

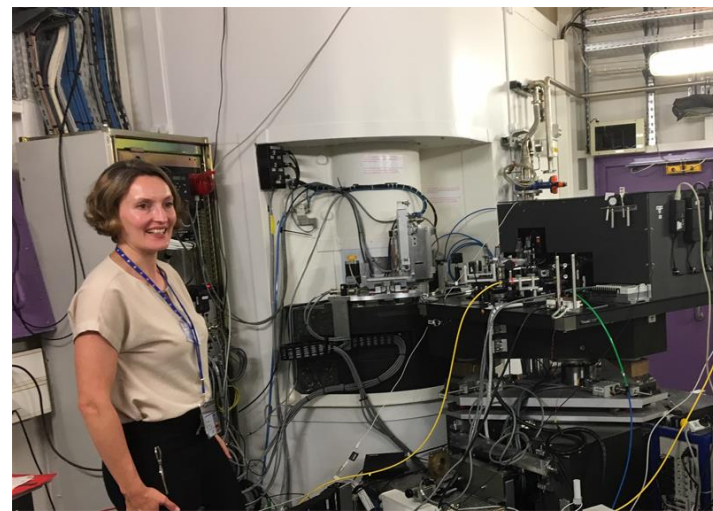
Synthesis, features, and applications of nano-polycrystalline diamond: Toward multi-Mbar pressures in multianvil apparatus

Tetsuo Irifune^{1), 2)}

*Geodynamics Research Center (GRC), Ehime Univ.
and
Earth-Life Science Institute (ELSI), Tokyo Inst. Tech.*



3 February 2014, ESRF WS



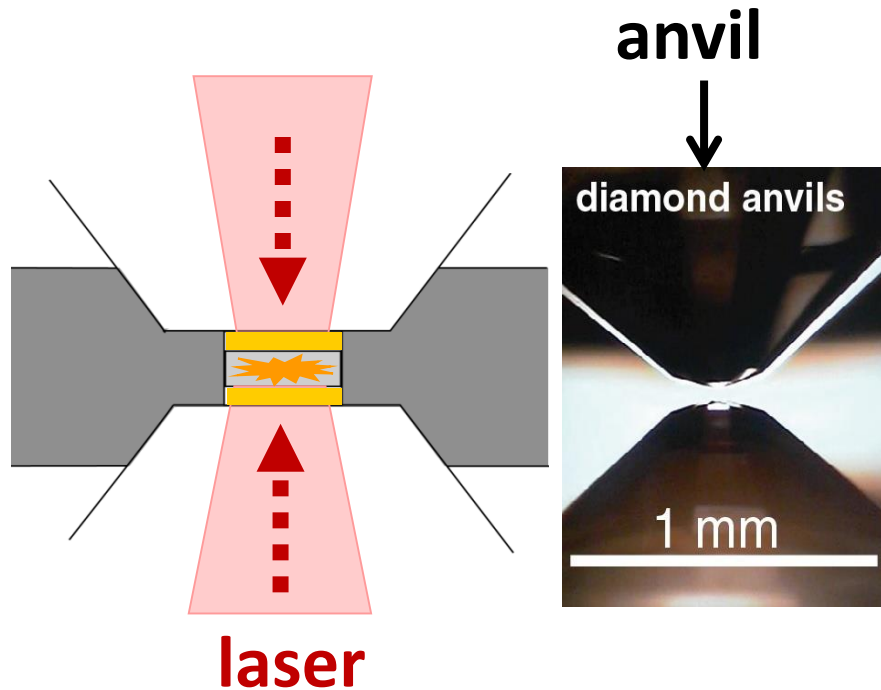
18 June 2019, HP School, ESRF

Topics

- 1) Synthesis, features and applications of NPD**
- 2) Higher P/T generation in KMA using WC, SD, and NPD anvils

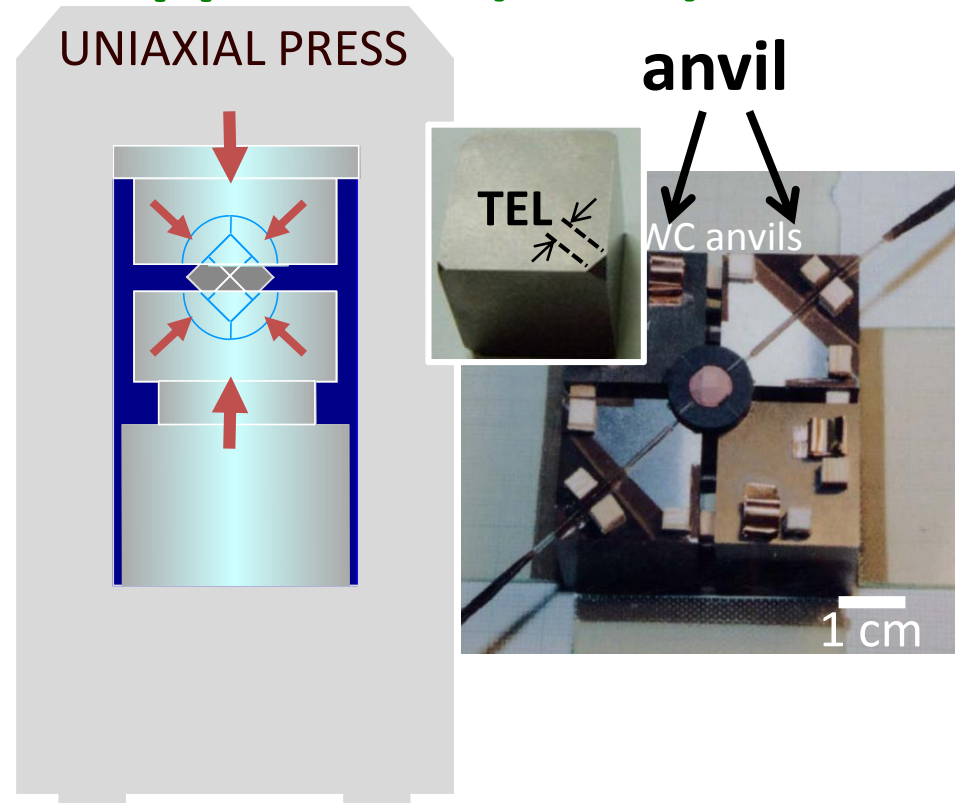
Static high-pressure apparatus

Laser Heated Diamond Anvil Cell (LHDAC)



Pressure: ~ 400 GPa
volume: $\sim 10^{-5}$ mm³

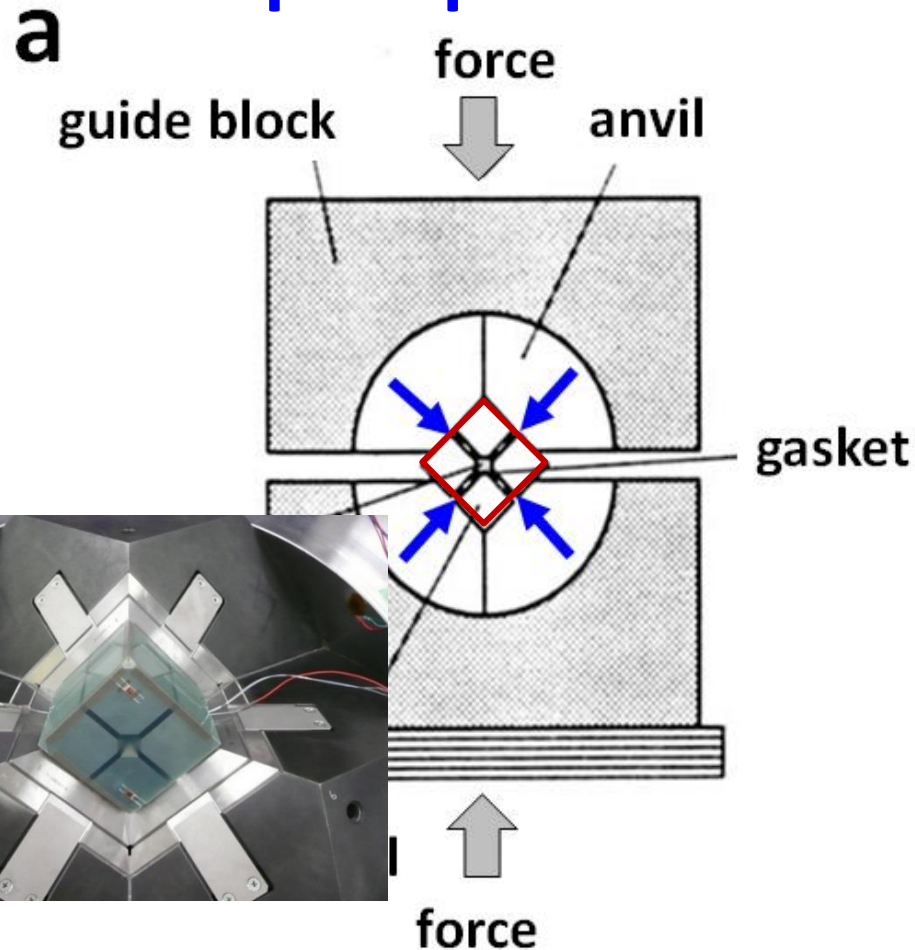
Kawai-type Multianvil Apparatus (KMA)



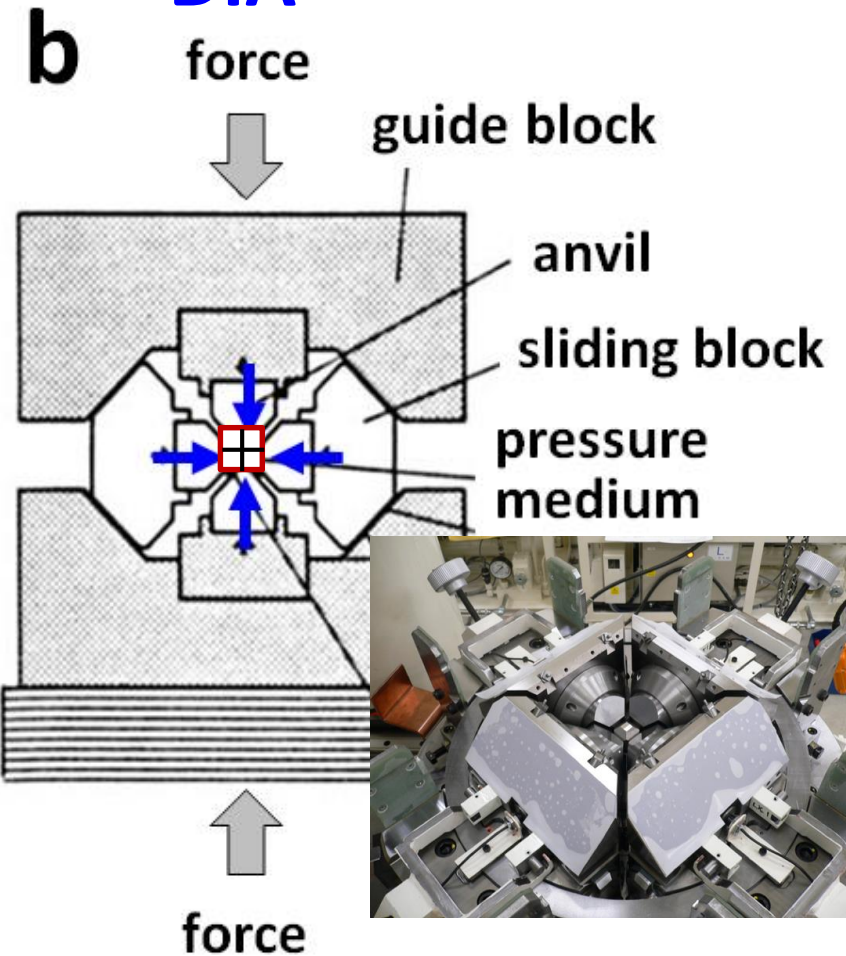
Pressure: ~ 30 GPa
volume: ~ 1 mm³

Guide-blocks for KMA

split-sphere



DIA



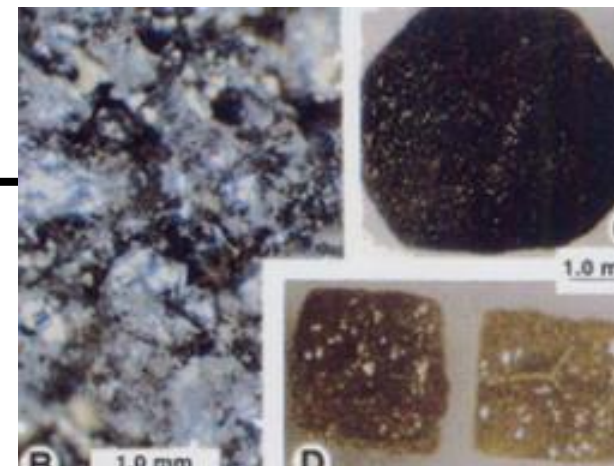
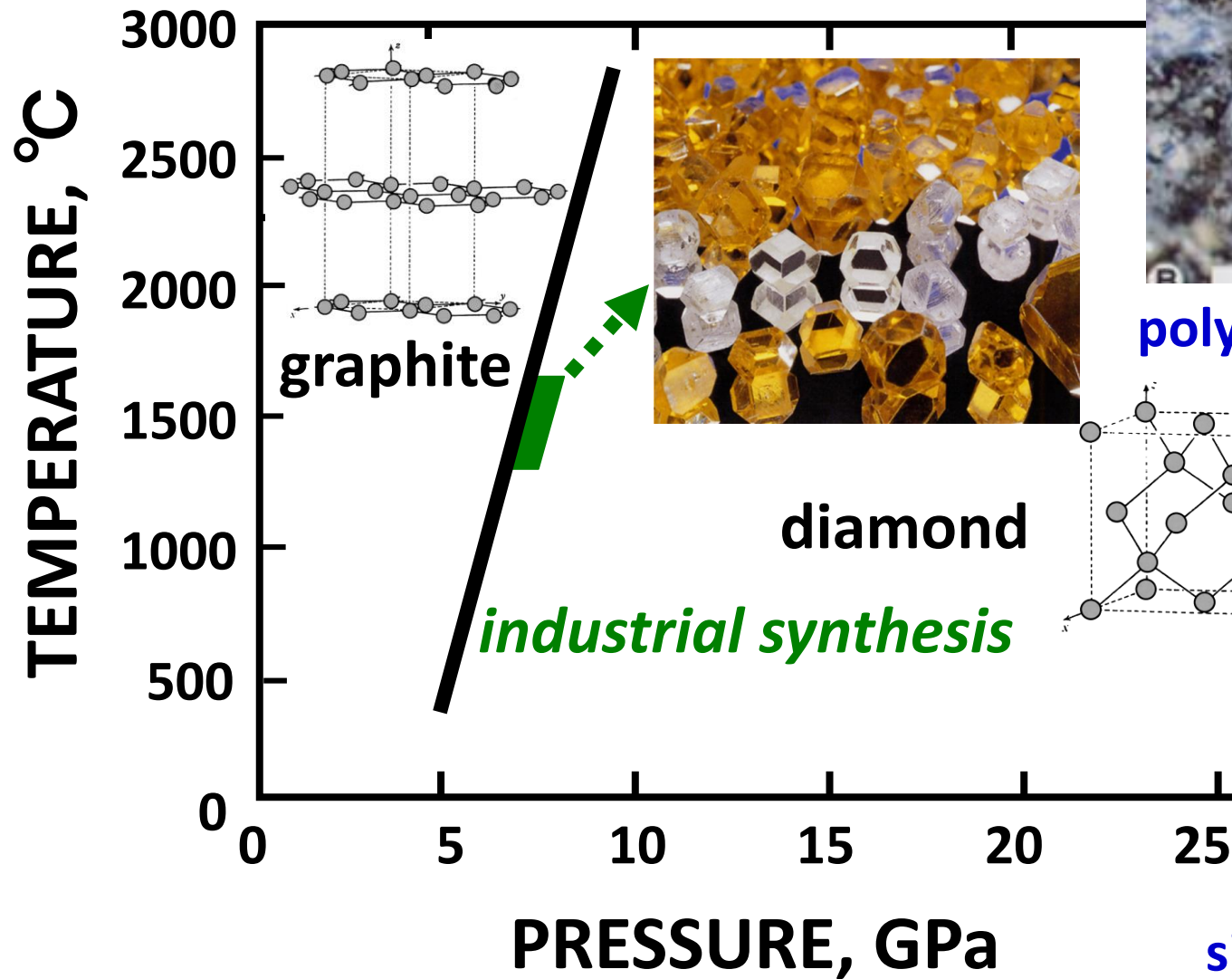
- $\sqrt{3}$ times more efficient
- easier operation

- precise alignment
- easier in situ X-ray obs.

