# Synchrotron X-Ray Topography Measurements on 4H-SiC Epitaxial Layer

Isaho KAMATA, Central Research Institute of Electric Power Industry (CRIEPI)

Kamata@criepi.denken.or.jp

Silicon carbide has excellent properties such as a wide energy band gap, high thermal conductivity and high break down voltage. Thus, SiC power devices are possible to be low loss and high temperature resistant devices. Therefore, high performance SiC power devices applying for electric power distribution and transmission are expected to develop.

Although SiC has superior properties, actual SiC devices can not demonstrate sufficient performance at the present. It is mainly because that SiC substrates and epitaxial layers contain crystal defects in a high density. Therefore, to improving device performance, it is required to reduce the defects.

There are some defects in SiC crystal such as micropipes (hollow core defects), non-hollow core screw dislocations and edge dislocations. The defects can be evaluated by KOH etching. Etch pits exhibit crystal defect apparently. However, the KOH etching is a destructive evaluation. On the other hand, X-ray topography can measure the defects in SiC crystal to be non-destructive evaluation.

In this measurement, the 2 theta goniometer was used, and topography was carried out in the reflection geometry. Monochromatic X-ray beam is obtained by Si (111) or Si (311) monochrometer crystal. X-ray films, imaging plates and high-resolution nuclear emulsions were used to record the topography images.

Figure 1 shows topography image on SiC substrate. Although these defects can not observed on the substrate surface by optical microscope, these defects are clearly observed by X-ray topography.

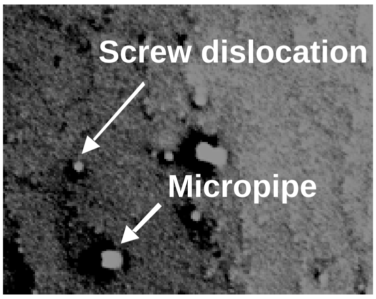



Fig. 1 Topography image on SiC substrate.

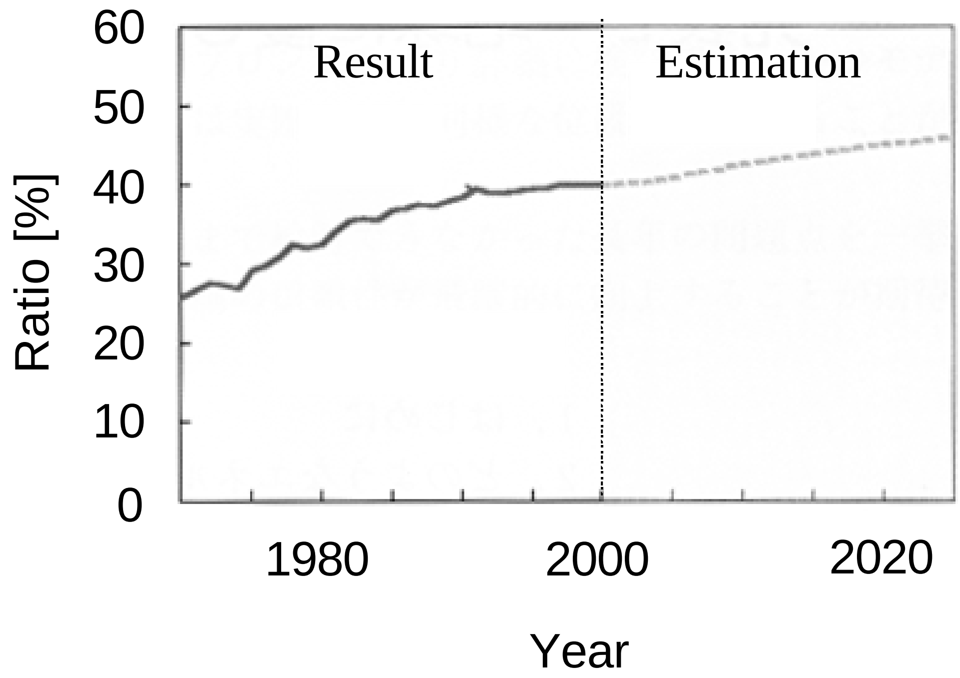
# Synchrotron x-ray topography measurements on 4H-SiC epitaxial layer

