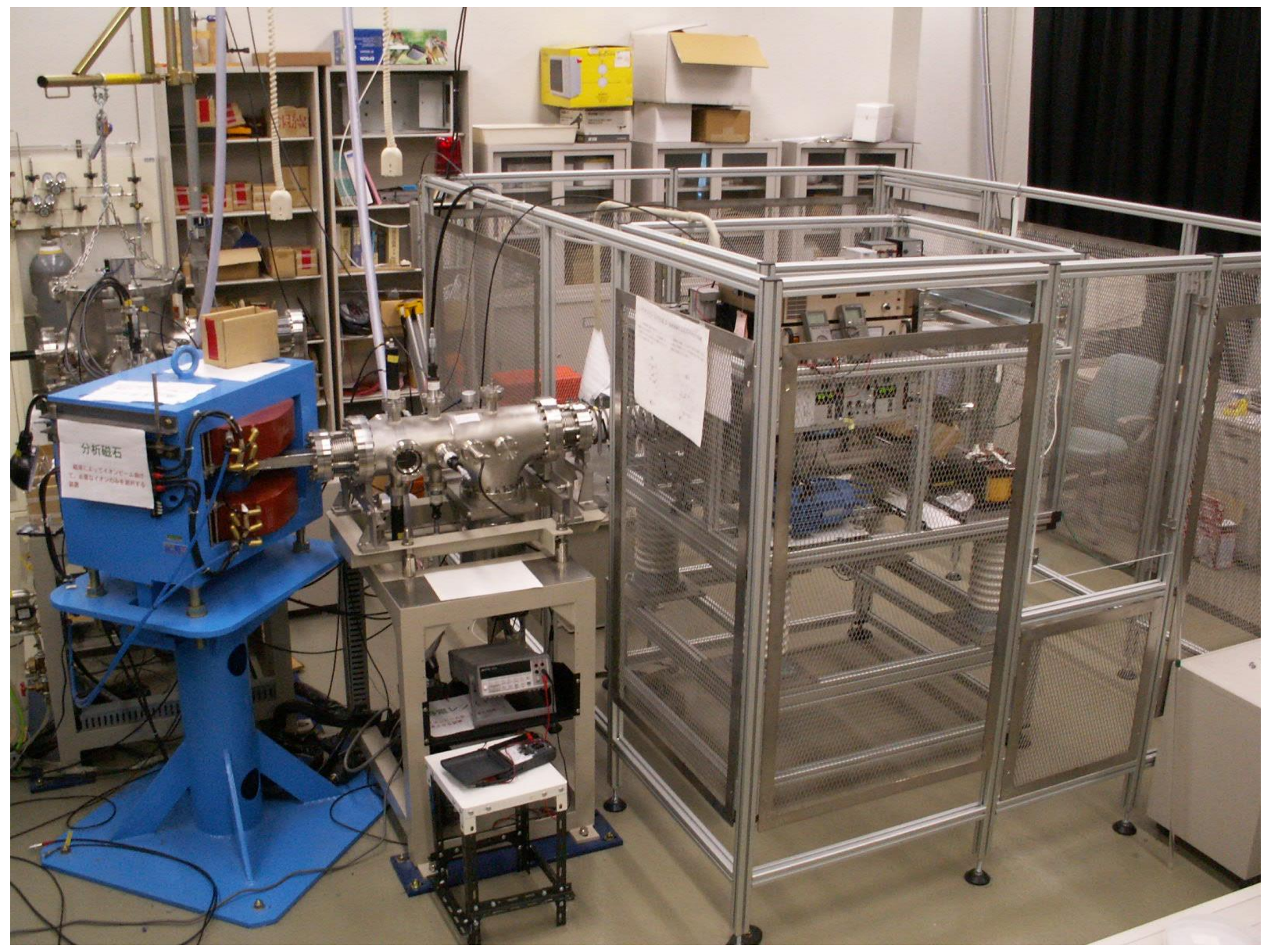


Fig. 3 HCI beam facility built at Kochi Univ. of Tech. [9)]
The facility includes an ECRIS, an acceleration system up to 130 kV, a transport and analysis, and an irradiation system.

