Lifetime Measurement of HBC-foil and Nanocrystalline Diamond foil by Using KEK 650-keV High Intensity H^- and DC ion Beam

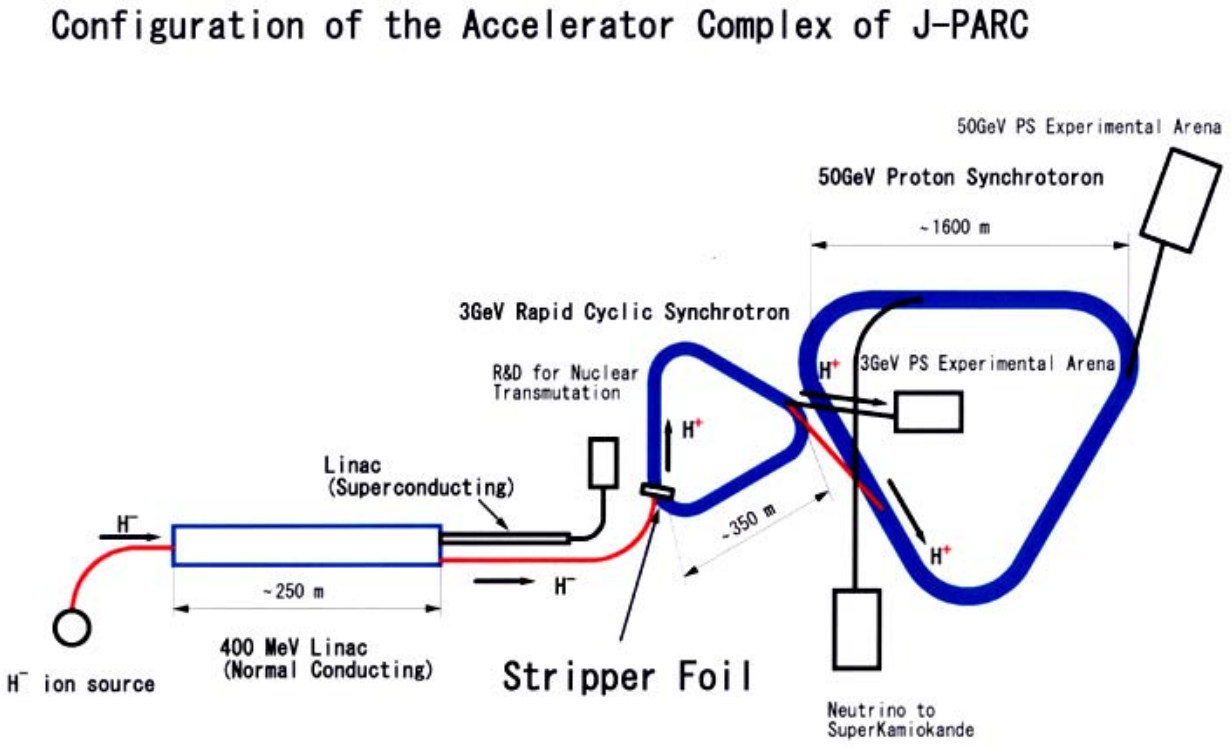
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H.Kawakami[a], R.W.Shaw[b],M.A.Plum[b],C.S.Feigerle[c]

a : KEK, b: SNS/ORNL, c: UT

Talks:

1. Requirement of HBC-foil
2. Preparation of the HBC-foil and the Nanocrystal diamond foil
3. Lifetime measurement by using KEK 650 keV H- and DC ion beam
4. Summary and Conclusion

Schematic layout of the Accelerator Complex of J-PARC and Stripper Foil Position



Injection Beam and Stripper Foil Properties of 3GeV ring at J-PARC

Kinetic energy	**200 MeV (first stage)**
	400 MeV (second stage)
Beam pulse length	**0.5 ms**
Repetition rate	**25Hz**
Average beam current	**0.333mA**
Beam Size	**10 mm x 10 mm**
Foil thickness	**300- 500 $\mu g/cm^2$**
Foil peak temperature	**>1800K**

(If average foil hitting number of bunched proton is >17 and Circulating bunched beam is 8.3x 10^{13}/bunch)

Road to the HBC-foil

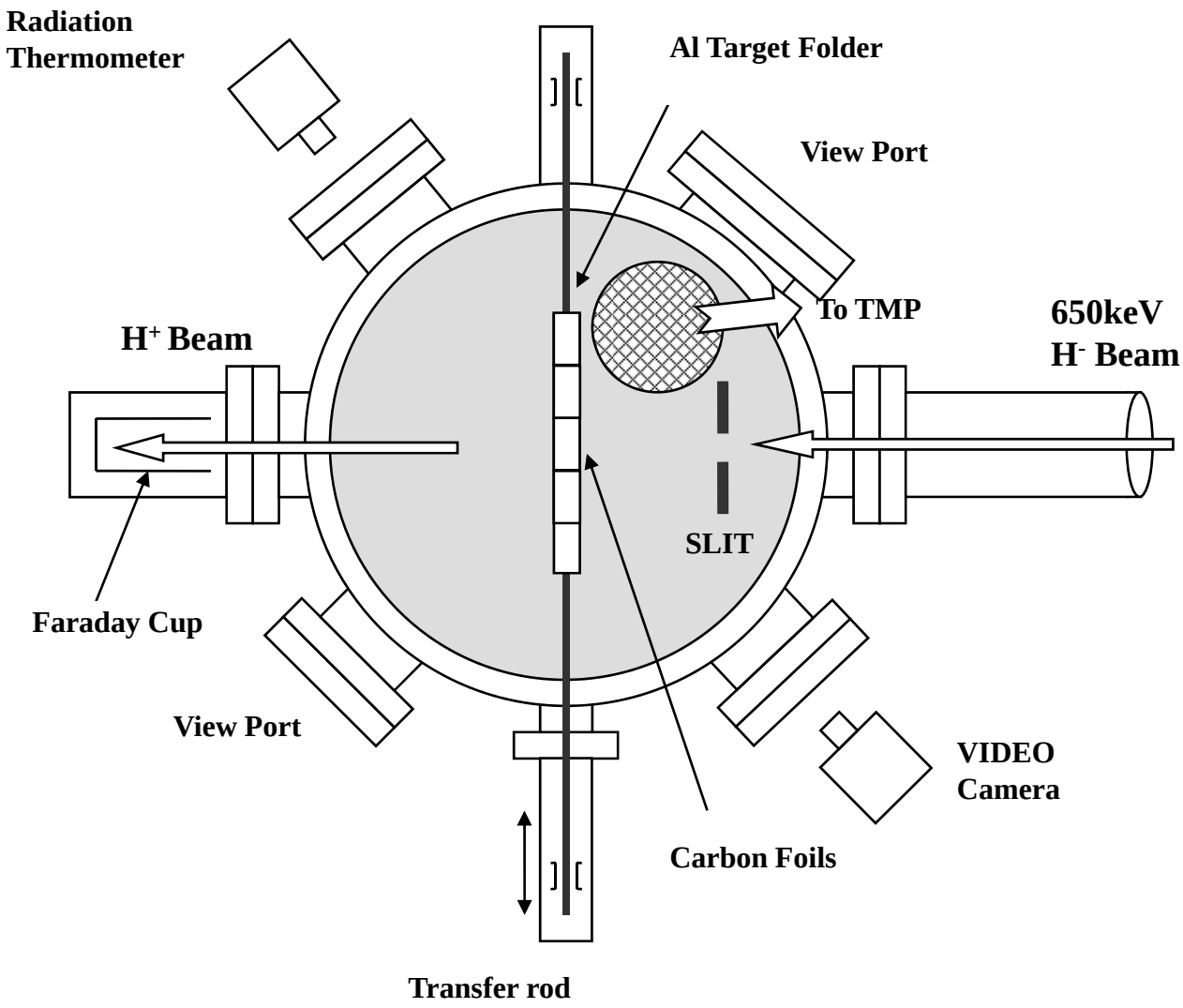
- **Limits of Cluster Foils;**
- **The max.accessible foil thickness:140±30 μg/cm^2**
- **Thickness reduction of original thickness:-3/4 or-75%**
- **And pin-holes were observed**