Isaho Kamata
Central Research Institute of
Electric Power Industry
(CRIEPI),

# Out line

- **Background in electric power field**
- **Properties of SiC**
- **Present status of SiC**
- **Evaluation of defects  -KOH etching**
- **Evaluation of defects  -X-ray topography**
- **Summary**

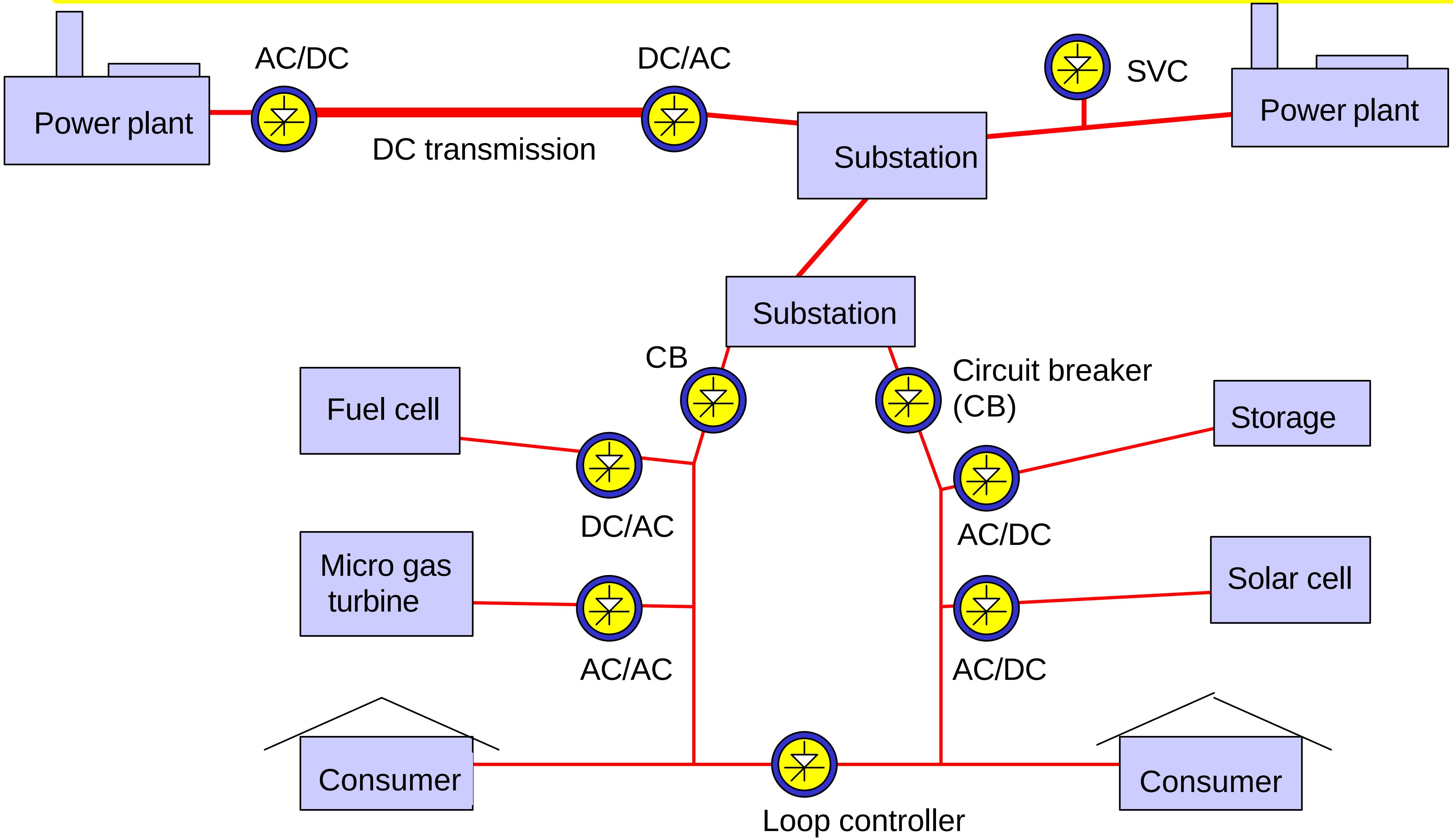
# Background in electric power field




Ratio of electric power in total energy consumed in Japan in each year [1].

[1] A. Nakaoka: The 21st Future Technology forum on Energy (2002) [in Japanese]

# Power electronics devices

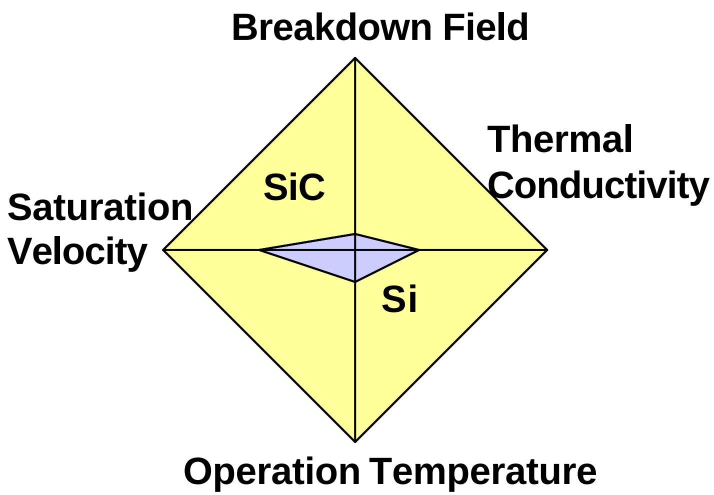



Electric power transmission and distribution systems in the near future.

# Materials for power electronics devices

| Material | | 4H-SiC | Si | GaAs | GaN | diamond |
|---|---|---|---|---|---|---|
| Energy Bandgap | [eV] | 3.26 | 1.12 | 1.42 | 3.42 | 5.47 |
| Electron Mobility | [cm2/Vs] | 1000 | 1350 | 8500 | 1200 | 2000 |
| Breakdown Field | [MV/cm] | 2.8 | 0.3 | 0.4 | 3 | 8 |
| Saturation Drift Velocity | [cm/s] | $2.2x10^{7}$ | $1.0x10^{7}$ | $1.0x10^{7}$ | $2.4x10^{7}$ | $2.5x10^{7}$ |
| Thermal conductivity | [W/cmK] | 4.9 | 1.5 | 0.46 | 1.3 | 20 |
| p-type controll | | ○ | ○ | ○ | △ | △ |
| n-type controll | | ○ | ○ | ○ | ○ | × |
| Thermal oxidation | | ○ | ○ | × | × | × |
| Conductive Wafer | | ○ | ○ | ○ | △(SiC) | × |
| insulating Wafer | | ○ | △(SOI) | ○ | △(Sapphire) | × |

Table 1. Material property and present situation of 4H-SiC, Si , GaAs, GaN and diamond [2].