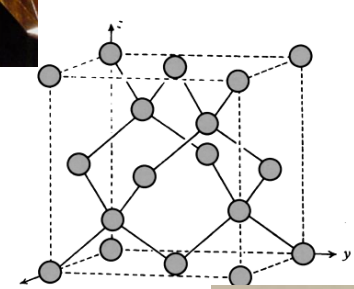
Large Volume Press at GRC



Synthesis of diamond

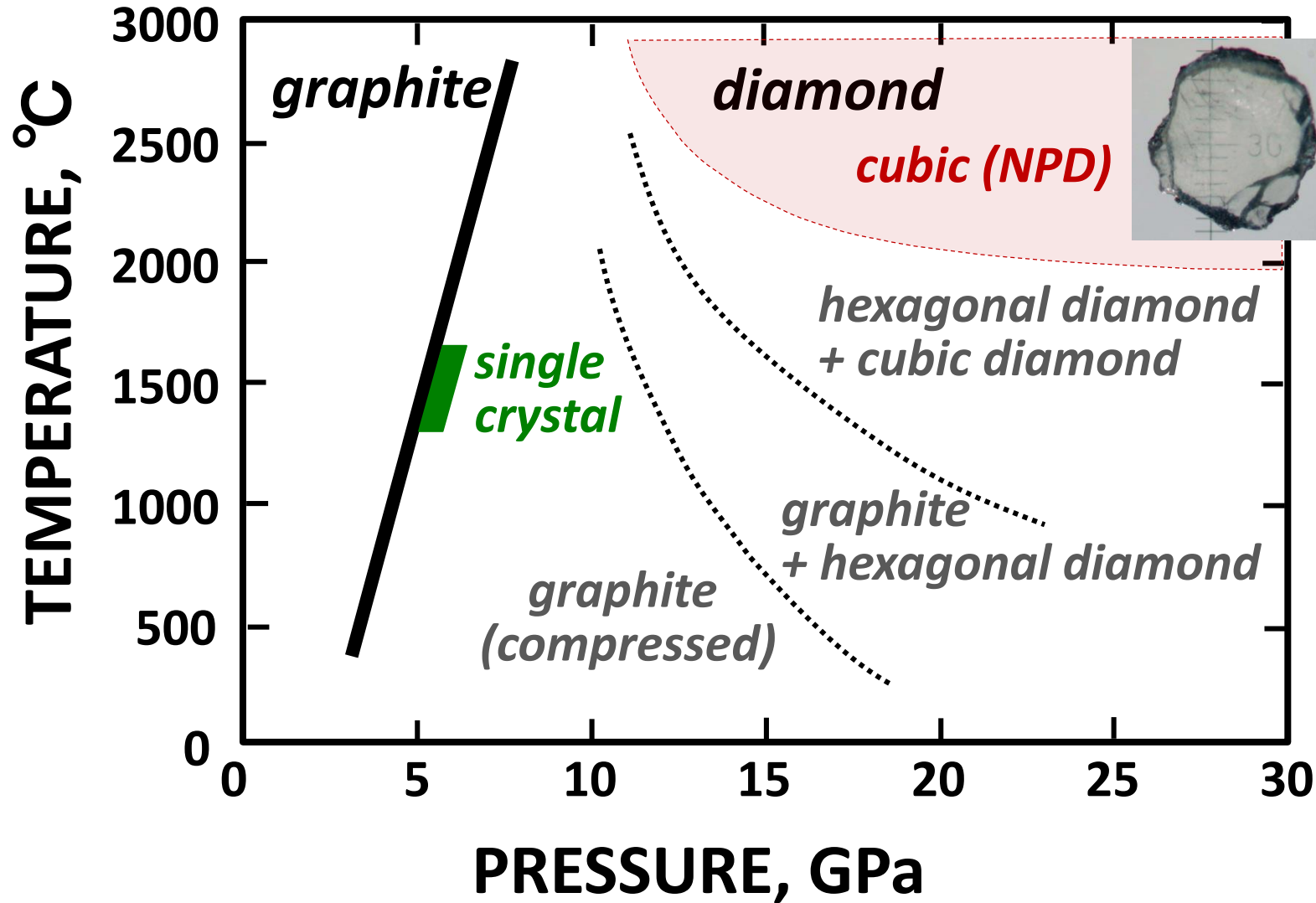


polycrystalline diamond

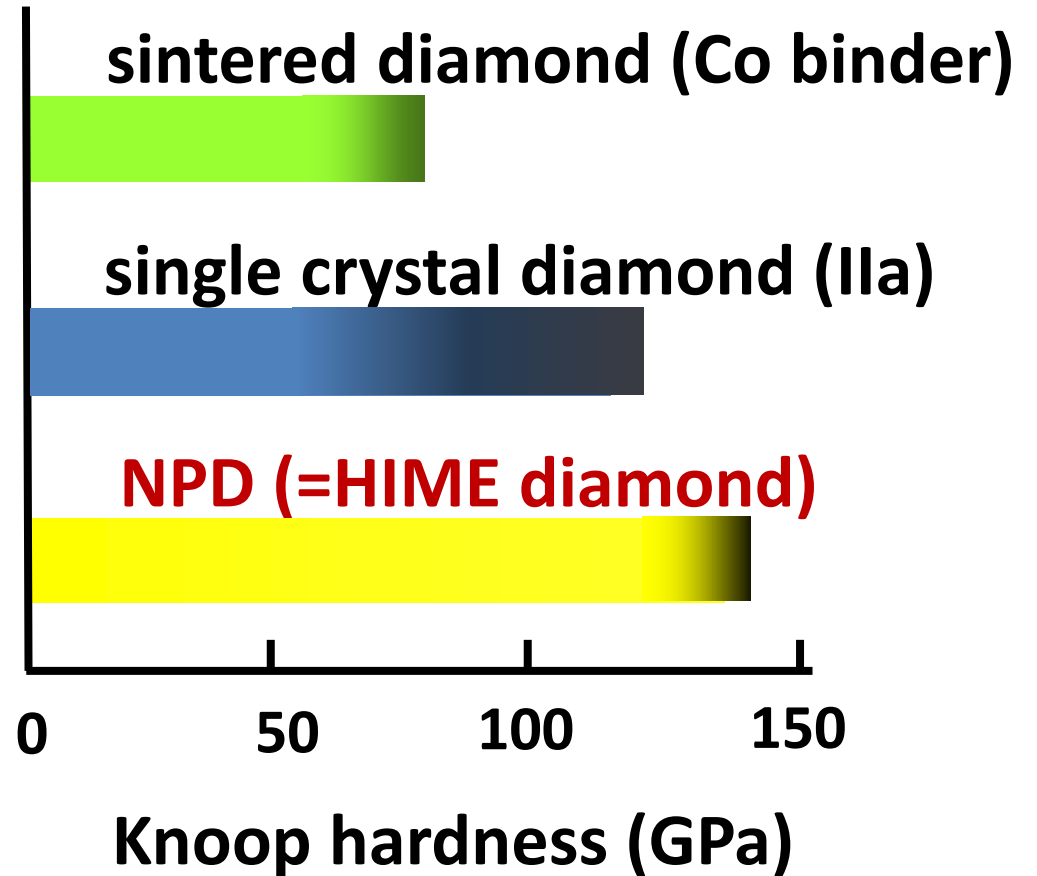
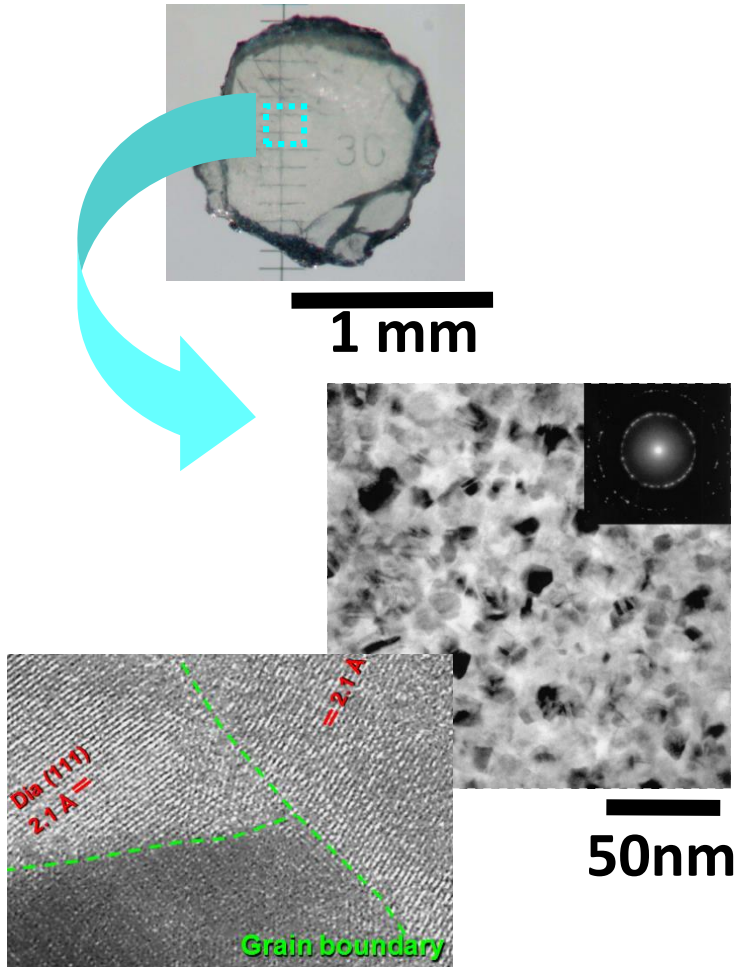


sintered diamond
(Co binder)

Synthesis of NPD at very high P, T



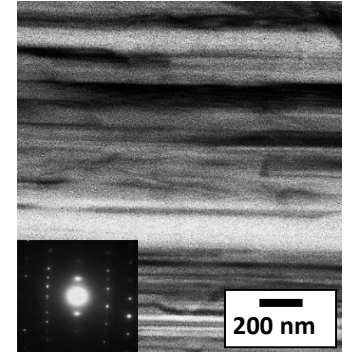
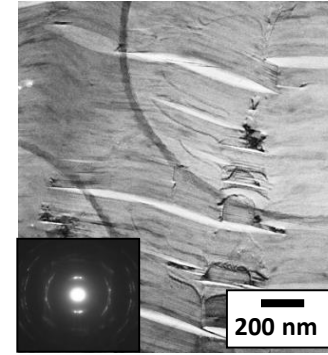
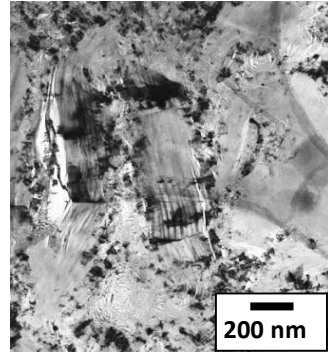
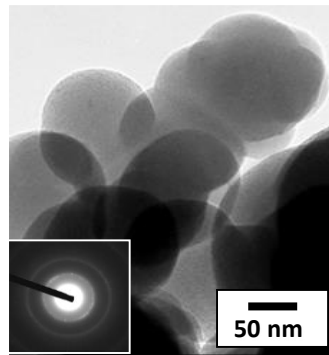
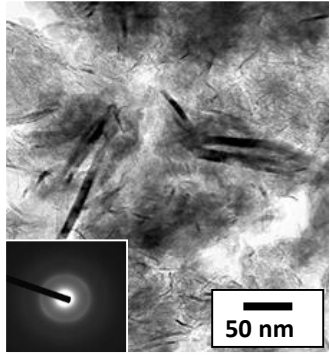
Nano-polycrystalline diamond (NPD)



Irifune et al., Nature (2003)

NPDs with various microstructures

Carbon sources



amorphous graphite

glassy carbon

graphite

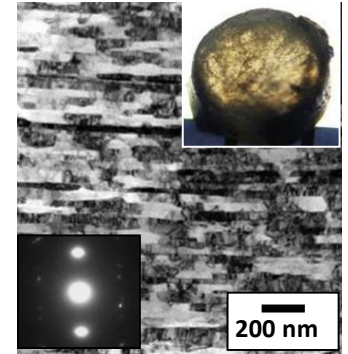
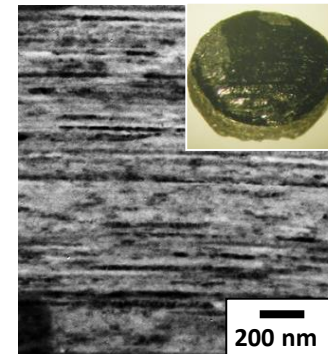
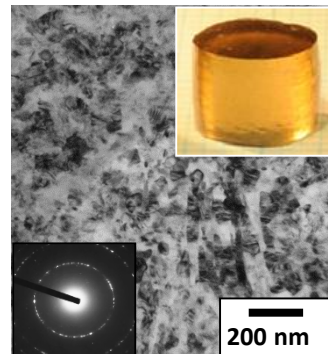
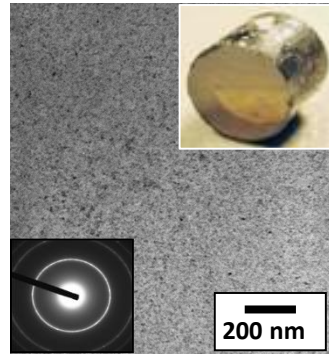
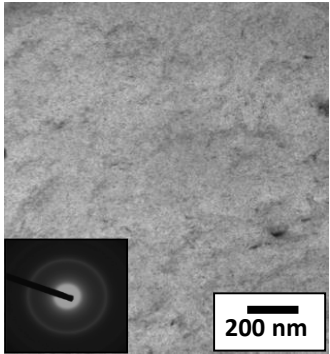
highly oriented graphite

Low

Crystallinity of carbon source

High

Resultant diamonds



amorphous diamond

ultra-fine NPD

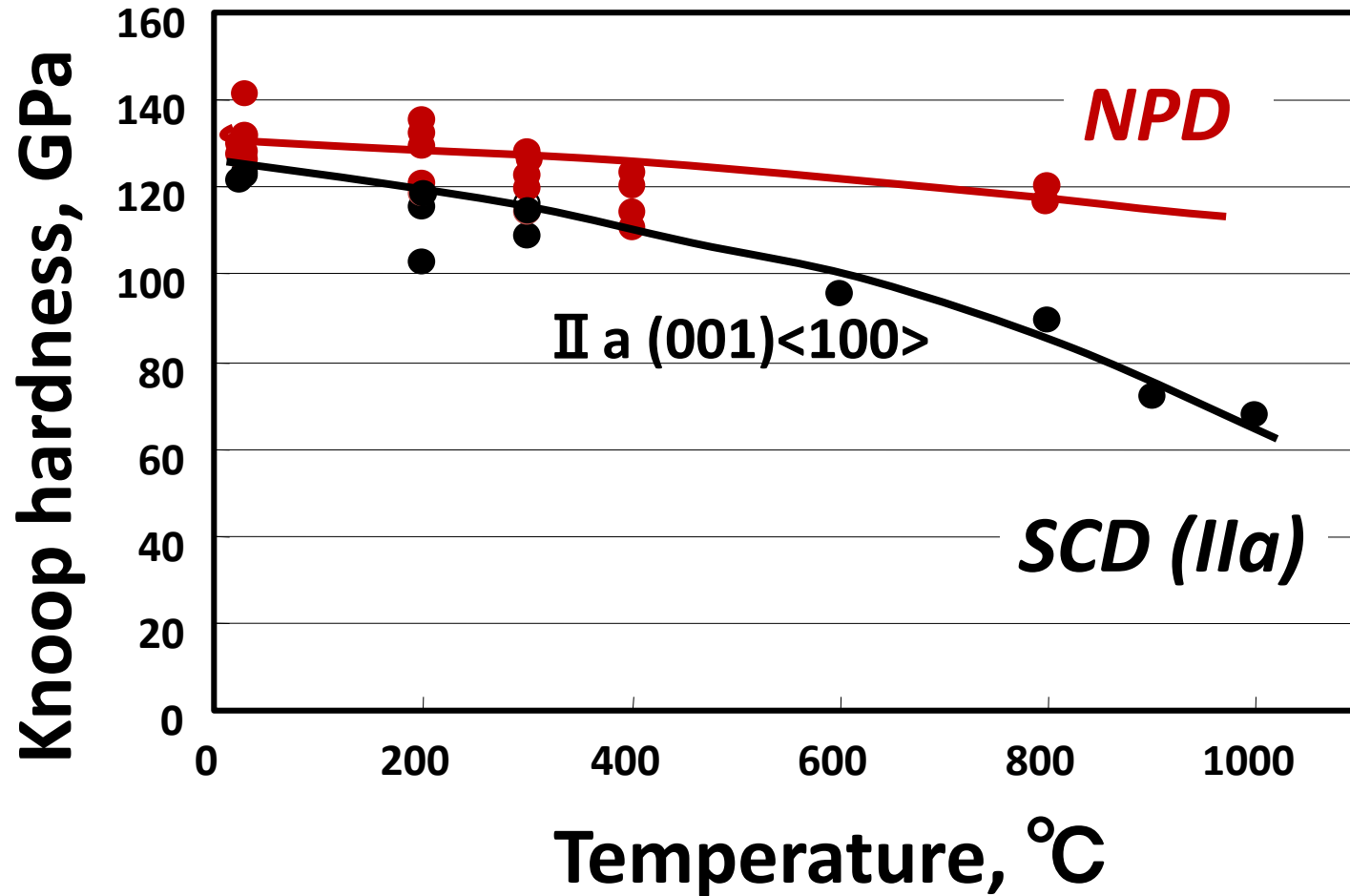
NPD

Layered NPD

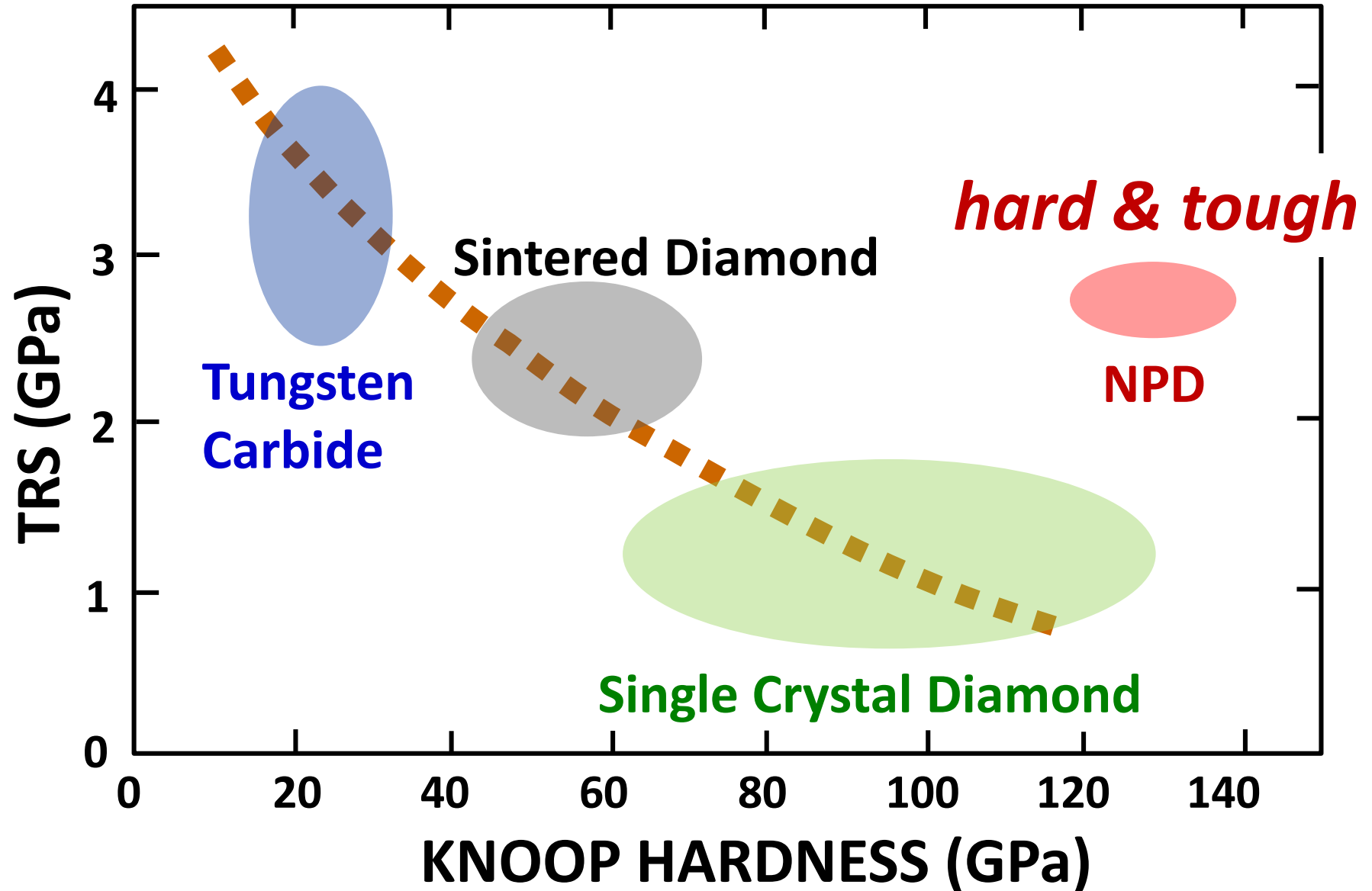
Sumiya et al., High Press. Res. (2006); Sumiya & Irifune, J. Mat. Res. (2007); Guillou et al., Carbon (2007); Ohfuji et al., Phys. Chem. Min. (2012); Isobe et al., J. Nanomater. (2013)