- **In order to overcome these problems**

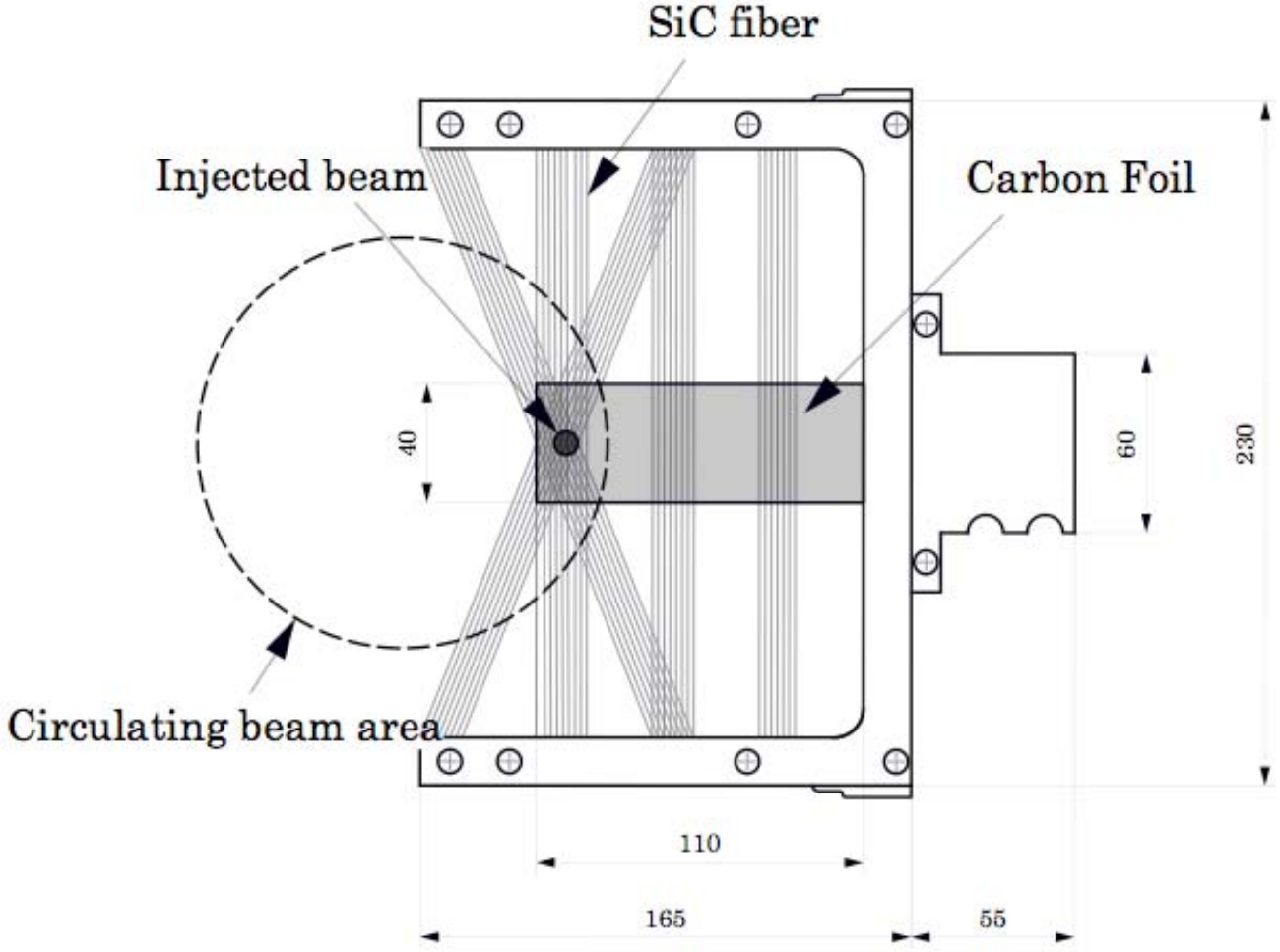
- **We have tried to mix the graphite rod with foreign atoms like Be, B, Al, Si, etc.**
- **Among these, the boron-mixed foils showed especially good results.**

Stripper foils made by this method, which
We call Hybrid Boron mixed Carbon stripper foil

(HBC-foil)



Experimental apparatus for lifetime measurement of various carbon stripper foils for 650-keV at KEK



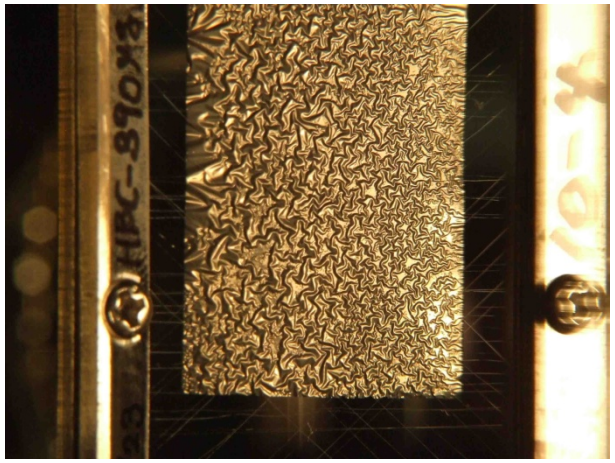
Target Mounting Holder for Ribbon type Carbon Stripper Foils at RCS of J-PARC

ICFA2008

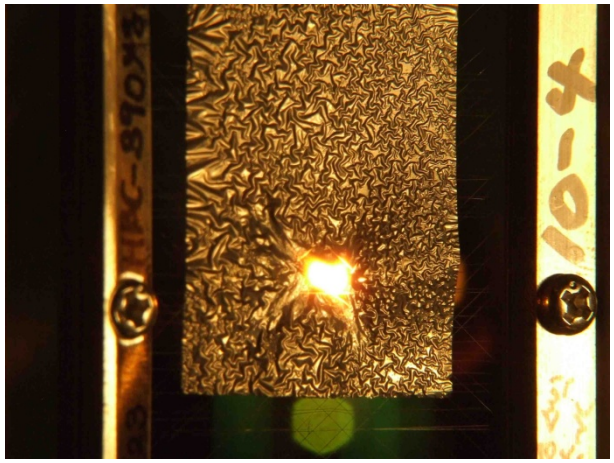
Pictures of Various Foils Tested by using 650 keV H^- and DC Ion Beam of 3.5 mmϕ beam spot

Single HBC-foil Sandwiched SiC fibers

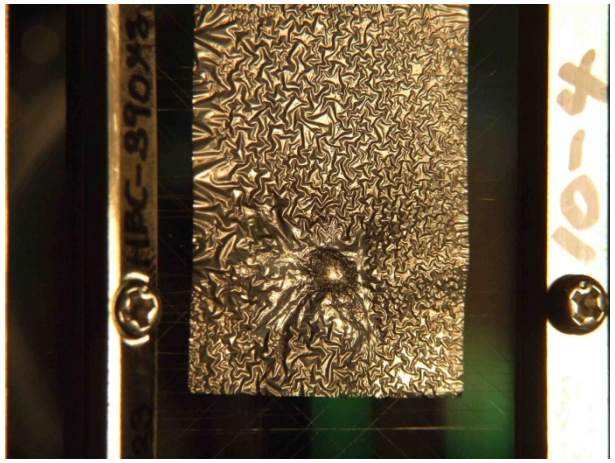
10-4 (HBC: 390μg/cm^2)