[2] H. Matsunami: *Technology of Semiconductor SiC and Its Application* (2003) [in Japanese]

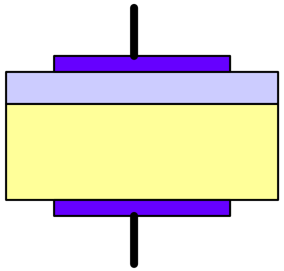
# Present status of SiC

Excellent properties of SiC

↓

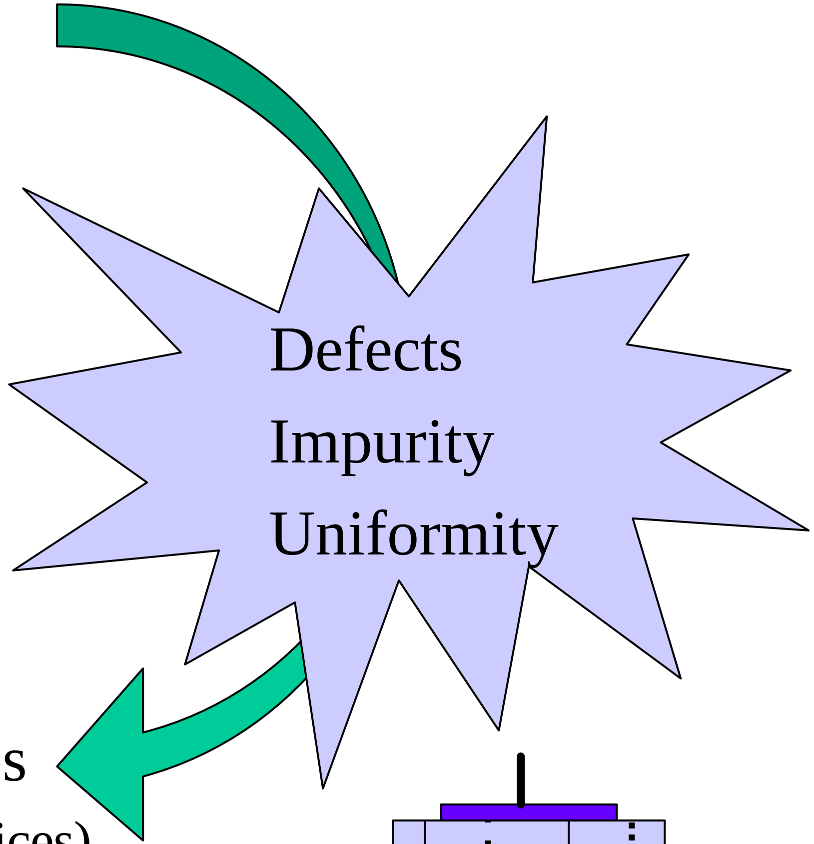
High quality SiC layer

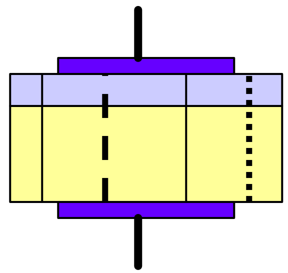
↓



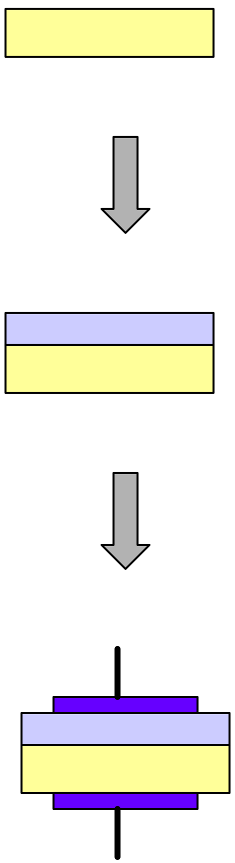
High performance SiC power devices

(High temperature resistant and low-loss devices)