Hardness at high temperature

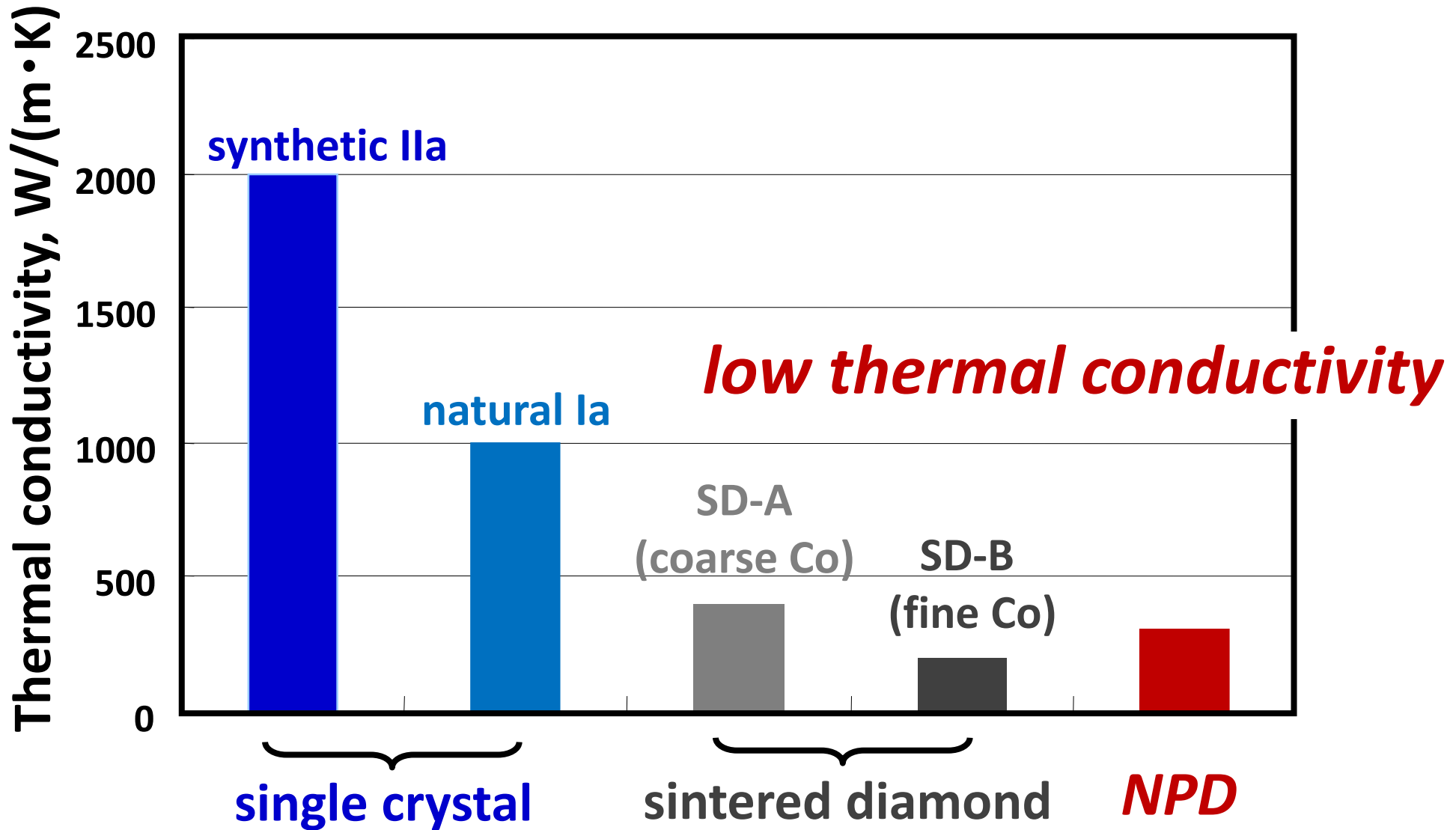
high thermal stability and durability



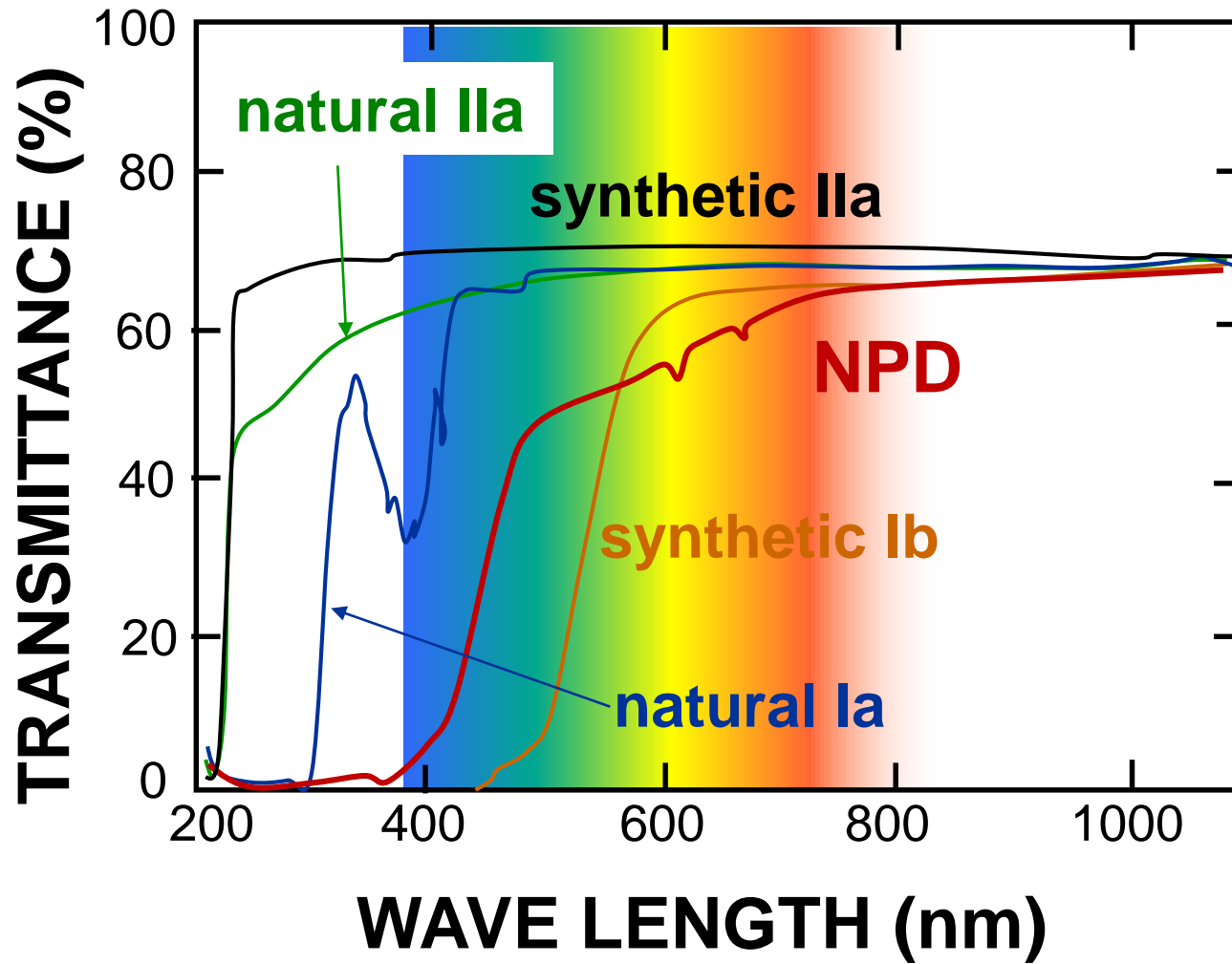
Hardness vs Toughness



Thermal conductivity



Optical transparency



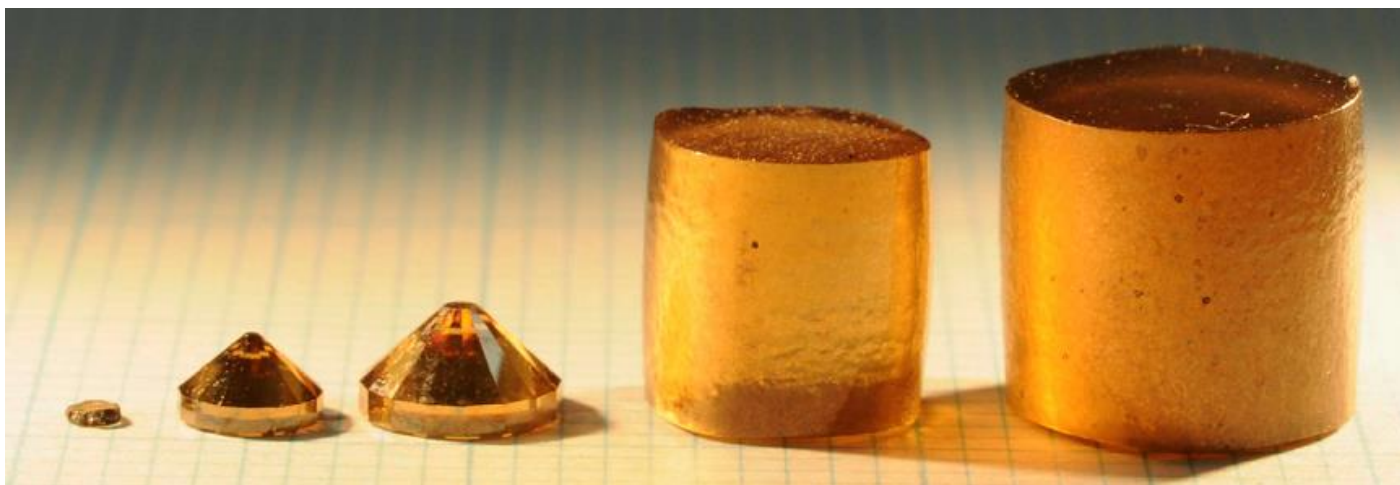
Synthesis of larger NPD



ORANGE-3000 (2003-)



BOTCHAN-6000 (2009-)

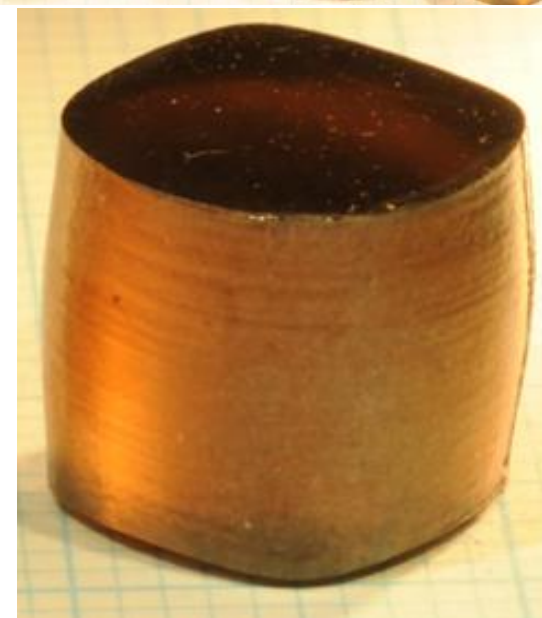


2003

ORANGE-3000

2009

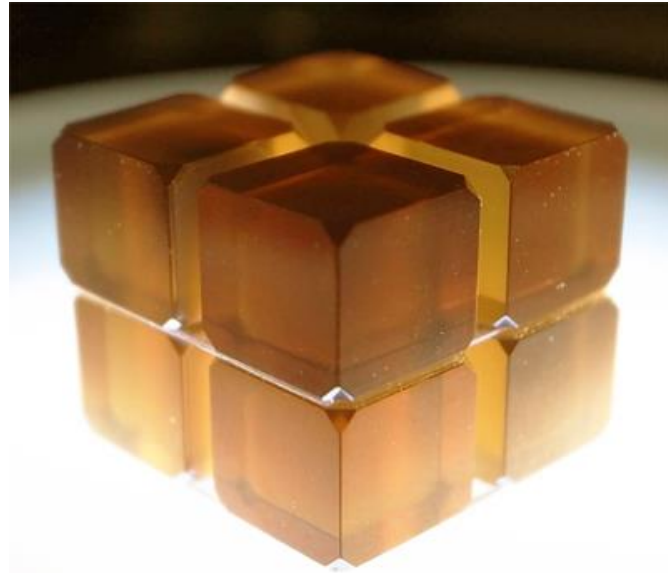
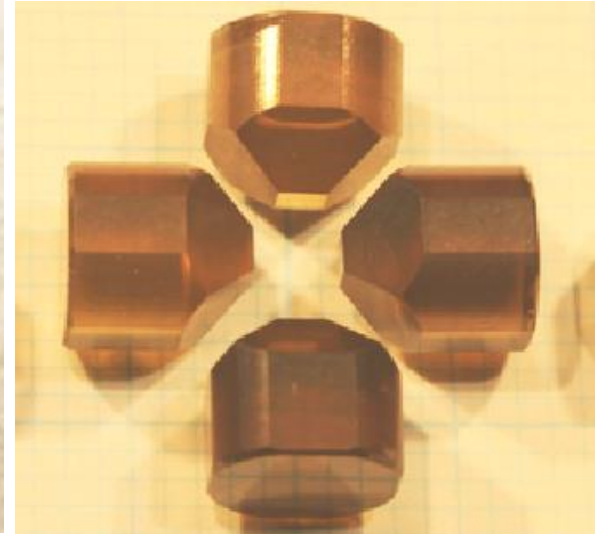
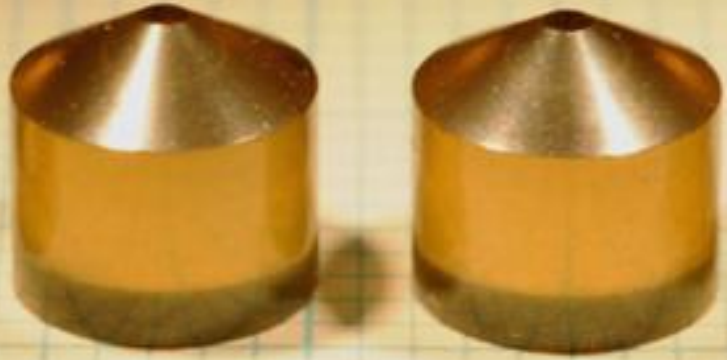
BOTCHAN-6000