$P_{RF} = 0 \sim 80$ W
$V_{ext.} = 0 \sim 30$ kV
$V_{accl.} = 0 \sim 100$ kV

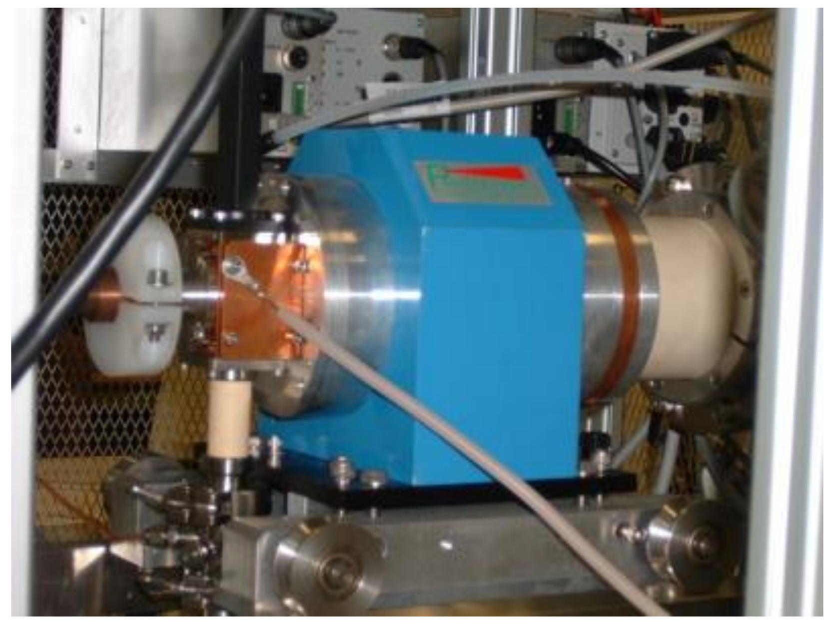


Fig. 4 ECRIS for multiple-charged ion beams
A 10 GHz NANOGAN, which is an ECRIS developed by PANTECHNIK Co., was installed.

## Irradiation of Ar-beam on SiC

Ar-beam was irradiated through a stencil mask.

Fig. 5 Stencil mask to form irradiation pattern. The mask has 2 x 0.1 mm x 4 slits.