# Study on SiC

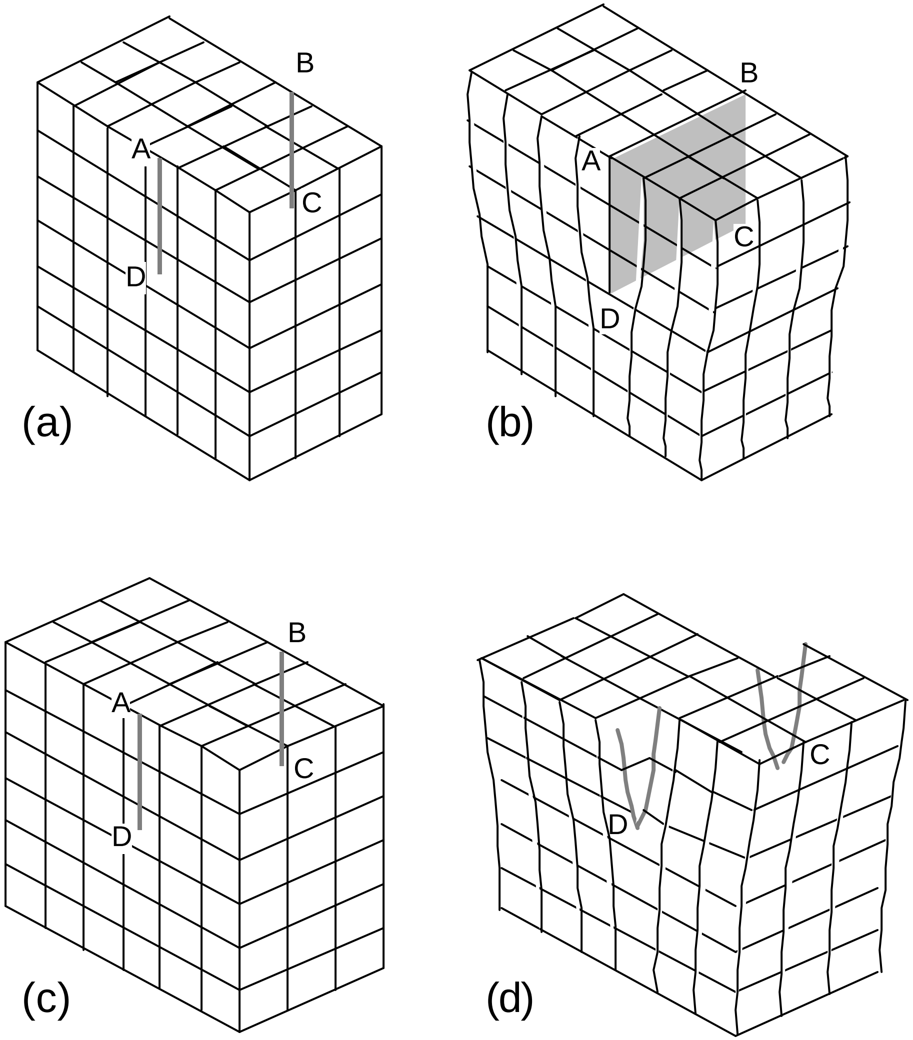


Substrates — Evaluation → KOH, Topography, Microscopy, SIMS

Epitaxial growth — Growth ⇕ Evaluation → KOH, Topography, Microscopy, SEM, TEM, SIMS, PL,