Before beam irradiation



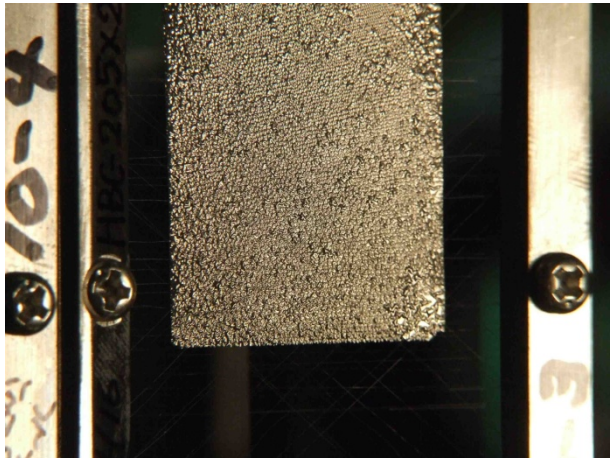
Under irradiation (107h)



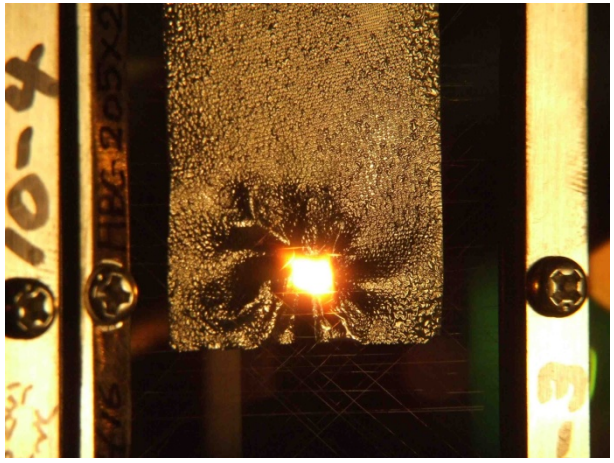
Survived (256.5h)

Double-Layered HBC-foil Sandwiched SiC fibers

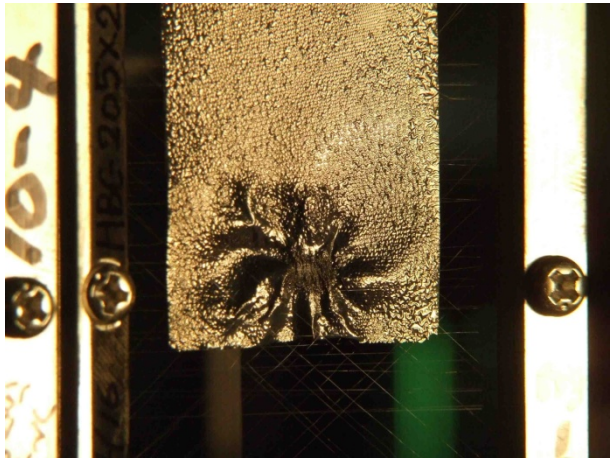
10-3 (HBC: 205x2=410μg/cm^2)



Before beam irradiation



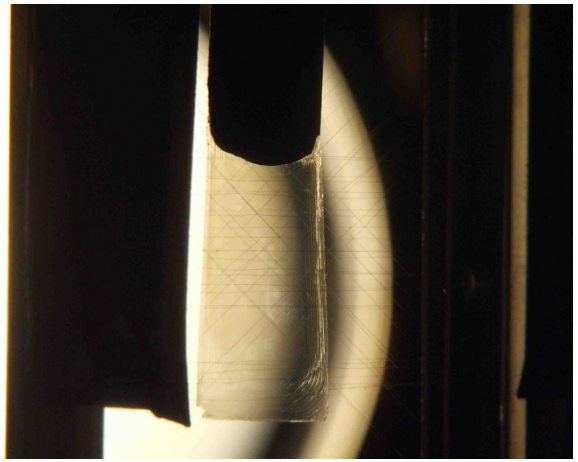
Under irradiation (104h)



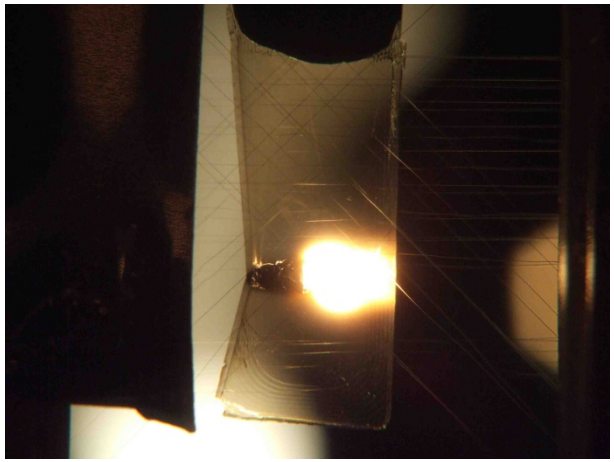
Survived (203.5h)

Microcrystalline Diamond Sandwiched SiC fibers f or SNS

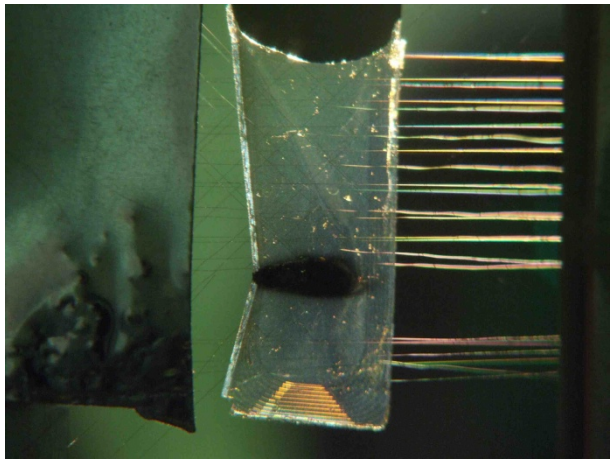
3-2 (SNS #510: 383μg/cm^2)



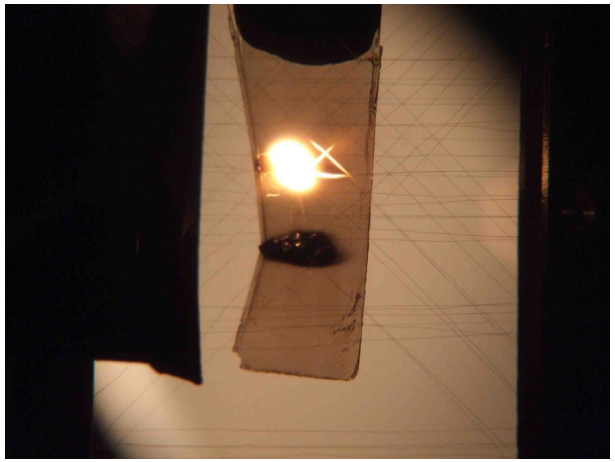
Before irradiation



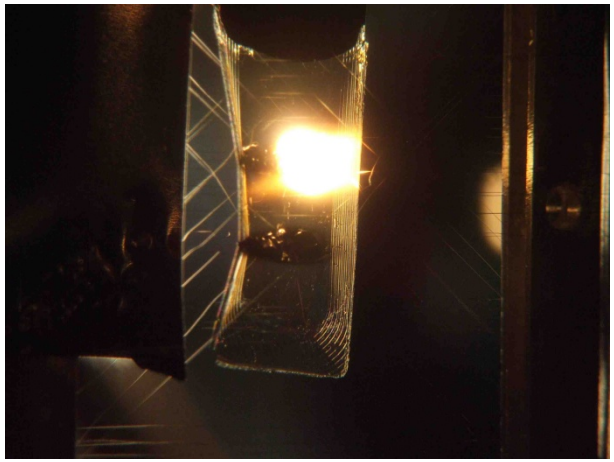
Under irradiation (6h)