1 cm

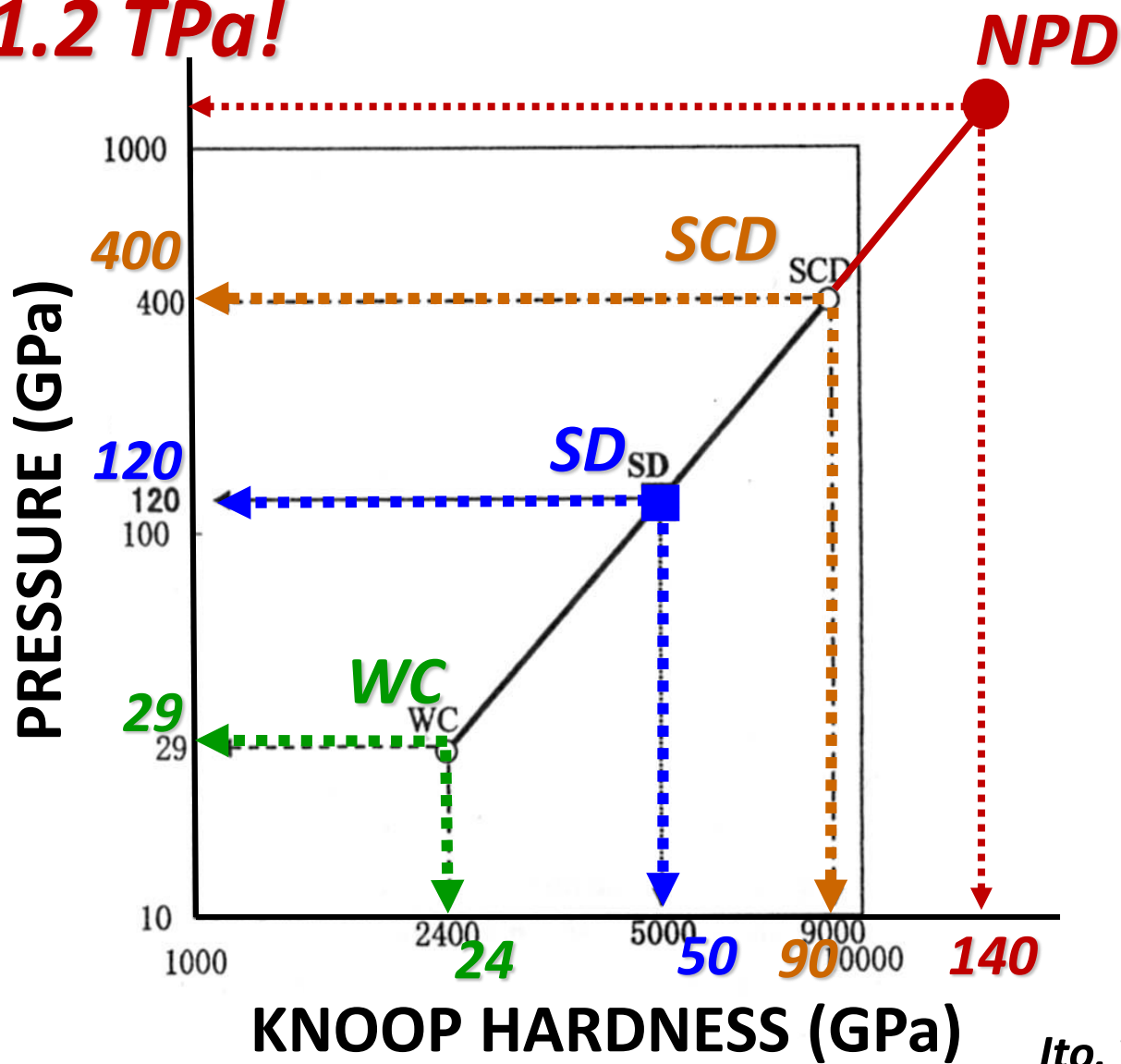
Irifune et al., Phys. Earth Planet. Inter. (2014)

Various NPD samples



Potential of NPD

1.2 TPa!

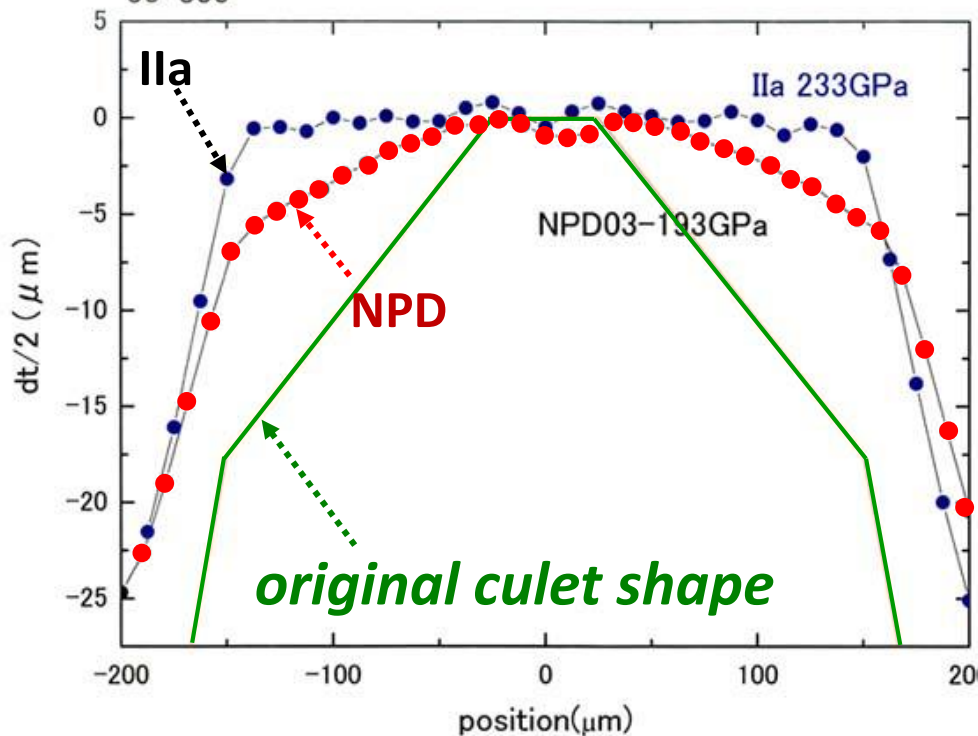


Ito, Treat. Geophys. (2007)

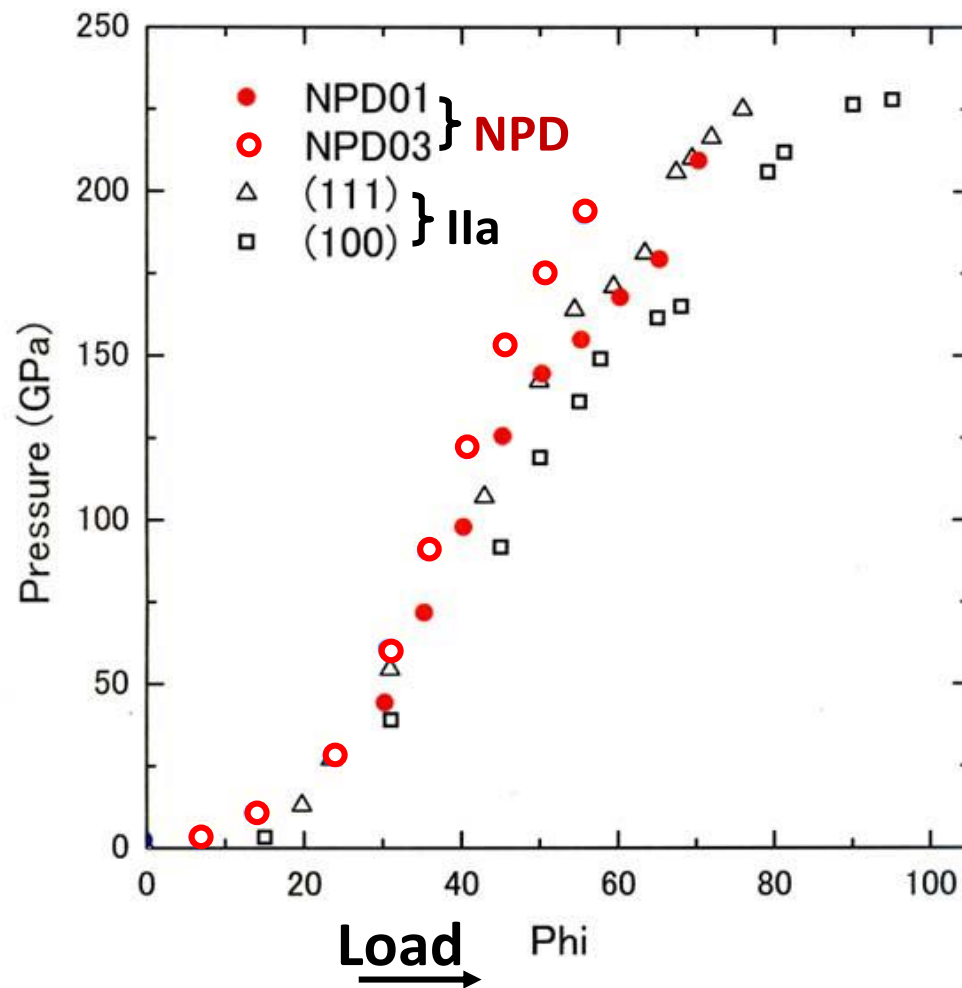
Application to DAC

Deformation of anvil top

50-300

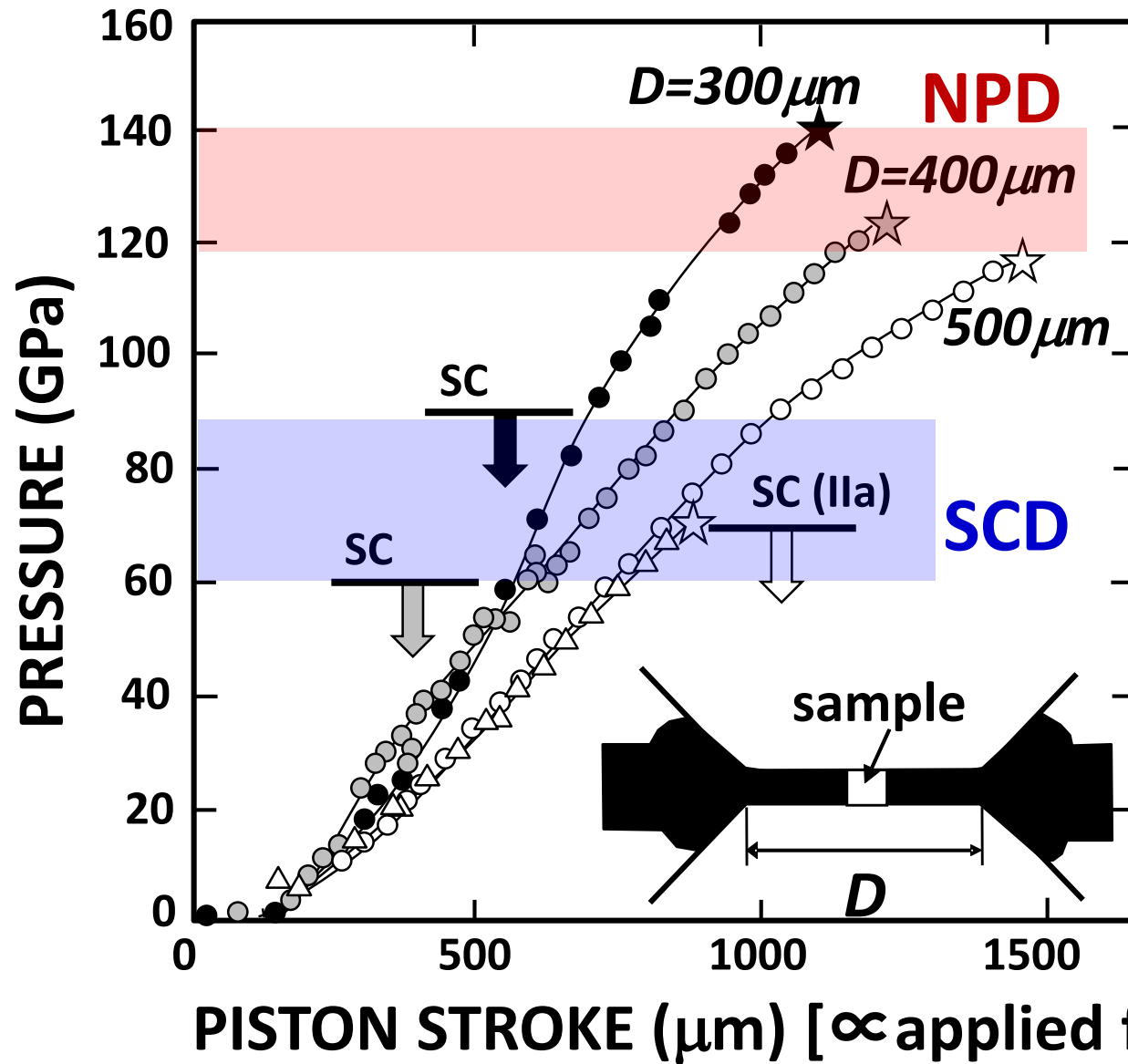


Pressure generation

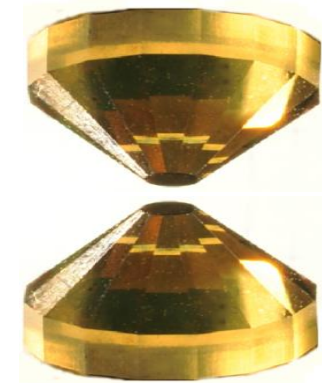


Nakamoto et al., Jap. J. Appl. Phys. (2007)

Pressure generation in L-DAC

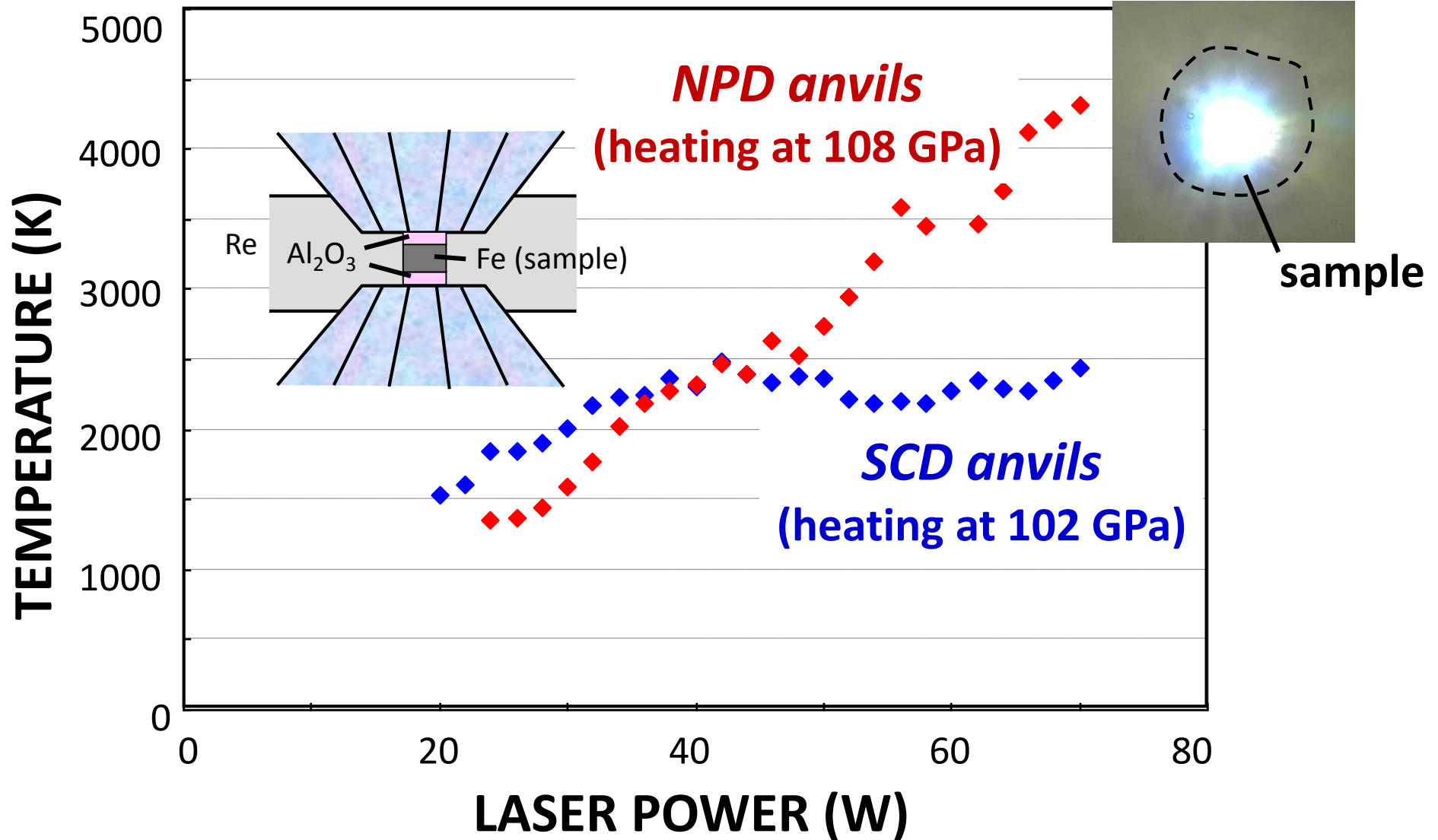


twice as high pressures



Laser heating

high heating efficiency



Achievement of TPa using “NCD”