Device fabrication — Process ⇕ Evaluation → I-V, C-V, DLTS, EL,

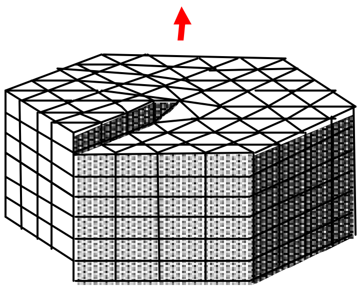
# Dislocations

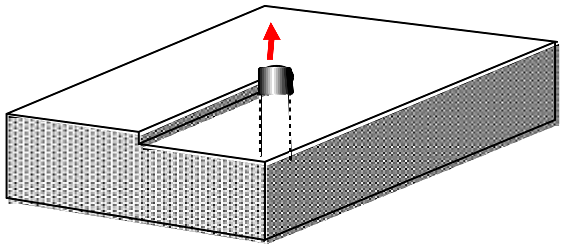


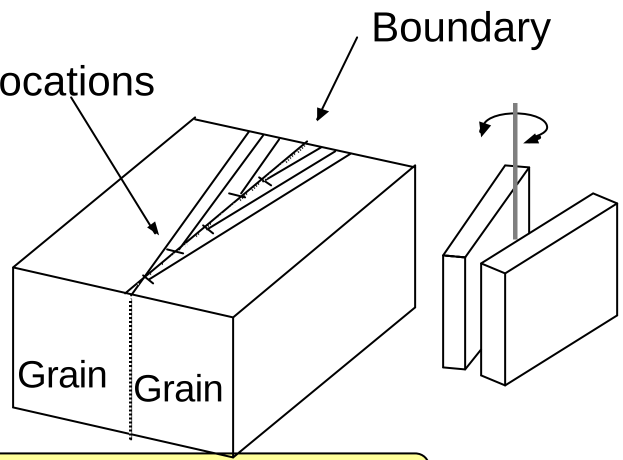

Edge dislocation

Screw dislocation

# Evaluation of defect -KOH etching-





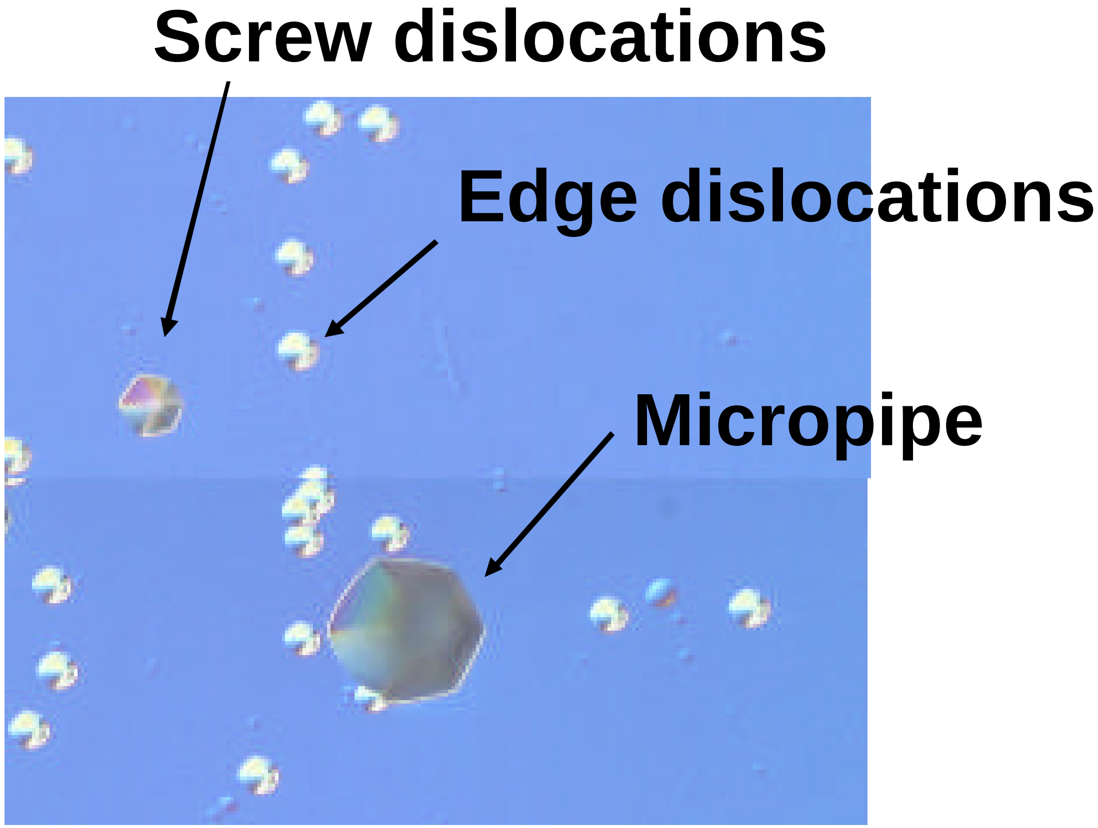