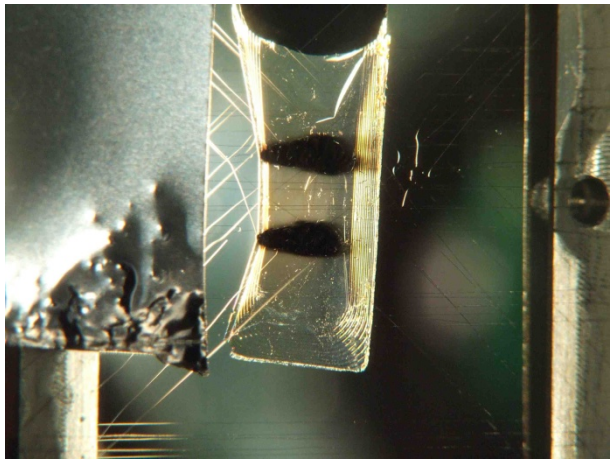
back bending (11h)



Irradiation after 3min



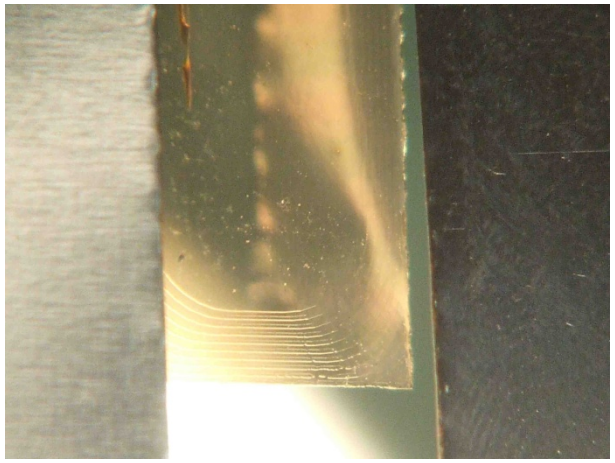
Under irradiation (5.0h)



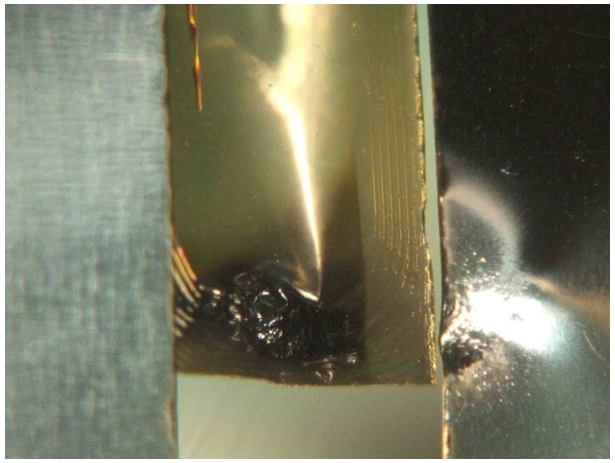
back bending (14h)

Nanocrystalline Diamond without SiC fibers

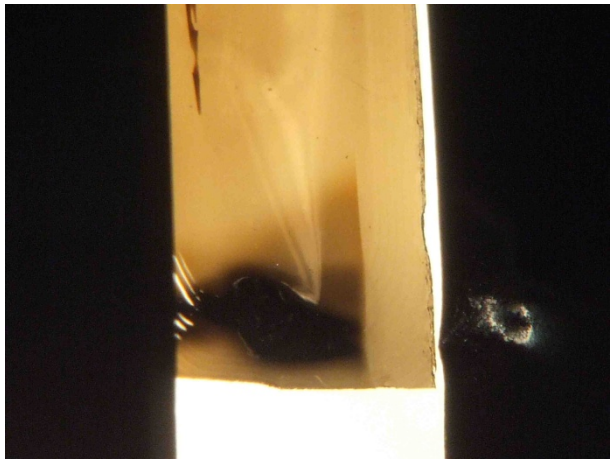
4-2 (SNS #527: 433μg/cm^2)



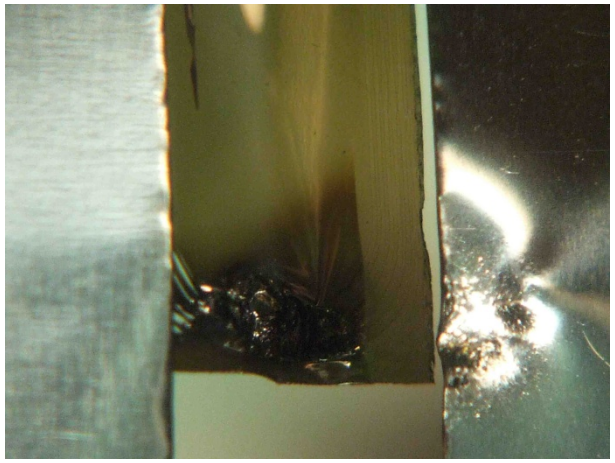
Before irradiation



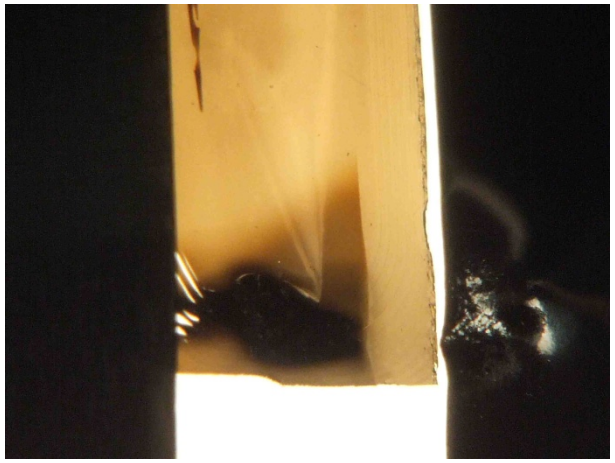
Under irradiation (10.5h)



Inside curing (10.5h)



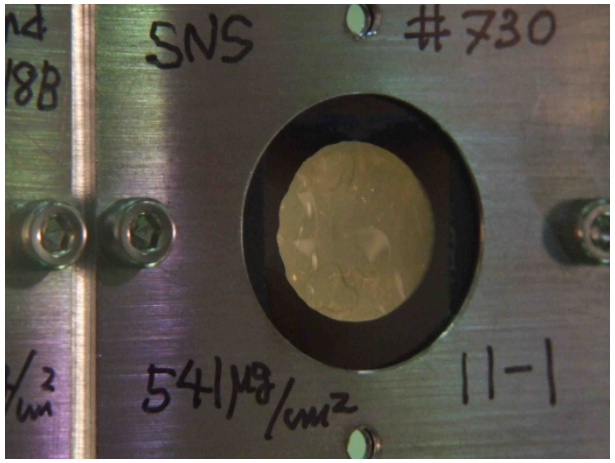
Inside curing (21h)



Inside curing (21h)

