Miniaturization of swelling structure fabricated on 6H-SiC surface by ion-beam irradiation

S. Momota[1)], K. Honda[1)], J. Taniguchi[2)]

1) Kochi Univ. of Tech., Tosayamada, Kochi 782-8502, Japan

2) Tokyo University of Science, Katsushika-ku, Tokyo 125-8585, JAPAN

Abstract :

3-dimentional (3D) structures in micro-nano meter scale are applied in various industrial fields and would expand their potential by applying high performance materials. Silicon carbide (SiC) crystal, which has good mechanical and electric properties, is one of hopeful materials. However, 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 a series of previous experiments, a swelling structure, which was fabricated by ion-beam (IB) induced expansion effect, was observed on crystal materials and the height changes depending on irradiation condition. In case of SiC crystal, the expansion rate is relatively large 10~20%. This result indicates the possibility of the expansion effect as a fabrication process for 3D structures on a surface of SiC substrate.

In this study, we have tried to reduce a size of swelling structure, fabricated on SiC substrate, down to 0.5 μm by Ar beam irradiation through two kinds of stencil masks, resist and Cr. We have successfully fabricated the swelling structures for the size 1 ~ 100 μm. And the height of the structures shows no remarkable size dependence.

Application of 3D structure in micro-nano meter scale

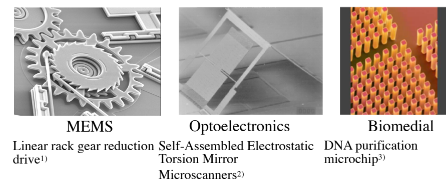

Fig. 1 Examples of products with micro-nano 3D structure

Advantages of SiC crystal

- High-power devices available at high temperature
- High mechanical strength
  Hardness : 55 GPa / Young's modulus 600~620 GPa[4)]

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 : μ_n (cm^2/Vs)	1400	900	8500	1250
Hole Mobility : μ_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°C)	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

However, a fabrication method for SiC crystal in micro-nano scale has not established yet.

Ion-beam (IB) induced swelling effect caused by volume expantion

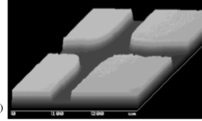

Fig. 2 Swelling structures on beta-SiC irradiated by Ni (4 MeV) [6)]

A) Lower fluence (~ 10^{15} cm^{-2} or lower) compared with conventional IB technologies.

B) Simple process

C) Lift-up process without deposition

D) Large volume swelling for SiC : Max. 8~20%[7)]

Purpose of this study

We have tried to reduce a size of swelling structures on 6H-SiC substrate down to 0.5 μm by IB irradiation using a stencil mask.

Experimental

Procedure

1) Production of patterned mask

Mask

6H-SiC

6H-SiC : 330 μm-t, <1000>, Tanke Blue Co.
Mask a) Resist (SML-2000, 2100nm)
b) Cr (240 nm)

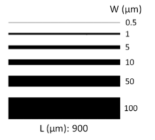

Fig. 3 Mask pattern of resist and Cr on SiC substrate.

2) Irradiation of ion beam

Ar^{1+} (100 keV) or Ar^{4+} (400 keV)

3) Removal of patterned mask

Irradiation facility

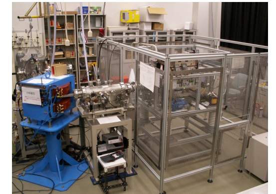

Fig. 4 HCI beam facility built at Kochi Univ. of Tech. [8)]
The facility includes an ECRIS, an acceleration system up to 130 kV, a transport and mass analysis, and irradiation systems.

Results

Transfer of mask pattern

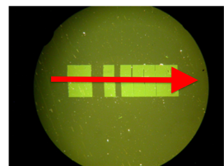

Fig. 5 Optical image of 6H-SiC irradiated after removing Cr mask.
Surface profile was measured along a direction indicated by a red arrow.

Surface profile of swelling structure fabricated on SiC

Surface profile of swelling structure was measured by AFM or Alpha-step.

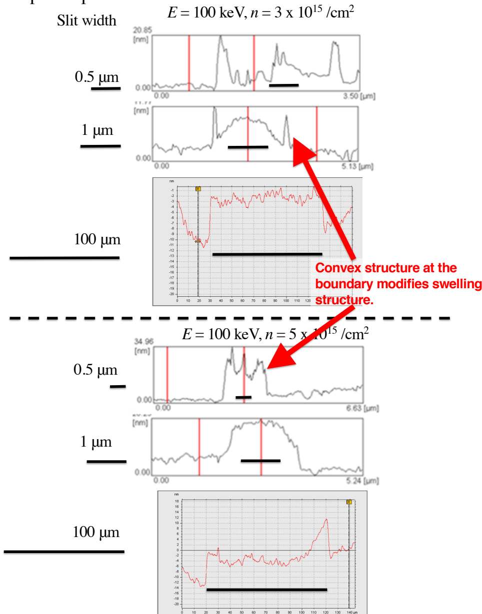

Fig. 6 Surface profile of SiC fabricated with Resist mask irradiated by 100 keV-Ar^{1+} beam.

E = 400 keV, n = 5 x 10^{15} /cm^2

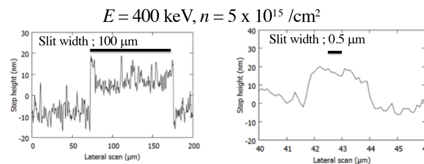

Fig. 7 Surface profile of SiC fabricated with Cr mask irradiated by 400 keV-Ar^{4+} beam.

Slit size vs. swelling height

Swelling height is obtained from observed surface profile.

Resist mask

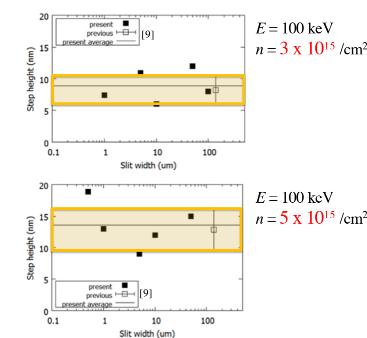

Fig. 7 Step height as a function of a width of slit for resist mask

Resist mask :

A) The height of IB-induced swelling structures on 6H-SiC substrate shows no significant slit width dependence in a width range between 0.5 and 100 μm .

B) Average value of the present results agrees with the previous one.

100 keV Ar-beam stops in resist mask.
Thickness of resist ; 2100 nm
R_P(100 keV, Ar) in resist : 105 nm (calculated by SRIM)

Cr mask

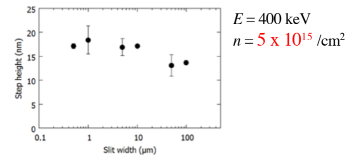

Fig. 8 Step height as a function of a width of slit for Cr mask

Cr mask :

A) As for resist mask, the height of IB-induced swelling structures shows no significant slit width dependence.

B) The present result is definitely smaller than the value (~ 40 nm) expected by considering beam-energy dependence.

Not-negligible amount of 400 keV Ar-beam would penetrate Cr mask to reach 6H-SiC substrate.
Thickness of Cr ; 240 nm (Density would be lower than literature value.)
R_P(400 keV, Ar) in Cr : 192 nm (calculated by SRIM)

Conclusions

A) 3D-structures on 6H-SiC substrate in micro-meter scale were successfully fabricated by IB induced swelling effect down to a width of 0.5μm.

B) Width dependence of structure height is small in the width range between 0.5 and 100 μm.

References

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