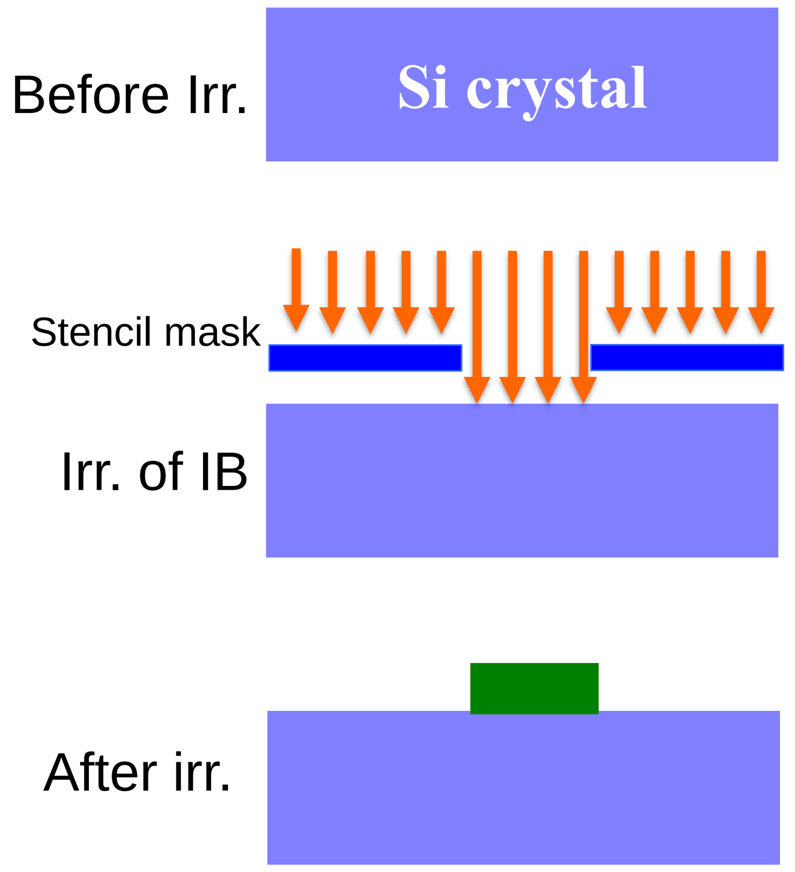
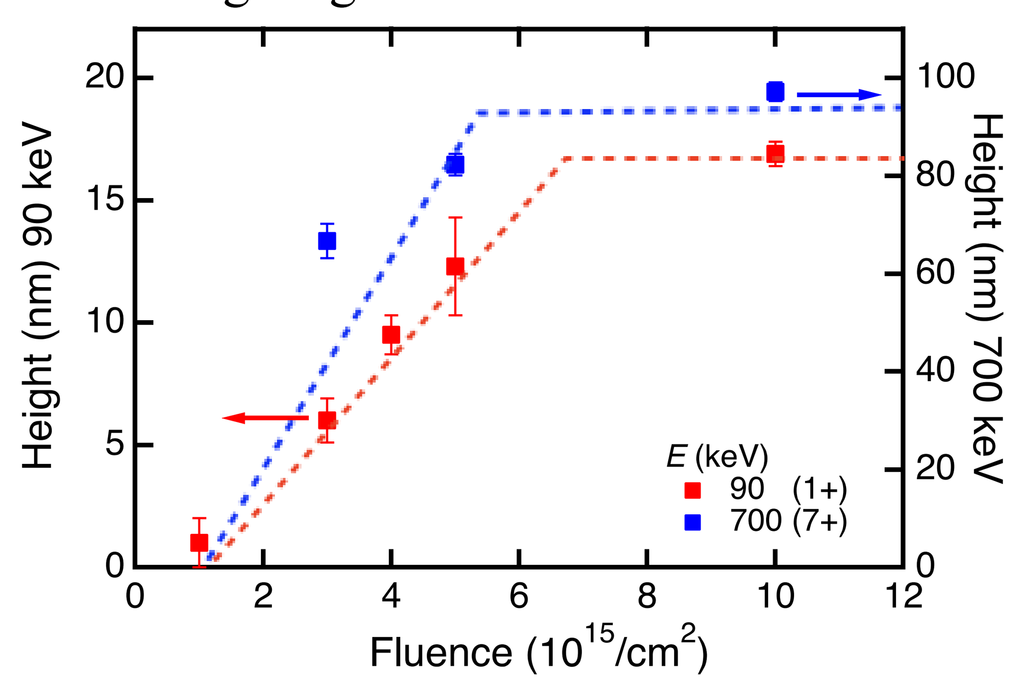



Fig. 6 Procedure to form swelling structure

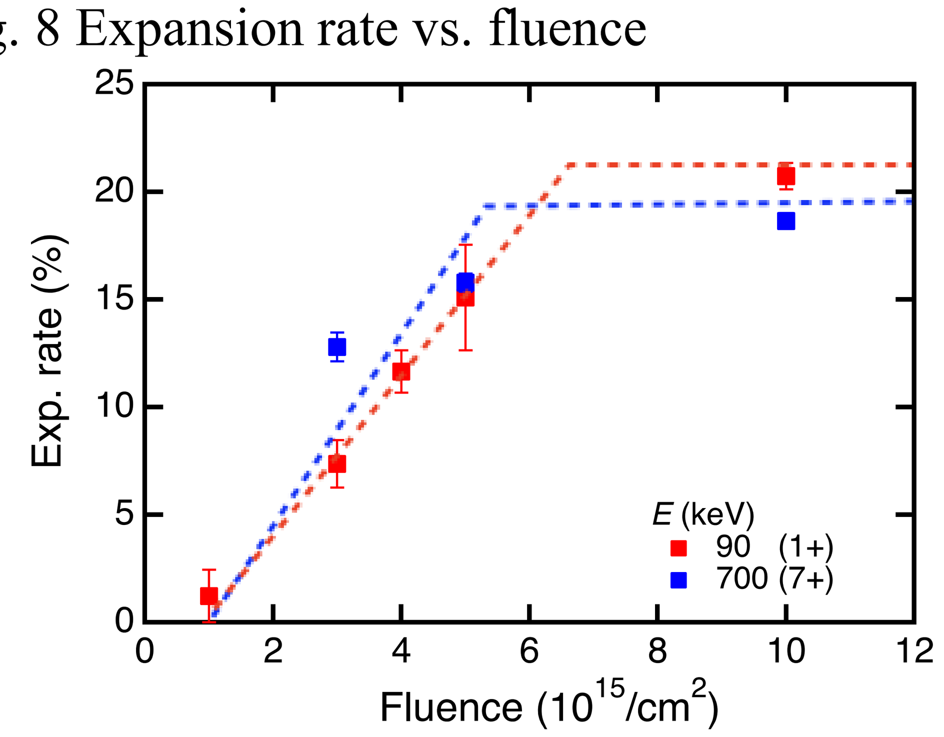
## Swelling induced by Ar-beam irradiation