Nanocrystalline Diamond with Si frame

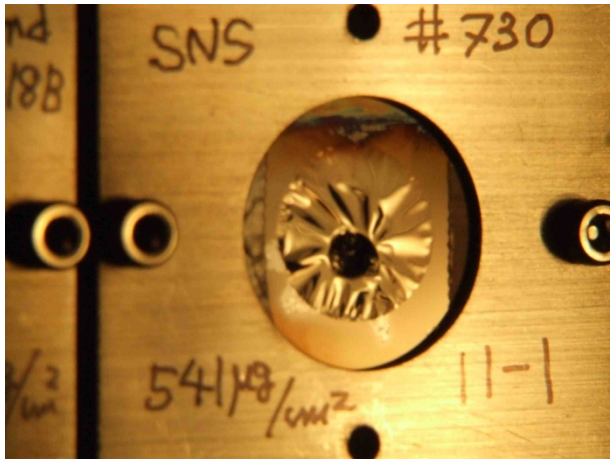
11-1 (SNS #730: 541μg/cm^2) 2008/07/17~7/20



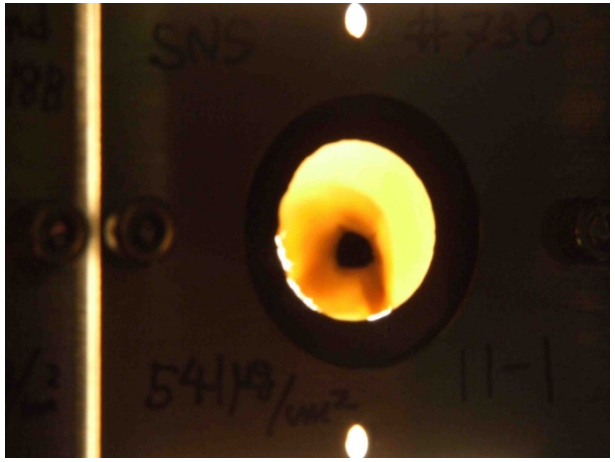
Before irradiation



Under irradiation (29h)



Surface (62h)



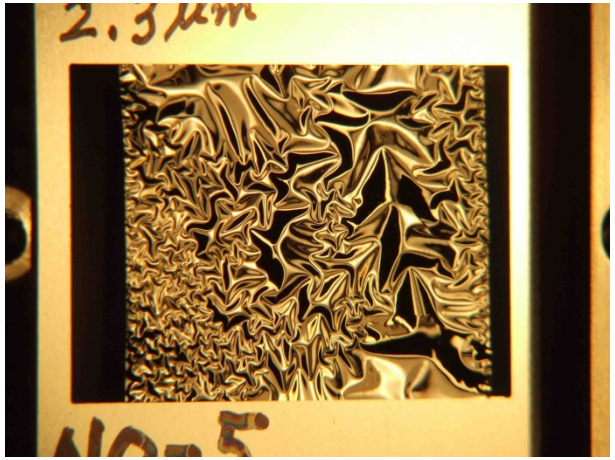
Surface (62h)



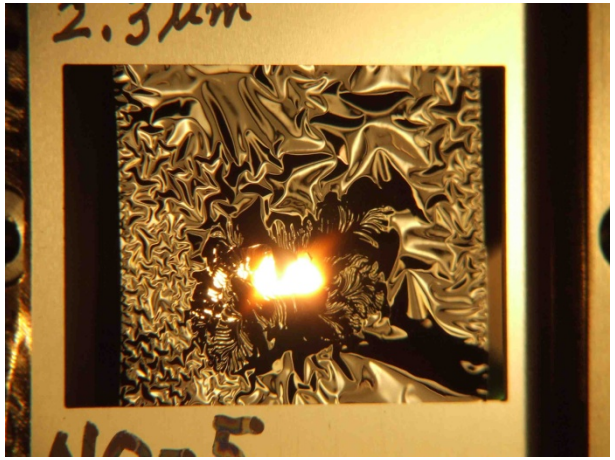
Surface (62h)

Multi-layered DLC for TRIUMF

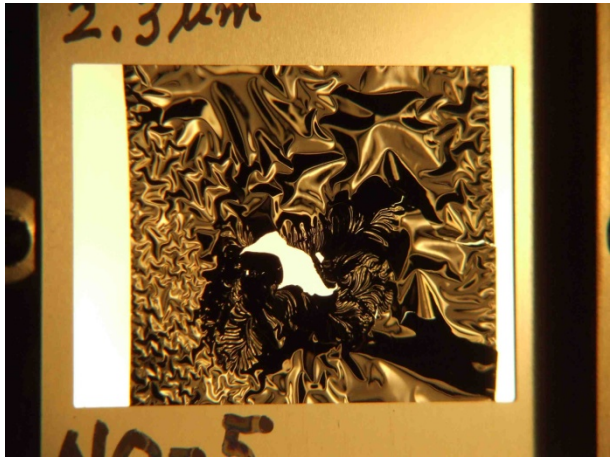
8-5 (TRIUMF Multi-layered DLC: 2.3μm/ 480μg/cm^2)



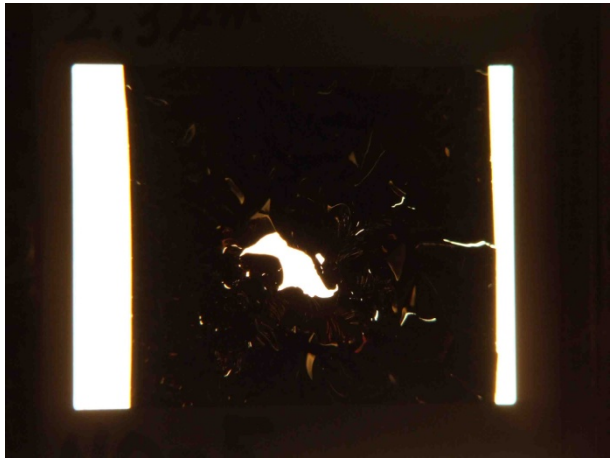
Before irradiation



Under irradiation (0.5h)



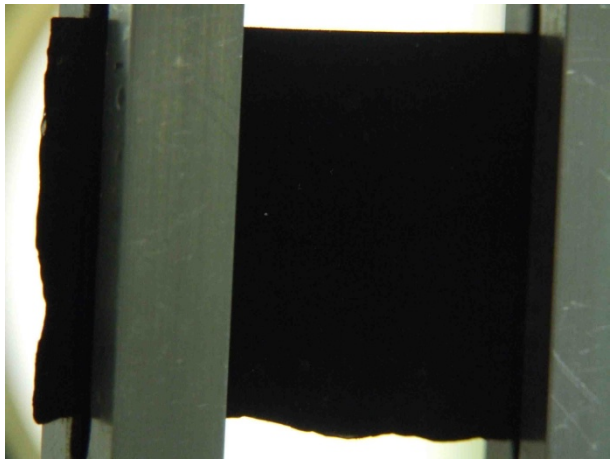
Broken (1h)