Screw dislocations | Micropipes | Edge dislocations

KOH etching ~ 500℃

Etch Pits

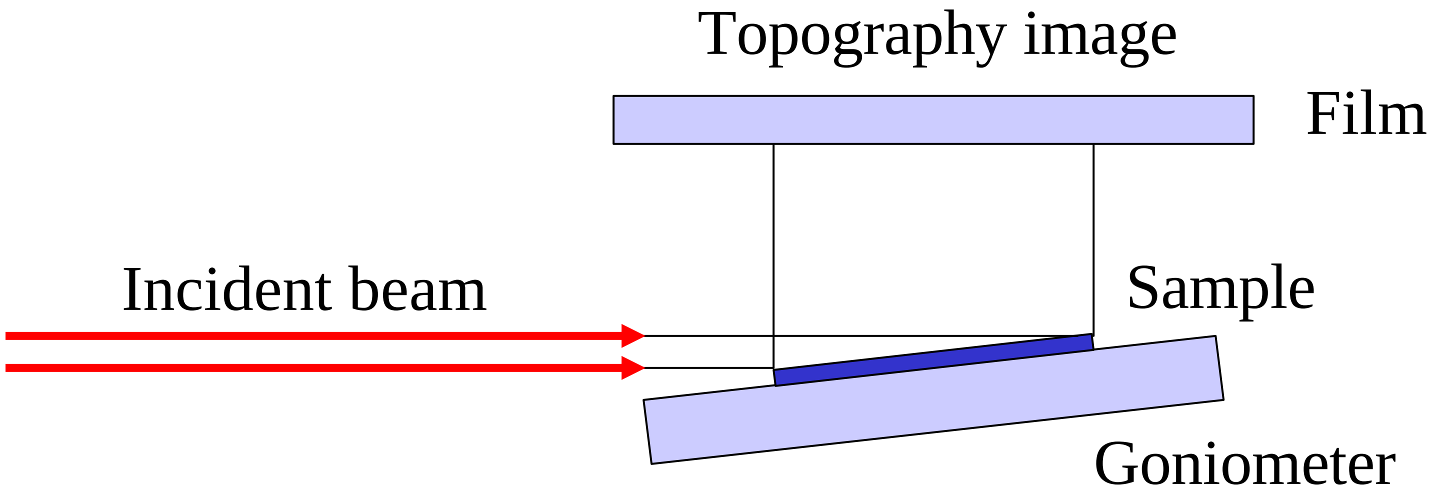
# Evaluation of defect -KOH etching-




Dislocations are easily analyzed by KOH etching as etch pits.

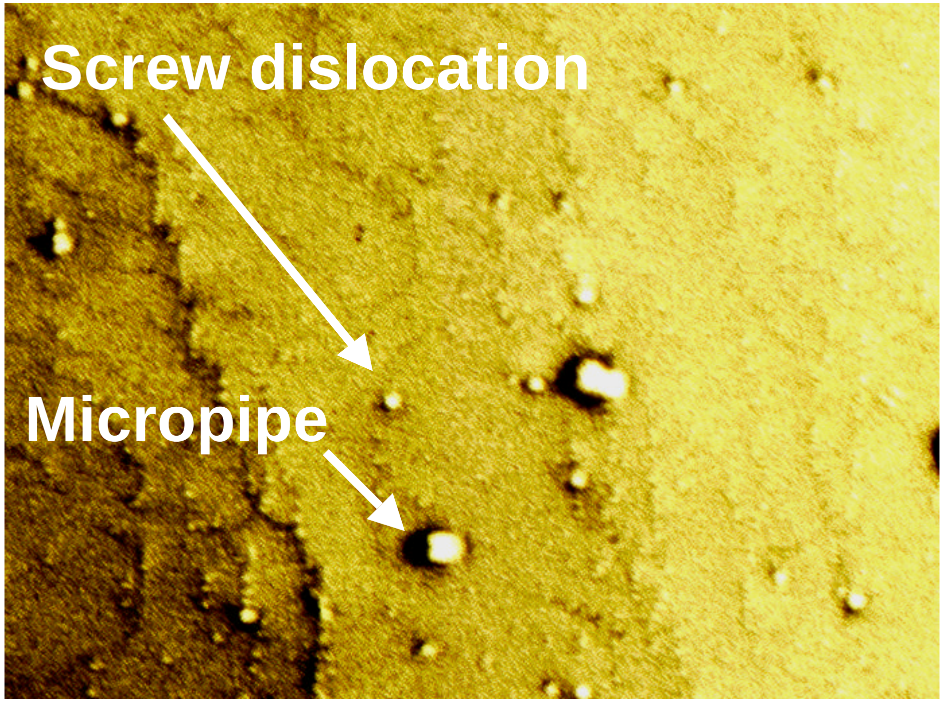
However, the KOH etching is destructive evaluation.