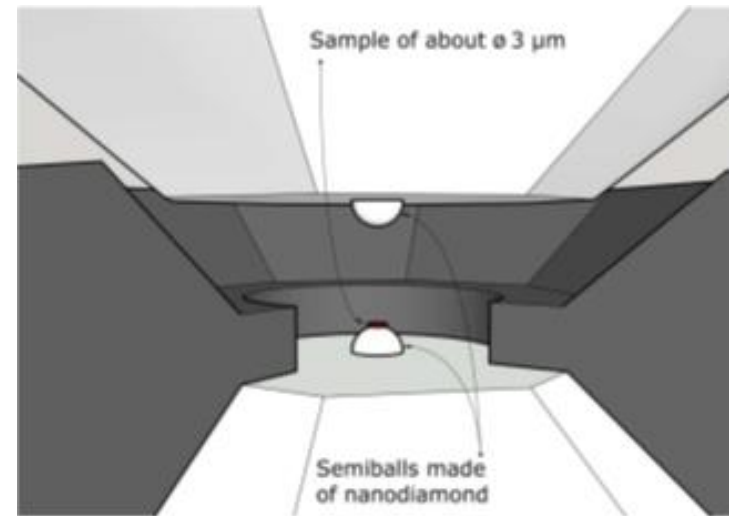
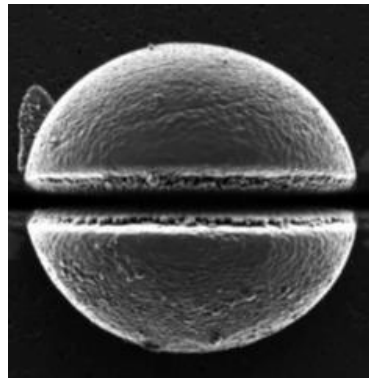
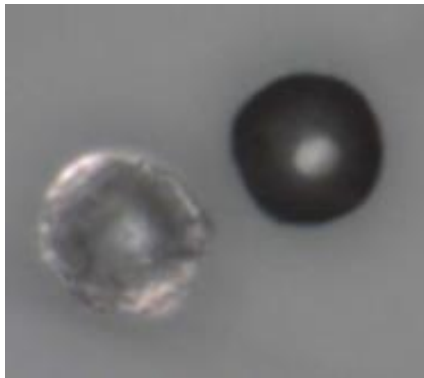
RESEARCH ARTICLE

MATERIALS SCIENCE

Terapascal static pressure generation with ultrahigh yield strength nanodiamond

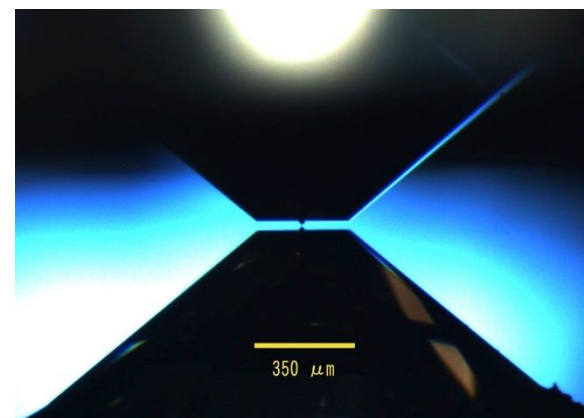
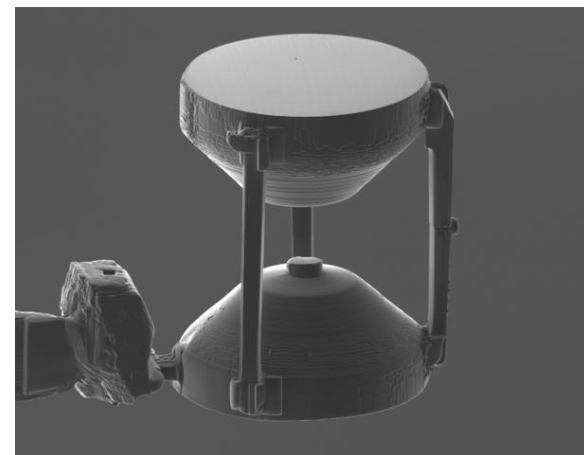
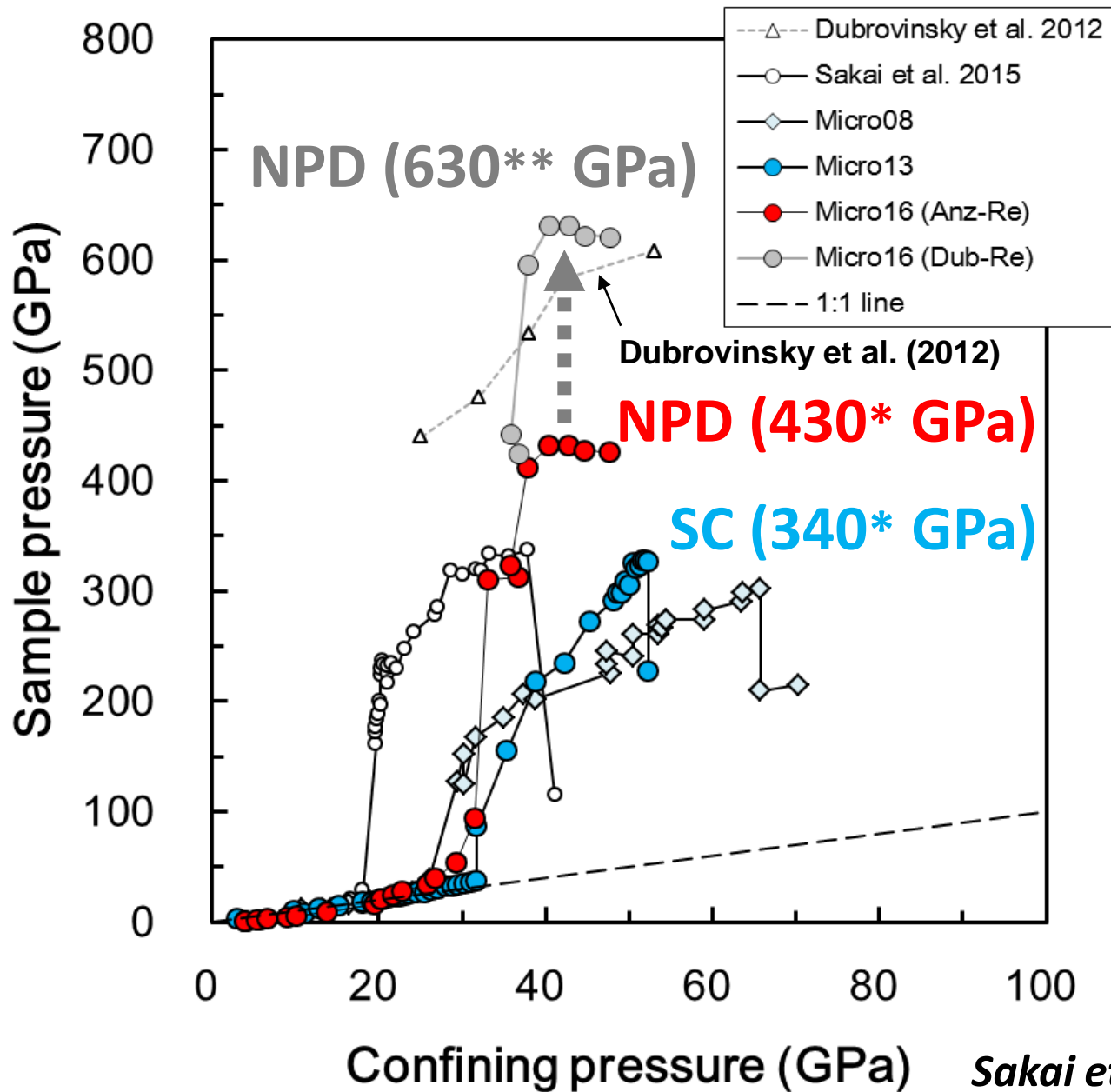
Natalia Dubrovinskaia,^{1*†} Leonid Dubrovinsky,^{2†} Natalia A. Solopova,^{1,2} Artem Abakumov,^{3‡} Stuart Turner,³ Michael Hanfland,⁴ Elena Bykova,² Maxim Bykov,² Clemens Prescher,⁵ Vitali B. Prakapenka,⁵ Sylvain Petitgirard,² Irina Chuvashova,^{1,2} Biliانا Gasharova,⁶ Yves-Laurent Mathis,⁷ Petr Ershov,⁸ Irina Snigireva,⁴ Anatoly Snigirev^{4,8}

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Dubrovinskaia et al., Sci. Adv. (2016)

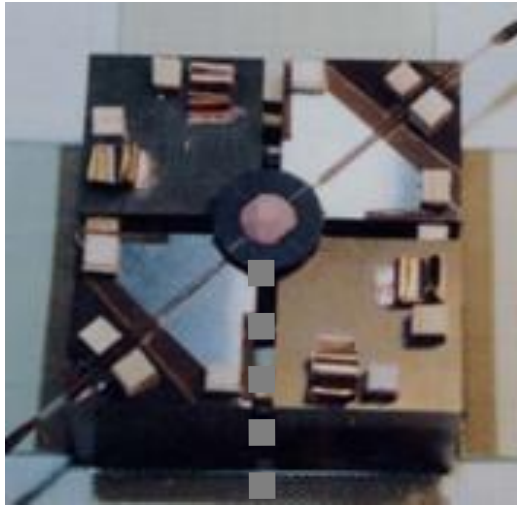
Double-stage DAC



Sakai et al., High Press. Res. (2018)

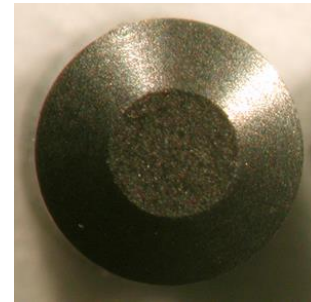
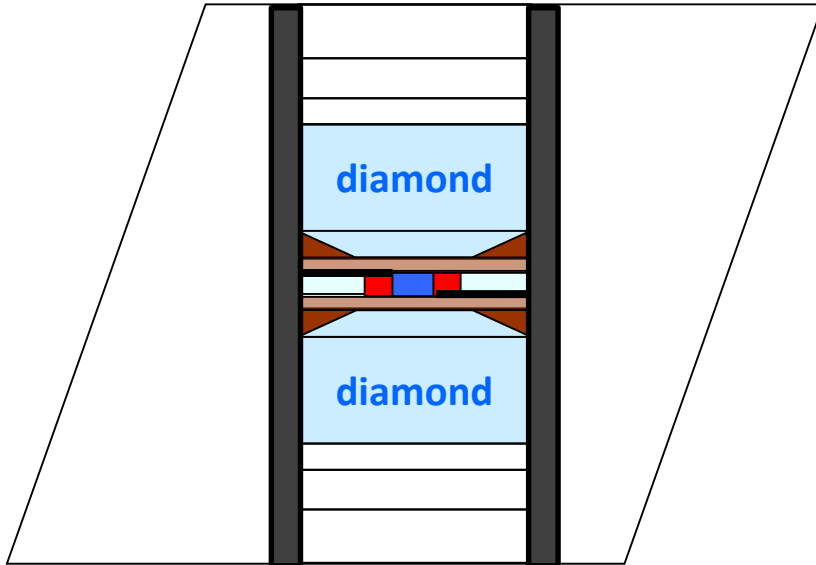
Application to 6-8-2 MA

6-8 MA



graphite heater

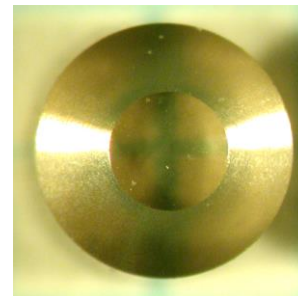
6-8-2 MA



1) sintered diamond with Co binder

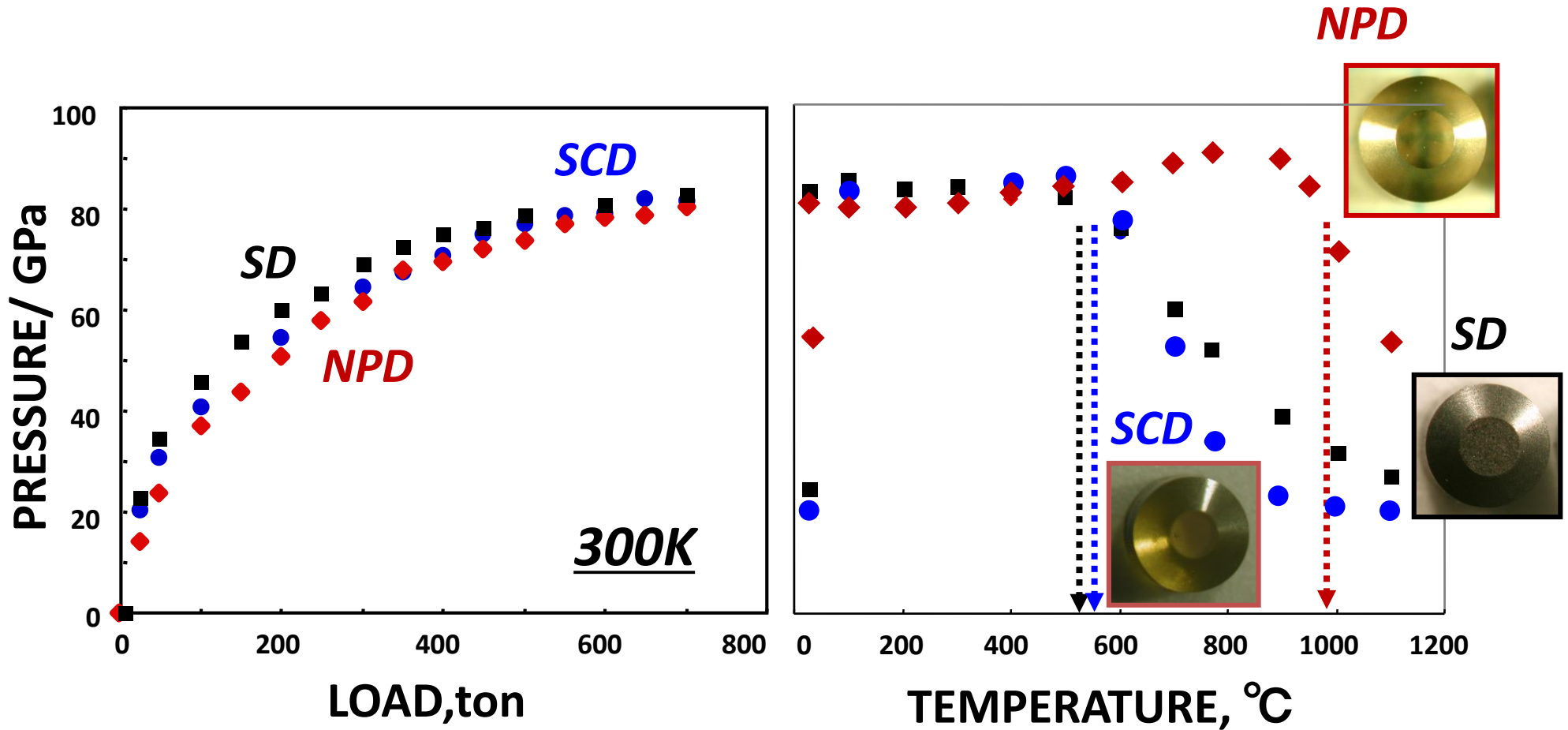


2) single crystal Ib diamond



3) NPD

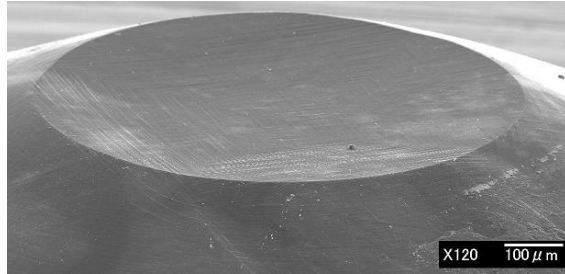
Performance of the 6-8-2 system



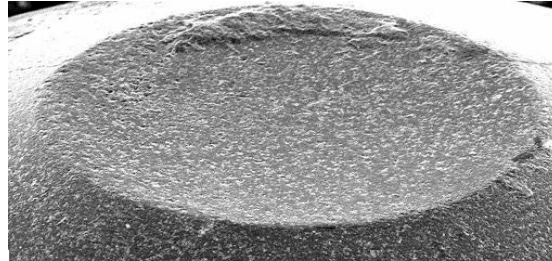
Kunimoto, Irifune et al., High Press. Res. (2008)

Deformation of anvil culets

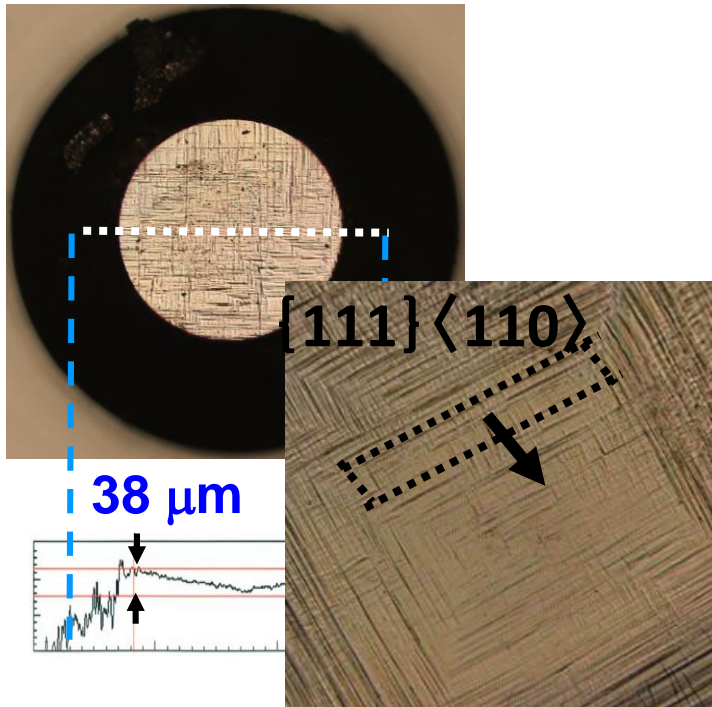
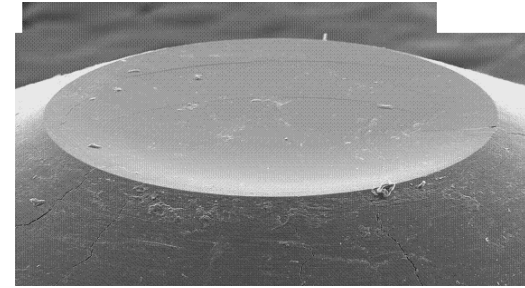
SCD Ib