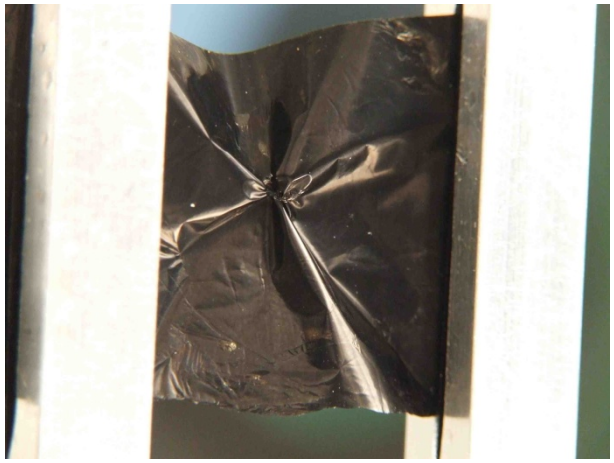
Surface image in dark

Carbon nano-tube for AIST

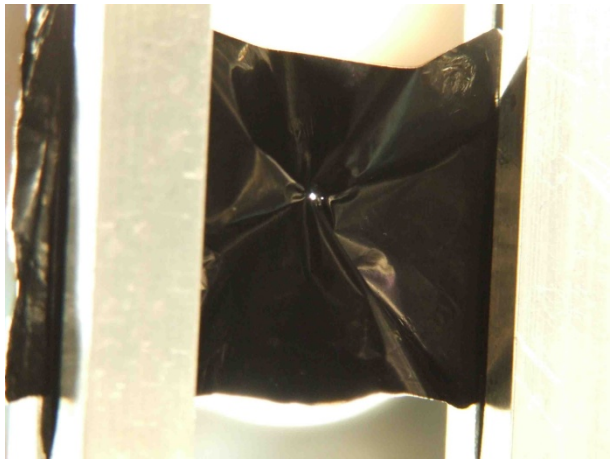
7-3 (CNT Sheet: 3~4μm/ 300~400μg/cm^2)



Before irradiation



Under irradiation (5h)



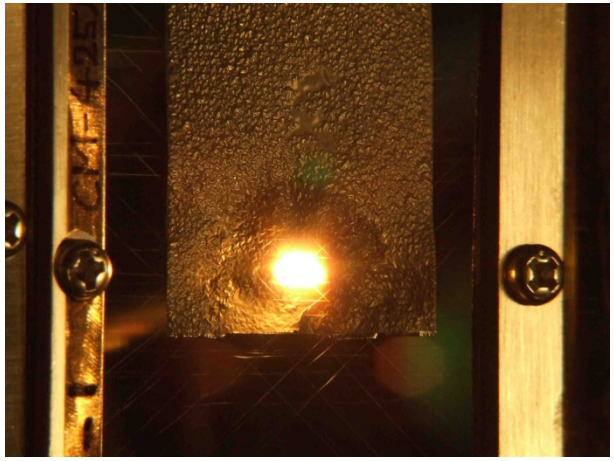
Broken by a hole (9h)

CM-foil for ACF (Arizona)

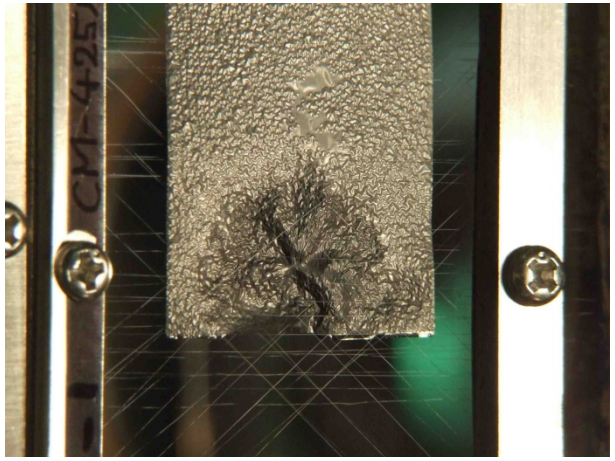
10-1 (CM: 425μg/cm^2) 2008/05/20,



Before irradiation



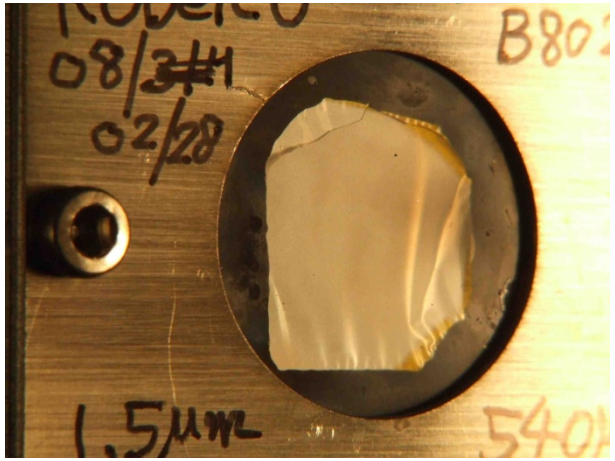
Under irradiation (0.5h)



Broken (1.5 h)

Microcrystal Diamond foil with Si frame (Kobelco)

11-2 (Diamond: 540μg/cm^2)