# X-ray topography measurements




| Energy [keV] | Wavelength [Å] | Diffraction |
|---|---|---|
| ~8 [keV] | ~1.54 [keV] | $(1\bar{1}08)$<br>$(11\bar{2}8)$ |

# Evaluation of defect -X-ray topography-



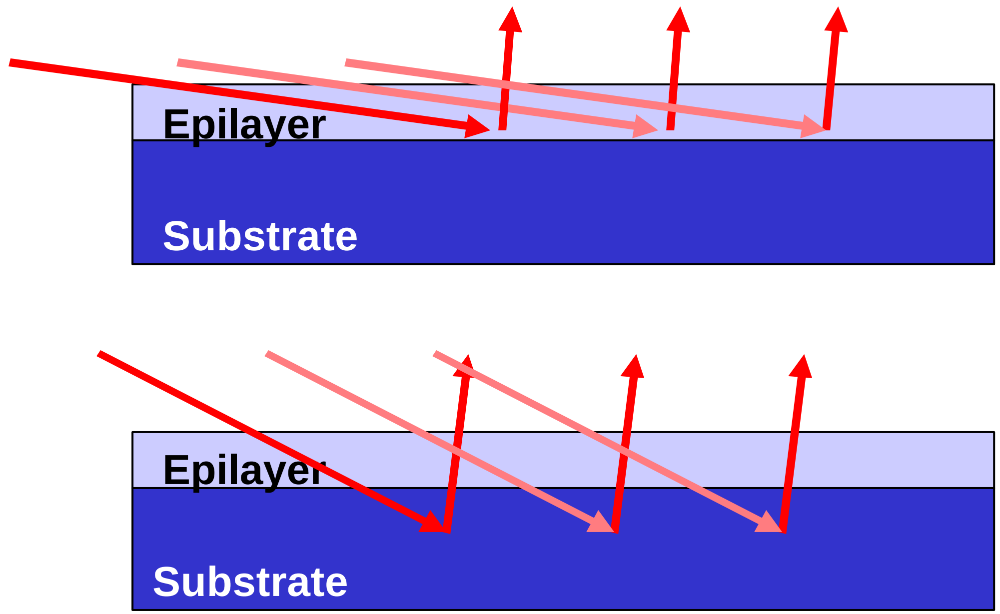

Dislocations are observed by X-ray topography.

Moreover, the X-ray topography is non-destructive evaluation.

# Further works -X-ray topography-

Change the diffraction angle (wavelength).

Obtain  topo images containing various depth information.



# Summary

To develop SiC devices, reduction of dislocations and defects are required.

KOH etching can be used for evaluation of the dislocations in SiC, however, the KOH etching is destructive evaluation.

On the other hand, X-ray topography is non-destructive evaluation.

Dislocations (screw dislocations and micropipes) are observed by the Synchrotron X-ray topography.