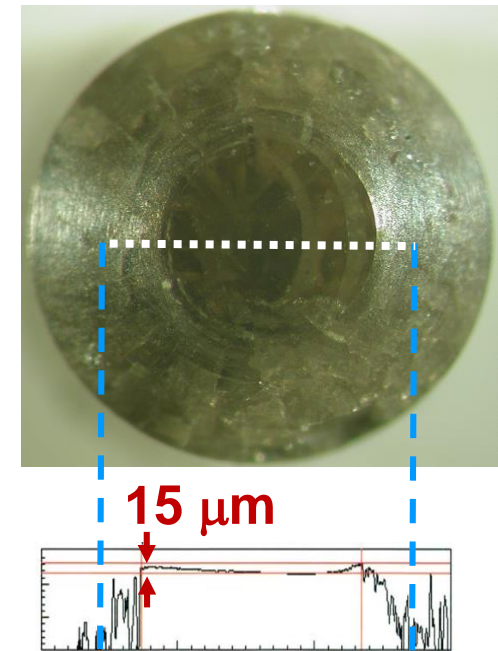
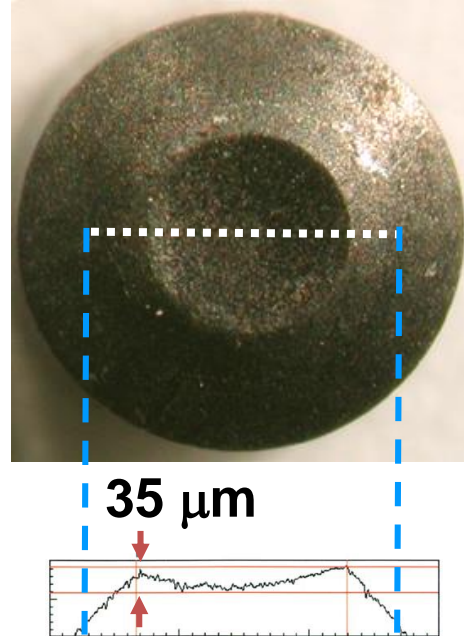
SD (Co binder)



NPD



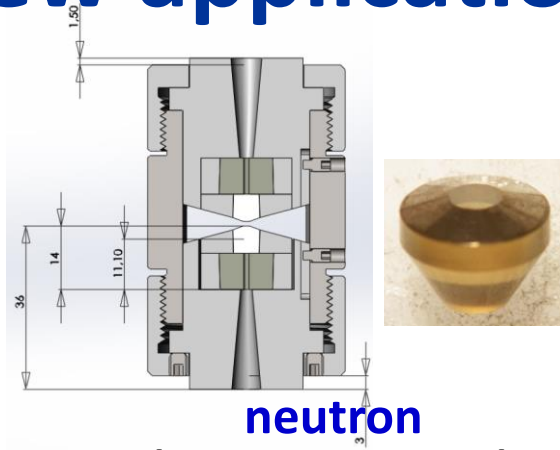
(100)



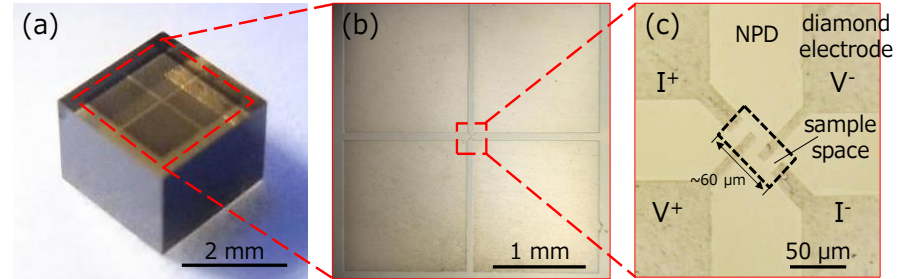
Various new applications



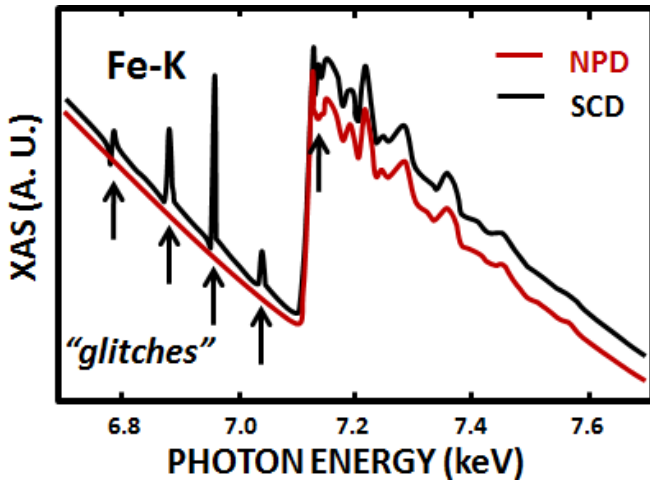
multi-anvil
(Kunimoto, Tange)



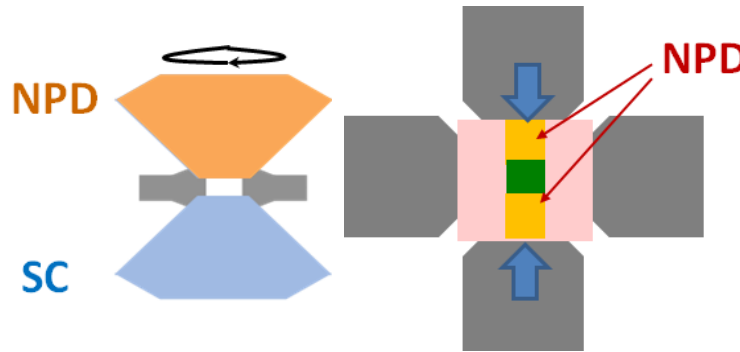
neutron
(Komatsu, Klotz)



electrical conductivity
(Matsumoto, Takano)



X-ray absorption spectroscopy
(Ishimatsu, Pascarelli, Rosa, etc.)



deformation
(Nomura, Azuma, Wang)



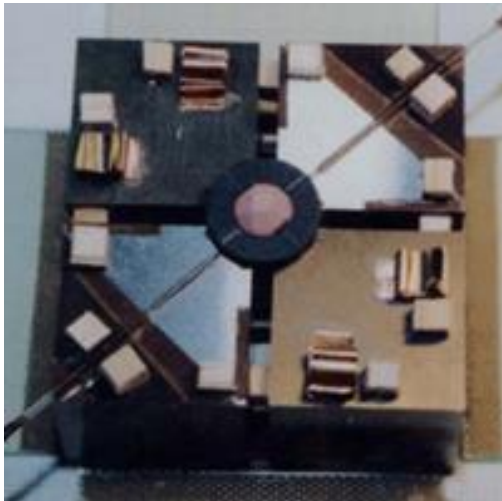
mortar & pestle
(Xie, Yoneda)

Topics

- 1) Synthesis, features and applications of NPD
- 2) Higher P/T generation in KMA using WC, SD, and NPD anvils

Anvil materials for KMA

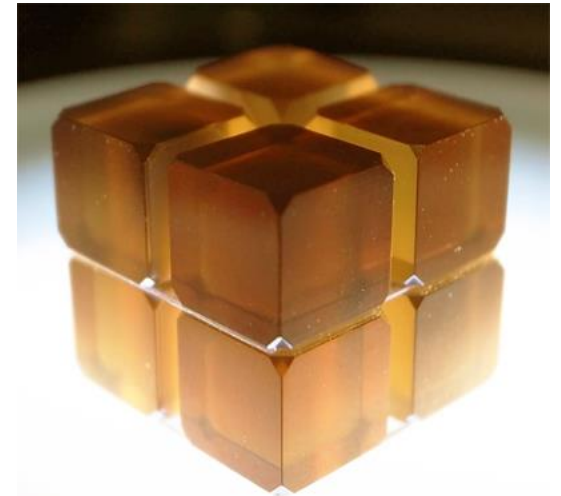
tungsten carbide
(WC)



sintered diamond
(SD)

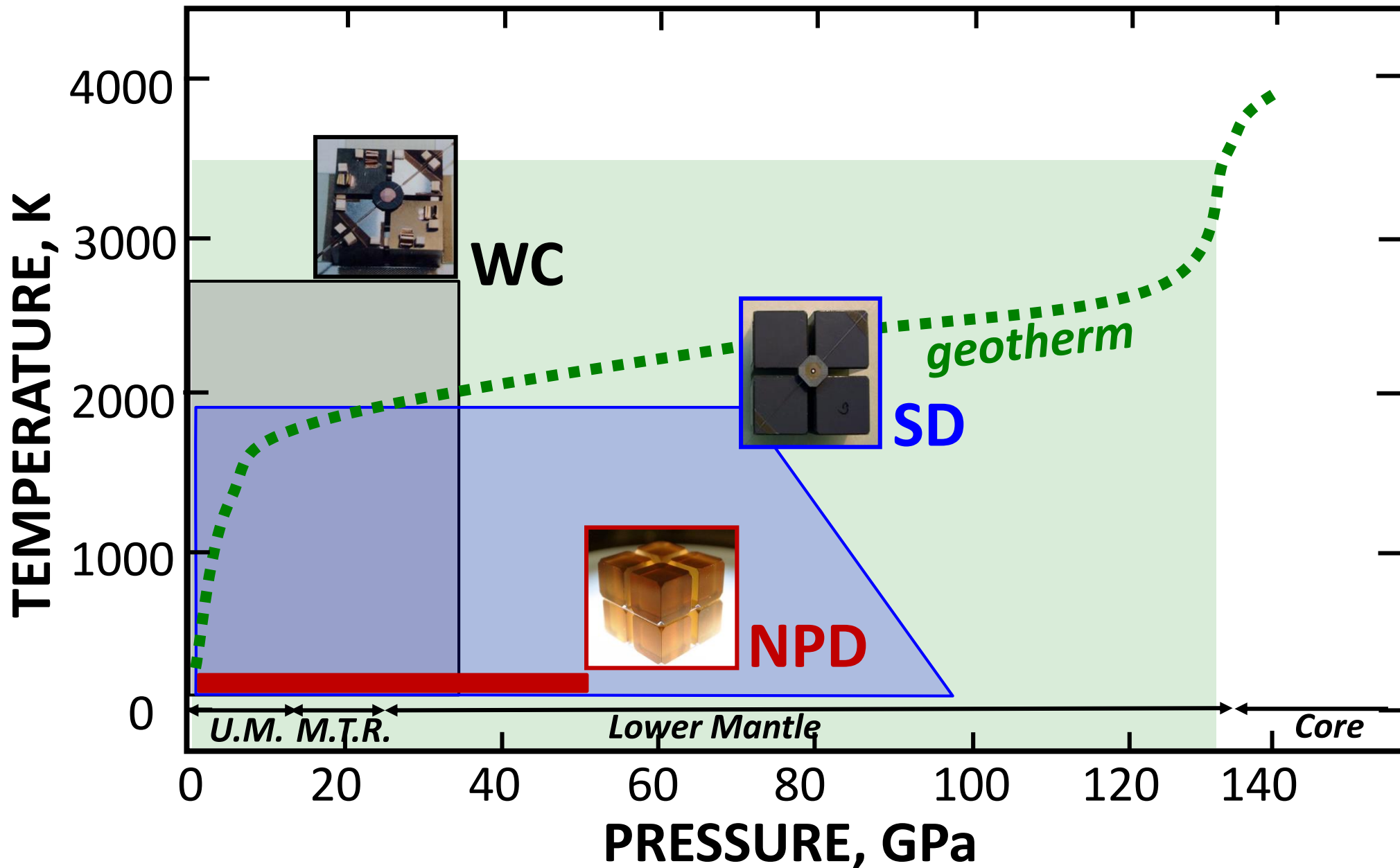


nano-polycrystalline
diamond (NPD)



Material	Hk (GPa)	E (GPa)	P (GPa)	Target P (GPa)
WC	25 - 30	650	~35	~50
SD	50 - 70	900	~100	~130
NPD	130 - 140	1200	~50	~200

HPT generation in KMA (around 2014)

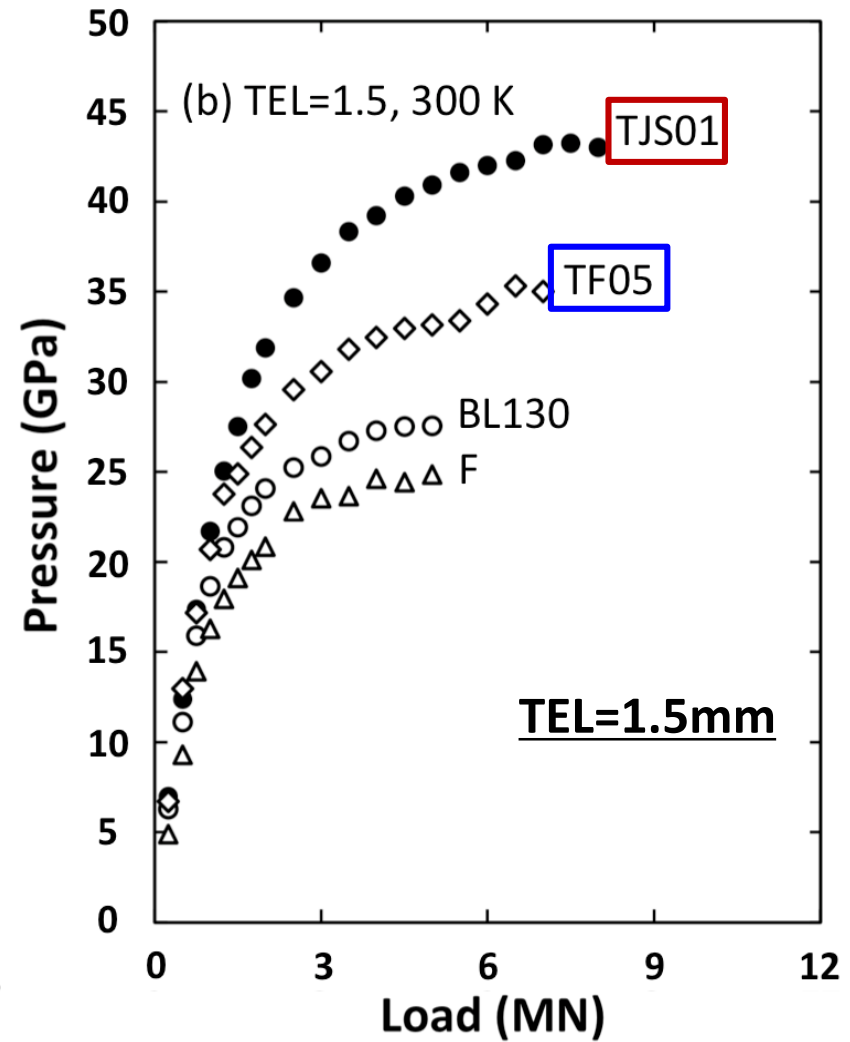
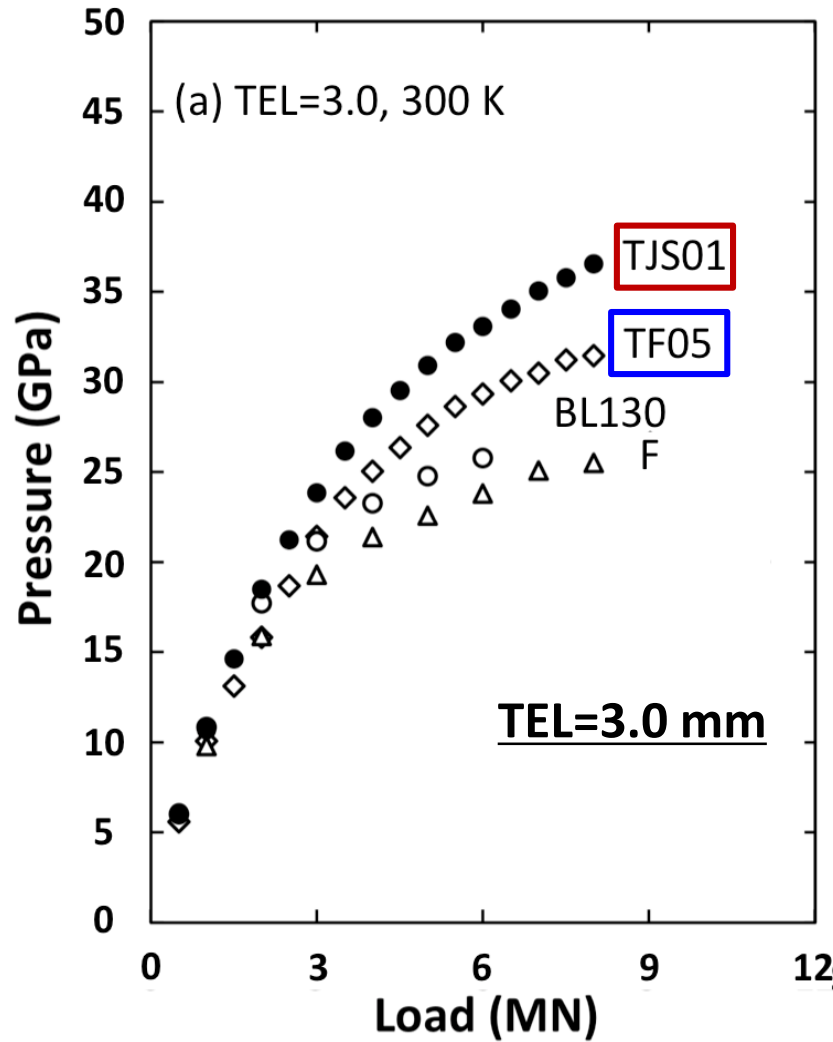