Fig. 7 Swelling height vs. fluence




- Swelling str. grow with fluence up to $n$ = 5~6 x $10^{15}$ /cm$^2$.
- Swelling height@10 x $10^{15}$ /cm$^2$ = 17 nm (90 keV)
  97nm (700 keV)

Fig. 8 Expansion rate vs. fluence




- Energy dependence is small.
- Max. expansion rate ~ 20%

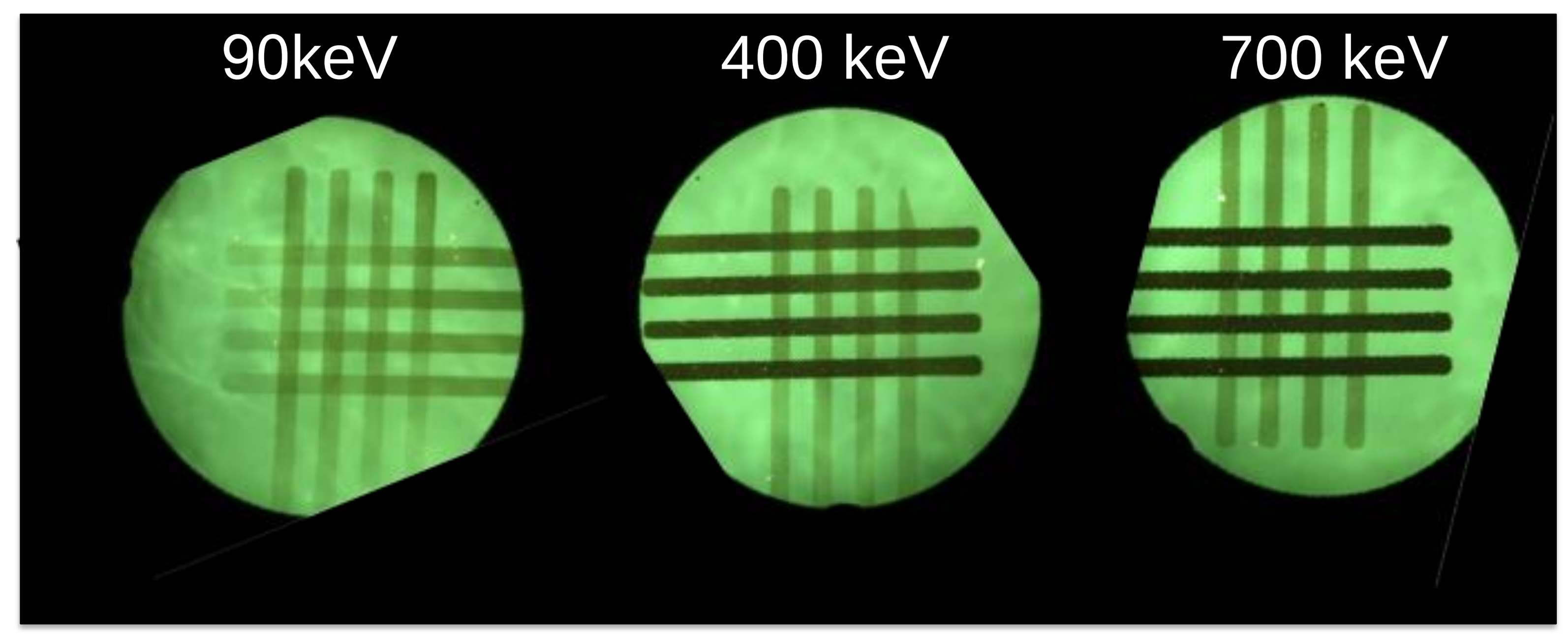
## 2-step irradiation

Fig. 9 Orientation of stencil mask for 2-step irradiation


2.5×$10^{15}$ /cm$^2$ / 90 keV
Expected swelling height = 6 nm

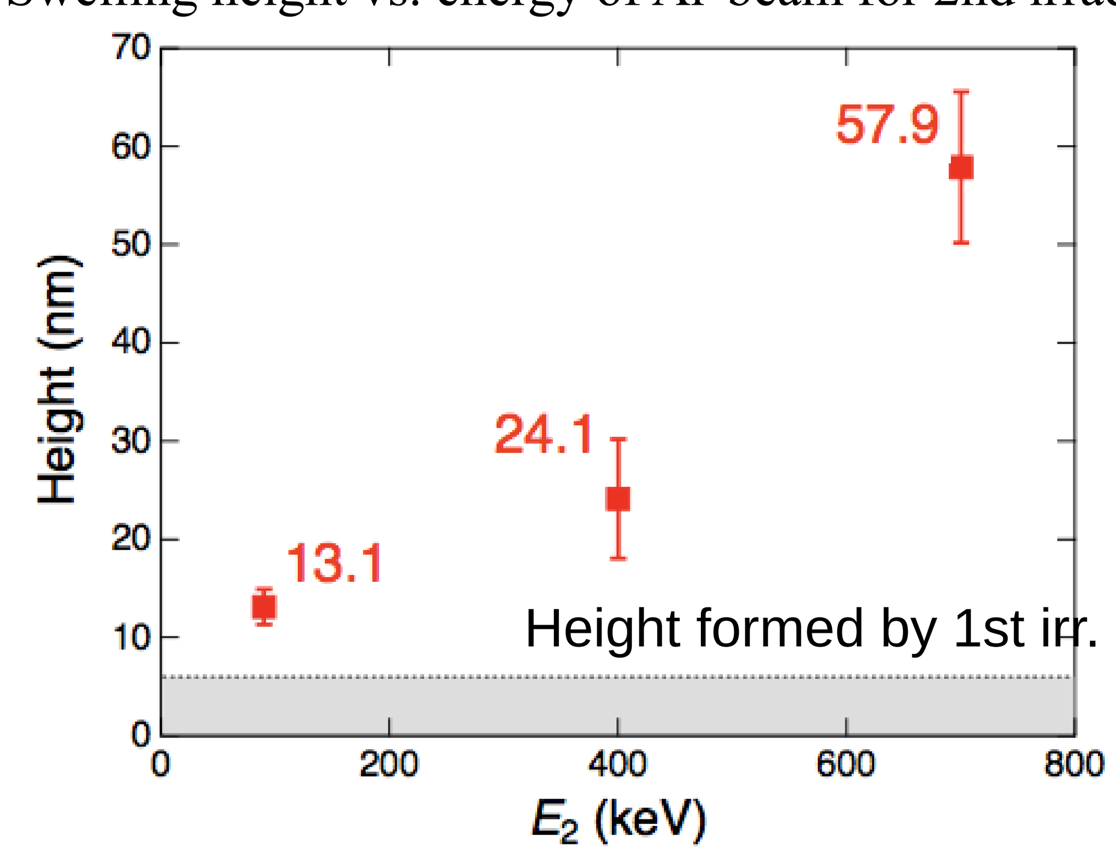
2.5×$10^{15}$ /cm$^2$ / 90, 400, 700 keV

Fig. 10 Photoimages of SiC after 2nd irradiation




## Swelling height formed by 2-step irradiation

Fig. 11 Swelling height vs. energy of Ar-beam for 2nd irradiation




- Additional swelling, observed at overlap, increases with beam energy of 2nd irradiation.
- Swelling height, fabricated by sequential irradiation, is consistent with sum of those by each irradiation. However, an ambiguity in observed swelling height remains.