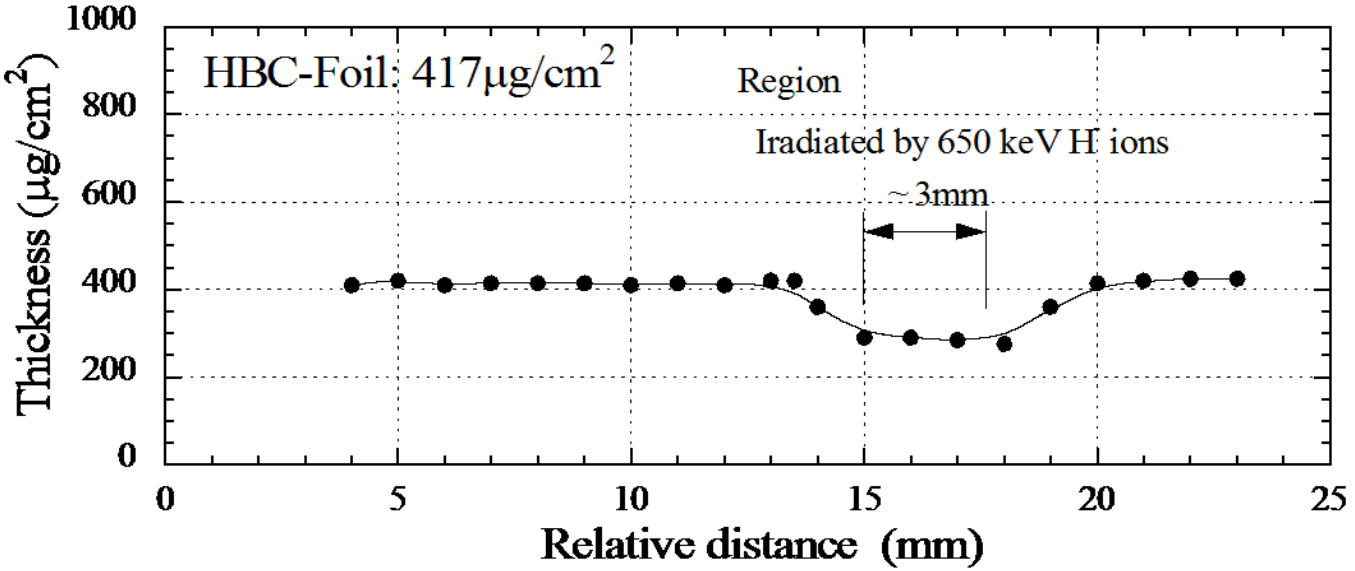
Before irradiation

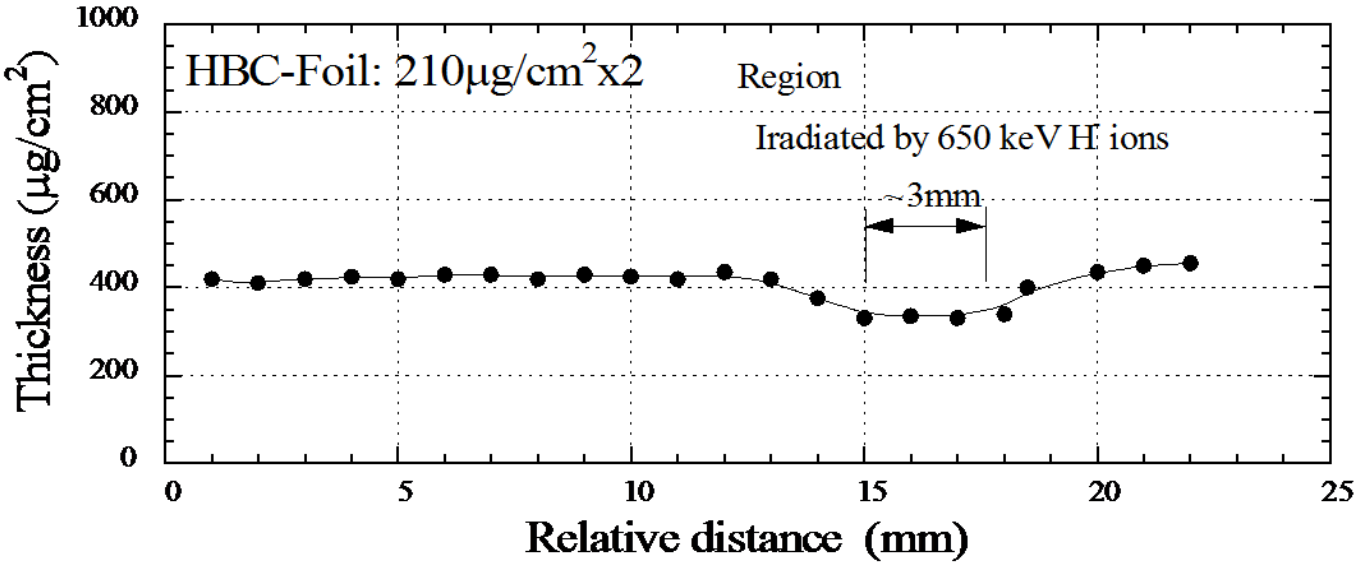


Under irradiation (31.5h)

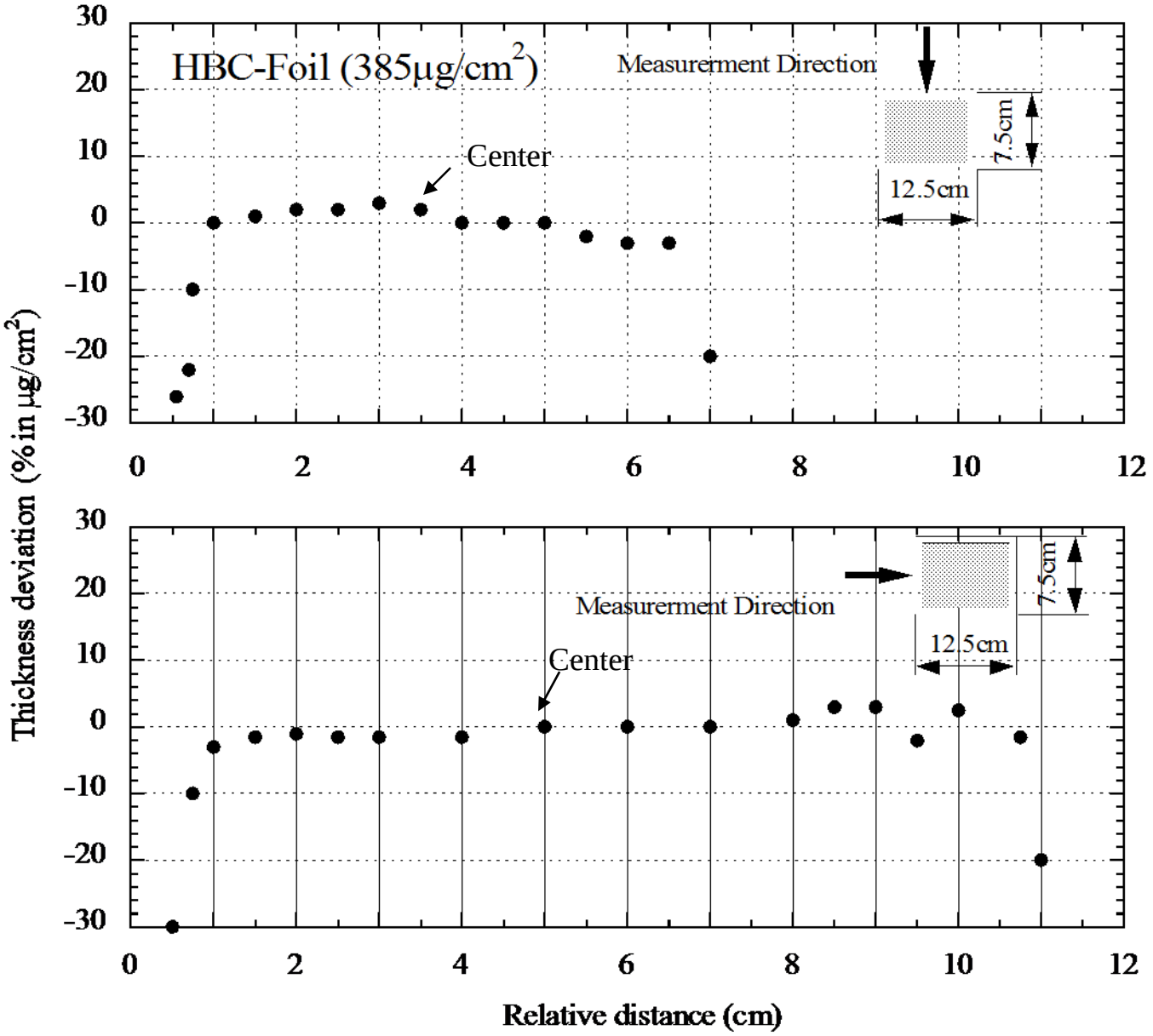


Broken (62h)





The reduction in thickness of the HBC-foil



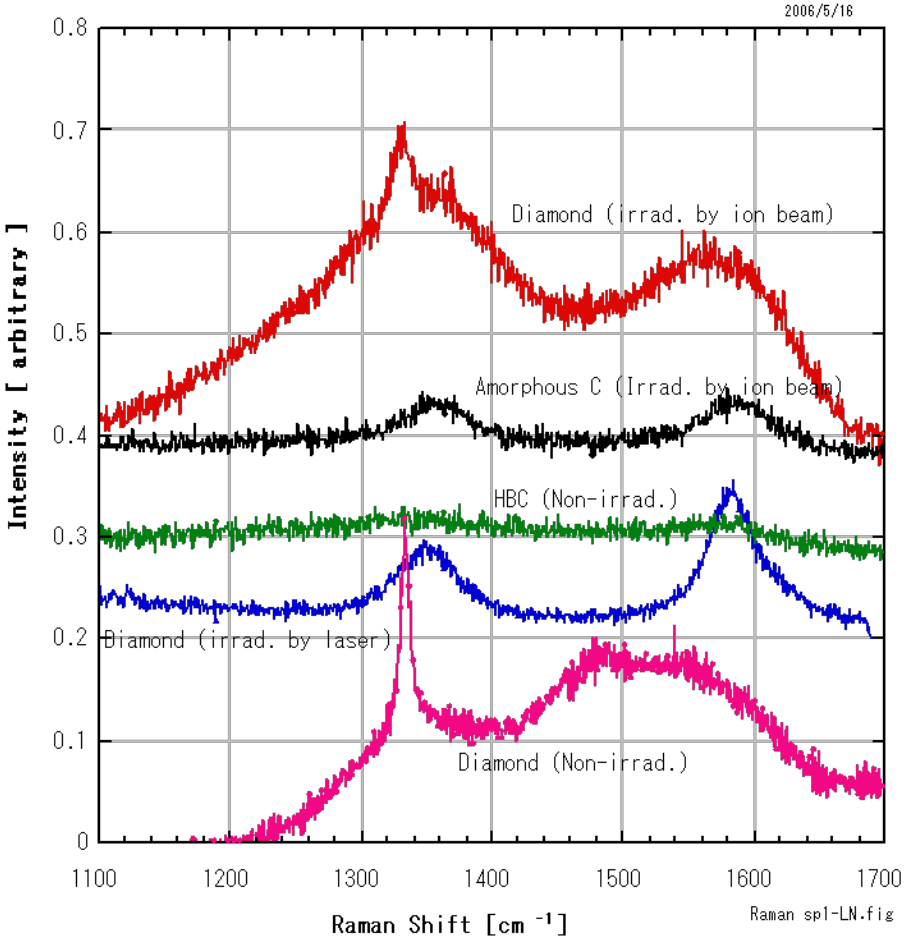
The thickness uniformity of the HBC-foil