Mechanical properties of WC anvil

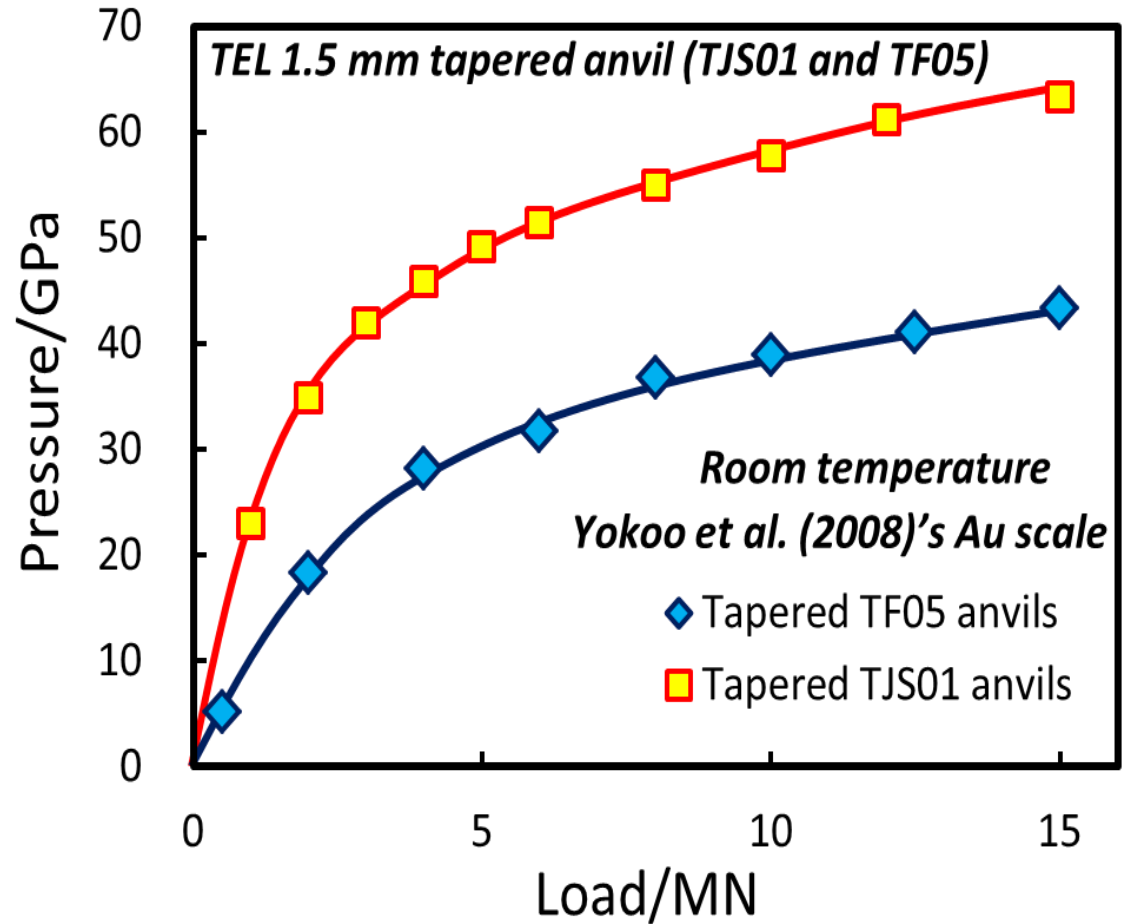
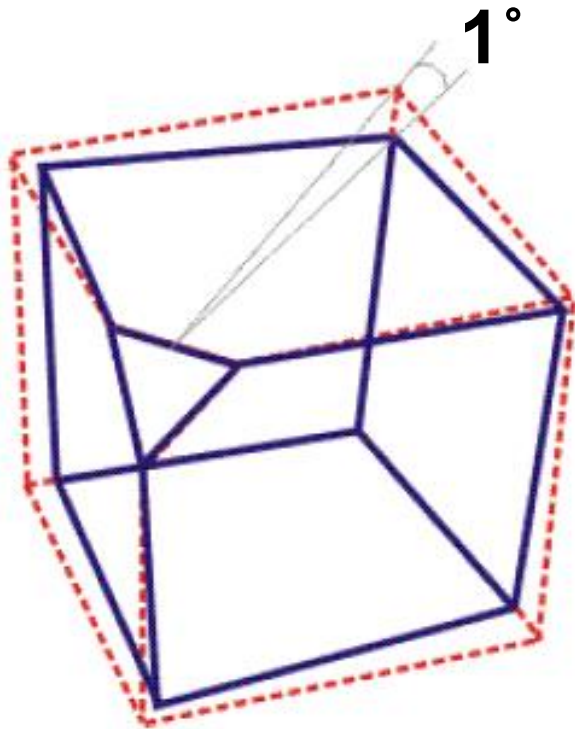
hardness

Product	Hv (GPa)	HRA	TRS (GPa)	E (GPa)
F	19.5	93.4	2.5	640
BL130	22	94.2	2.9	660
TF05	24	95.1	2.5	610
TJS01	27	>>95	2.6	660

Performance of the new WC anvil

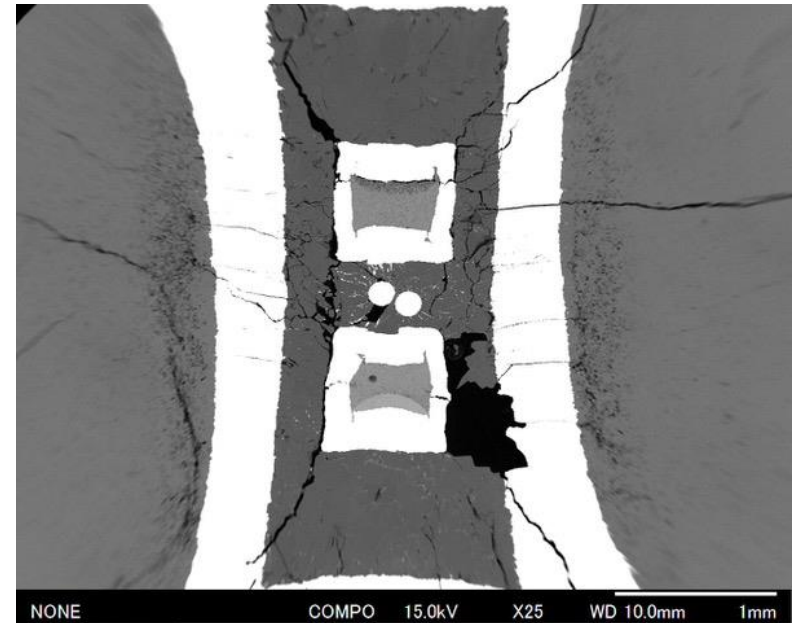
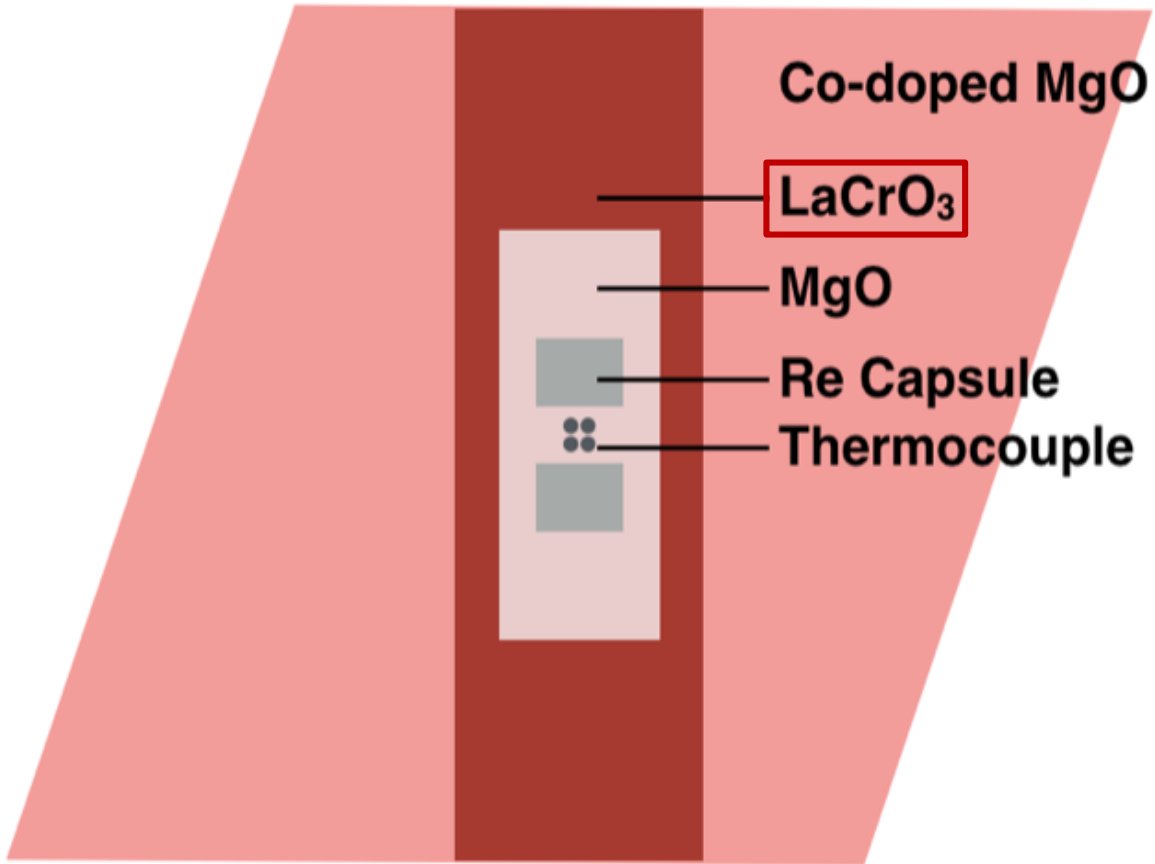


60 GPa with the new WC anvil



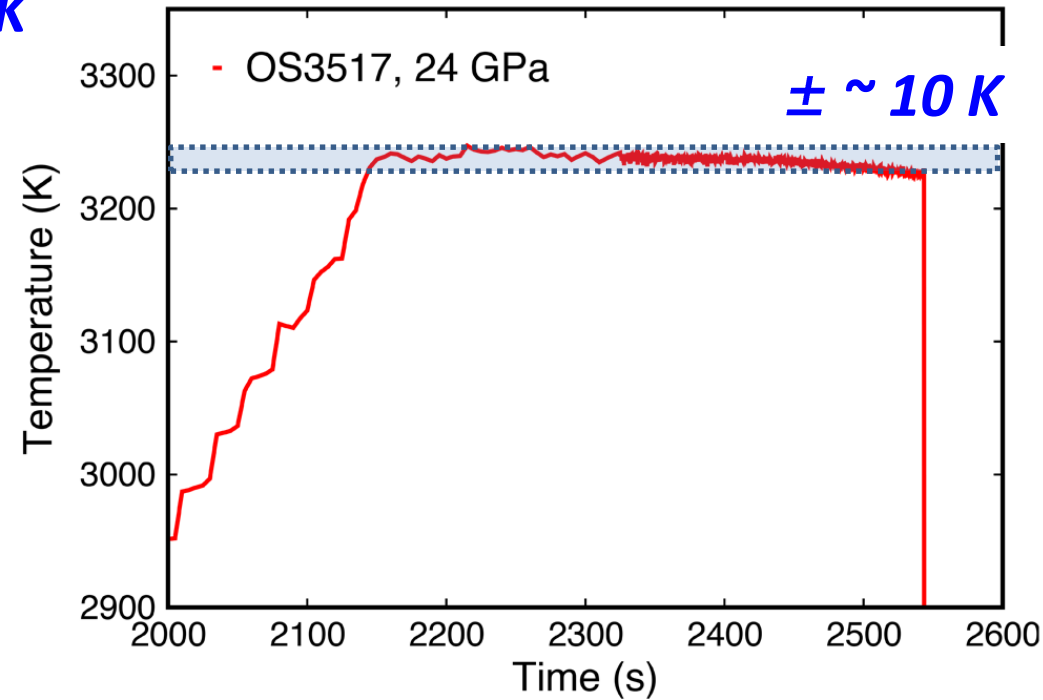
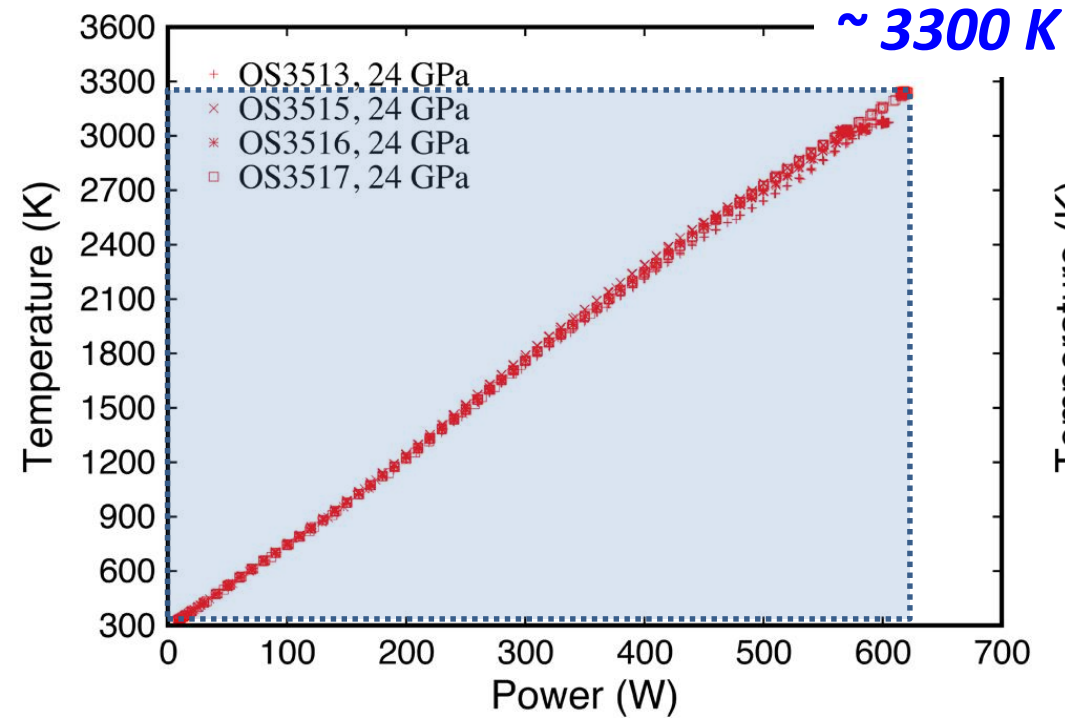
Ishii et al., Rev. Sci. Instrum. (2016)