## Modification of mechanical properties

Fig. 12 Nano-hardness and Young's modulus measured by means of nano-indentation method

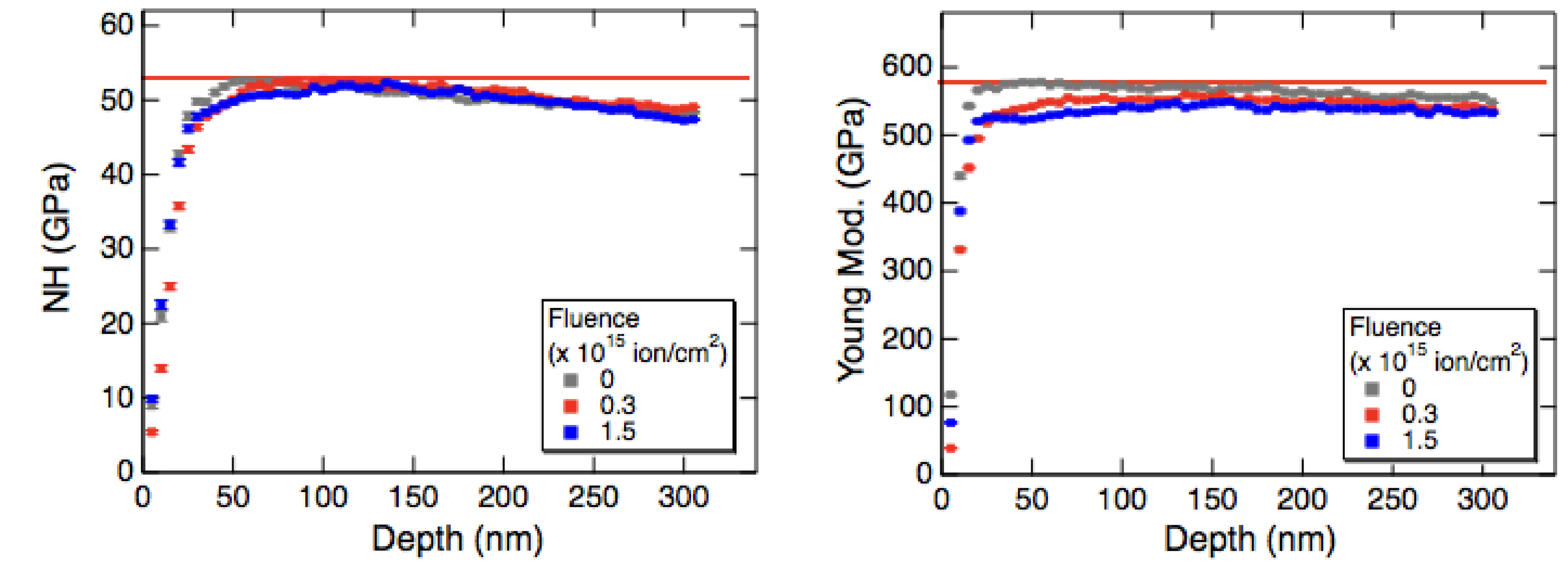
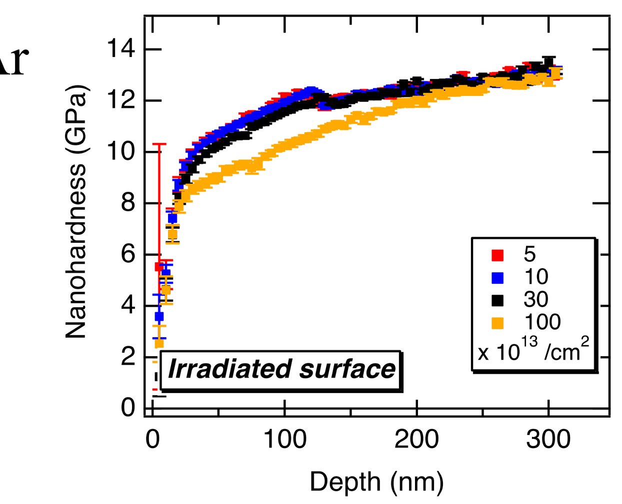



Fig. 13 Nano-hardness of Ar beam-irradiated Si




- Relative deterioration in nano-hardness of SiC crystal, induced by Ar-beam irradiation, is ~ 5%.
- SiC crystal keeps high mechanical property against Ar-beam irradiation compared with Si crystal.

## Conclusions

1) Swelling structures with the height ~100 nm was formed on SiC crystal by irradiation of $Ar^{7+}$ beams (100 × 7 keV, 5x$10^{15}$ /cm$^2$).
2) 2-step swelling structures were successfully fabricated through 2-step irradiation method.
3) Swelling structure on SiC crystal would be good candidate to apply as mechanical elements in micro-nano meter scale.

### References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