Table-1 Lifetime of various foils

Type of foil	Lifetime (h)	Initial thickness ($\mu g/cm^2$)	Thickness Reduction (%)	Foil conditions	Beam Current (μA)	Foil Temperature (K)
Uncertainty		±10			±10	±100
Single HBC sandwiched by SiC fibers (KEK)	256.5 survival	417	30.0	No deformation, but pin-holes	90	1970
Double Layered HBC sandwiched by SiC fibers (KEK)	203.5 survival	210 x 2	26.0	Small shrinkage and No pin-holes	90	1950
Microcrystalline Diamond sandwiched by SiC fibers (SNS)	10.5	349	3.0	Back bending and No pin-holes	110	1930
Nanocrystalline Diamond without SiC fibers (SNS)	21.0	439	6.5	Back bending and pin-holes	130	1950
Nanocrystalline Diamond with Si frame (SNS)	62.0	541	2.1	Crack inside frame and No pin-hole	90	2100
Multi-DLC (TRIUMF)	1.0	480	Non-measurable due to a big hole	Broken	110	2260
Carbon nano-tube (AIST)	9.0	450	Non-measurable due to a big hole	Broken	90	1880
CM (Arizona) with SiC	1.5	425	Non-measurable due to a big hole	Broken	90	1920
Microcrystalline Diamond with Si frame (Kobelco)	61.5	540	5.7	Crack inside frame and Big a hole	90	2080

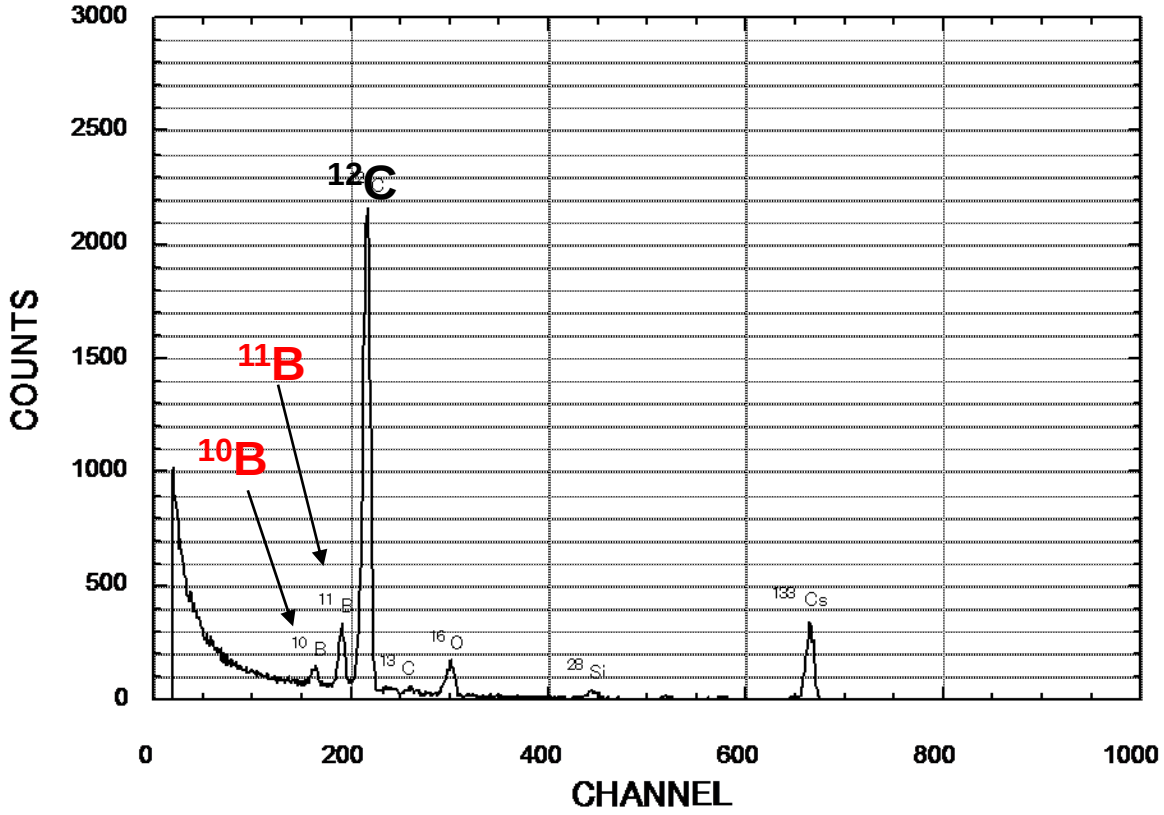
Lifetime of the foils was measured with a 650 keV H^- and DC ion beam and 3.5 ±1.0 mm of beam spot

Raman Spectra of DM,CM and HBC-foils



- **The DM-foils are irradiated by ion beam and laser. The CM (amorphous)-foil is irradiated by only ion beam. In all irradiated foils, we can clearly see broad peaks at around 1580 and 1350 cm^{-1}.**
- **The DM-foil irradiated by ion beam shows small peak at 1332cm^{-1}, in contrast by laser irradiation.**

Element analysis of thin HBC-foil



- **The spectrum was obtained by RBS with a 2 MeV He^+ ion, clearly showing the 10B and 11B nuclide peaks and several contamination. The both thickness corresponds to approximately 24 % of the carbon foil thickness.**

Specific gravity and resistivity of cluster foil in comparison with other forms of carbon.

Sample	Specific gravity (g/cm^3)	Resistivity (Ωcm)
Single crystal of graphite	2.26	10^{-4}parpendicular to c-axis
Fine grain graphite	1.75-1.9	~1 parallel to c-axis
		$1.5\text{-}1.8 \times 10^{-3}$
Diamond	3.5	$>10^{16}$
Cluster foil	1.85 ± 0.20	0.080 ± 0.005
CM foil	1.94 ± 0.19	0.015 ± 0.002
HBC-foil	1.20 ± 0.30	

Summary and Conclusion

1. We have measured the lifetime of various foils made by several methods by using KEK 650keV H^- and DC ion beam
2. Among these, the lifetime of the HBC-foils showed 256 h for single and 203.5 h for double layered HBC-foils, which correspond to about 170 and 135 times longer than that of the best CM foil. However, for the single HBC-foil we observed small pin-holes at the irradiated area and it's peripheries even at the 1900 $\pm$100K for 256 h long time irradiation.
3. Nano and microcrystalline diamond foils showed rather back bending at the high temperature of 2000$\pm$100K, but lasted longer than 20h.
4. Further R & D should be needed especially to reduce the pin-hole production for the HBC-foils at 2000K.