HT generation in WC-KMA



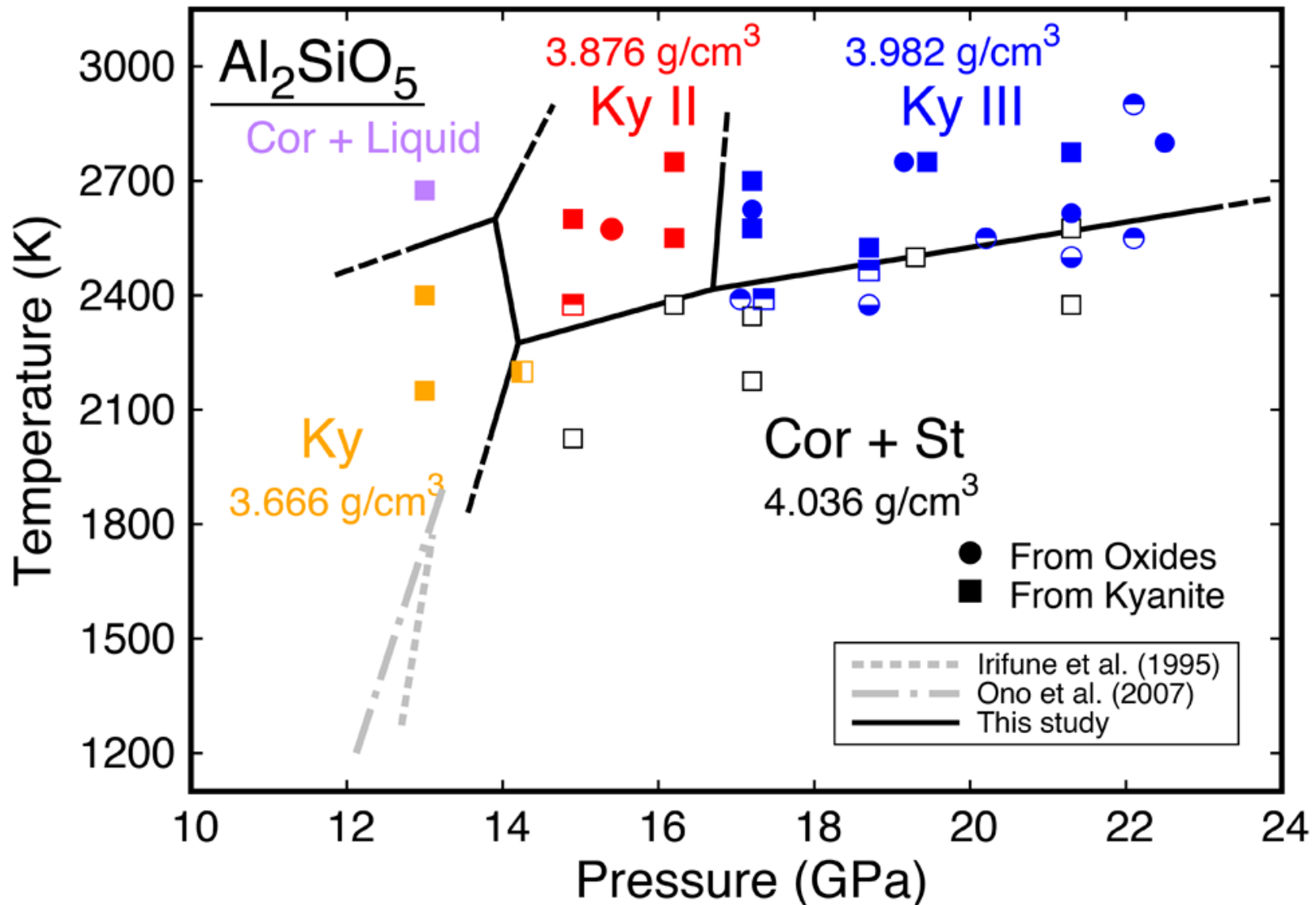
Courtesy of Y. Zhou

Generation and stability of HT in WC-KMA



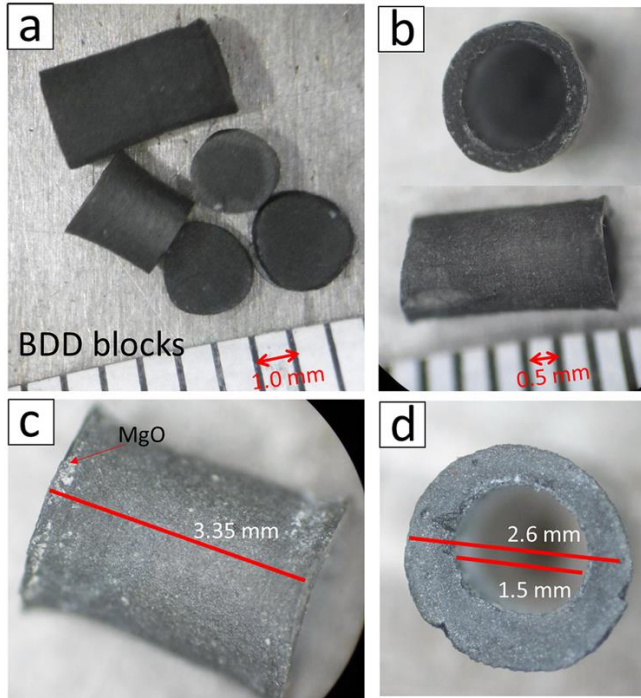
Courtesy of Y. Zhou

New HT phases of kyanite

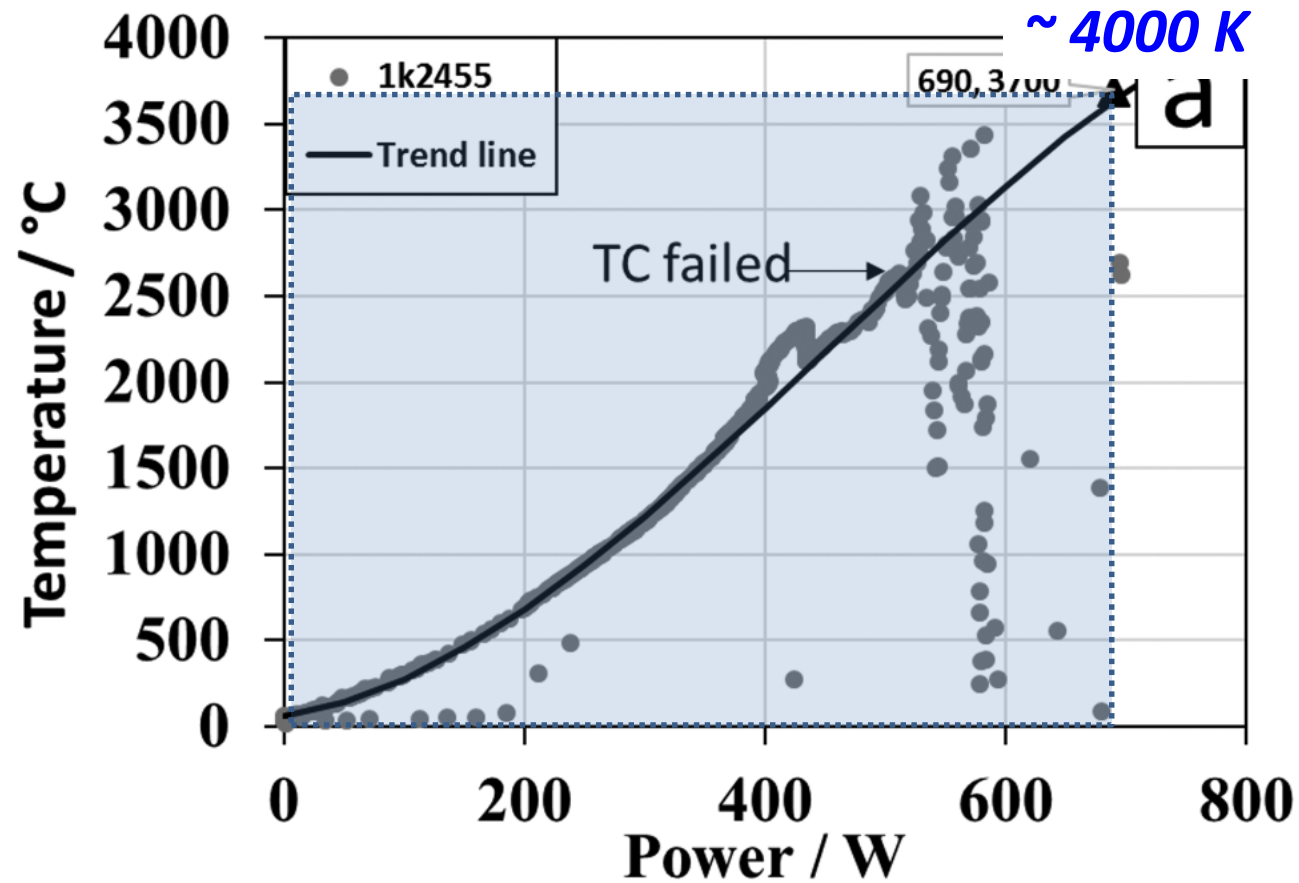


Zhou, Irfune et al., Geophys. Res. Lett. (2018)

Further higher T using B-doped diamond

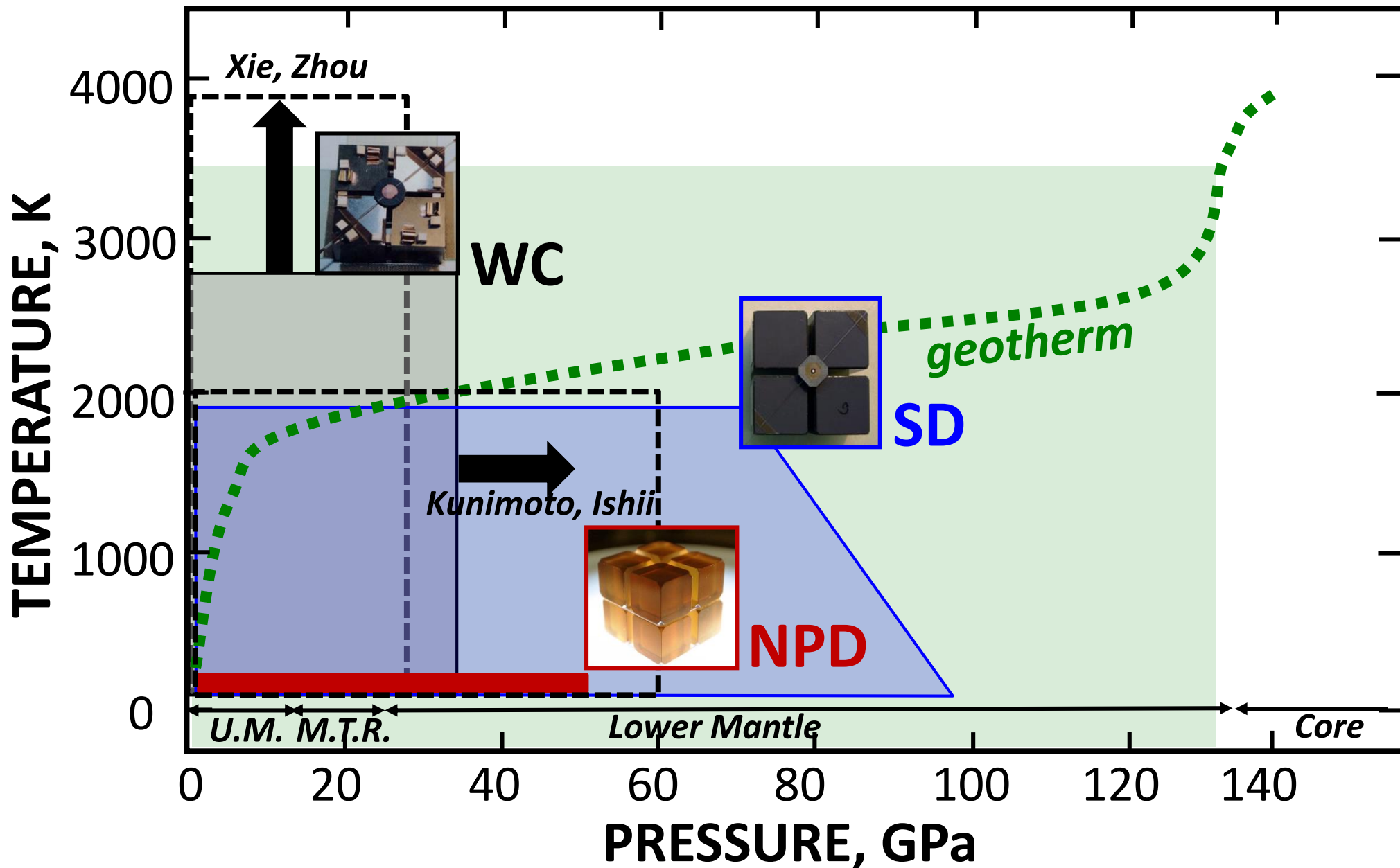


Hime-diamond mortar & pestle



Xie, Yoneda et al., Rev. Sci. Instrum. (2017)

HPT generation in KMA

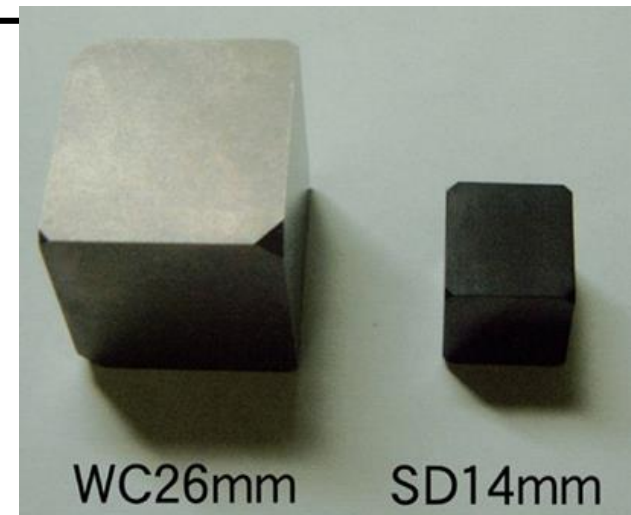


Mechanical properties of SD anvil

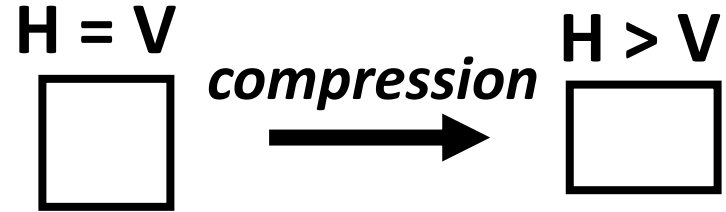
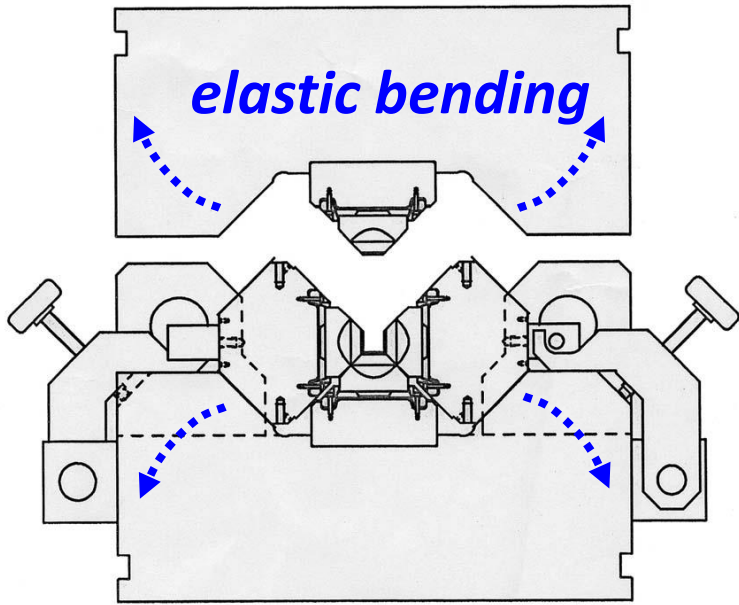
hardness

Product	Hv (GPa)	HRA	TRS (GPa)	E (GPa)
F	19.5	93.4	2.5	640
BL130	22	94.2	2.9	660
TF05	24	95.1	2.5	610
TJS01	27	>>95	2.6	660
WD700	60	-	2	900

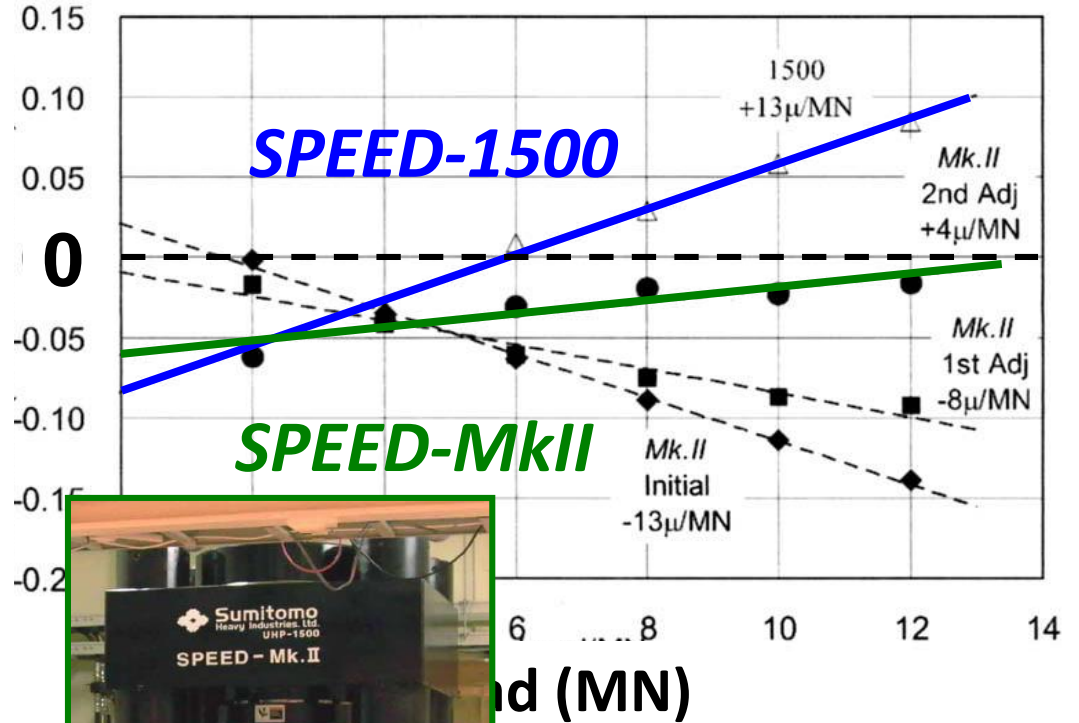
Sintered Diamond with Co binders



Elastic deformation of guide blocks



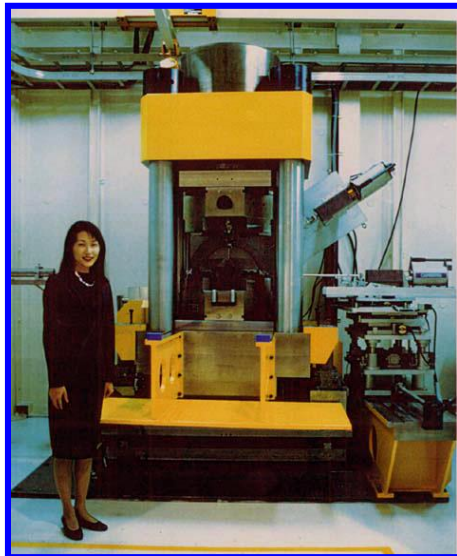
Horizontal - Vertical (mm)



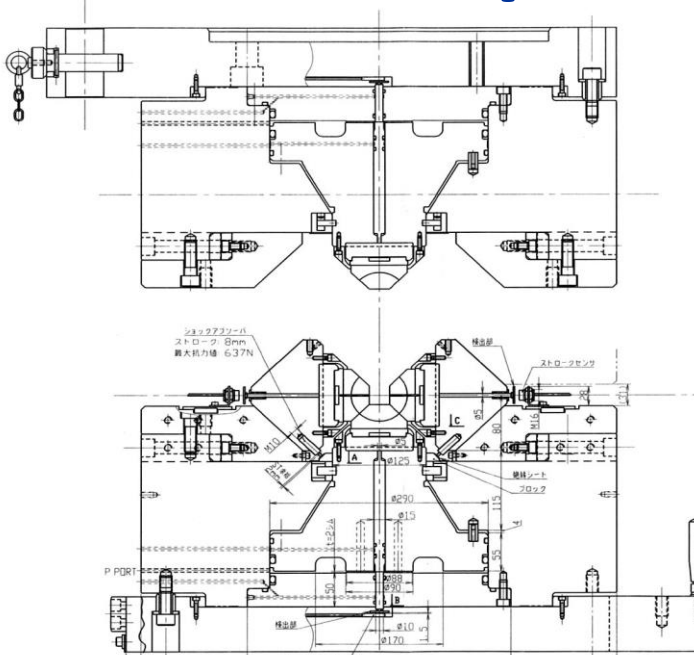
K

Earth Planet. Inter. (2004)

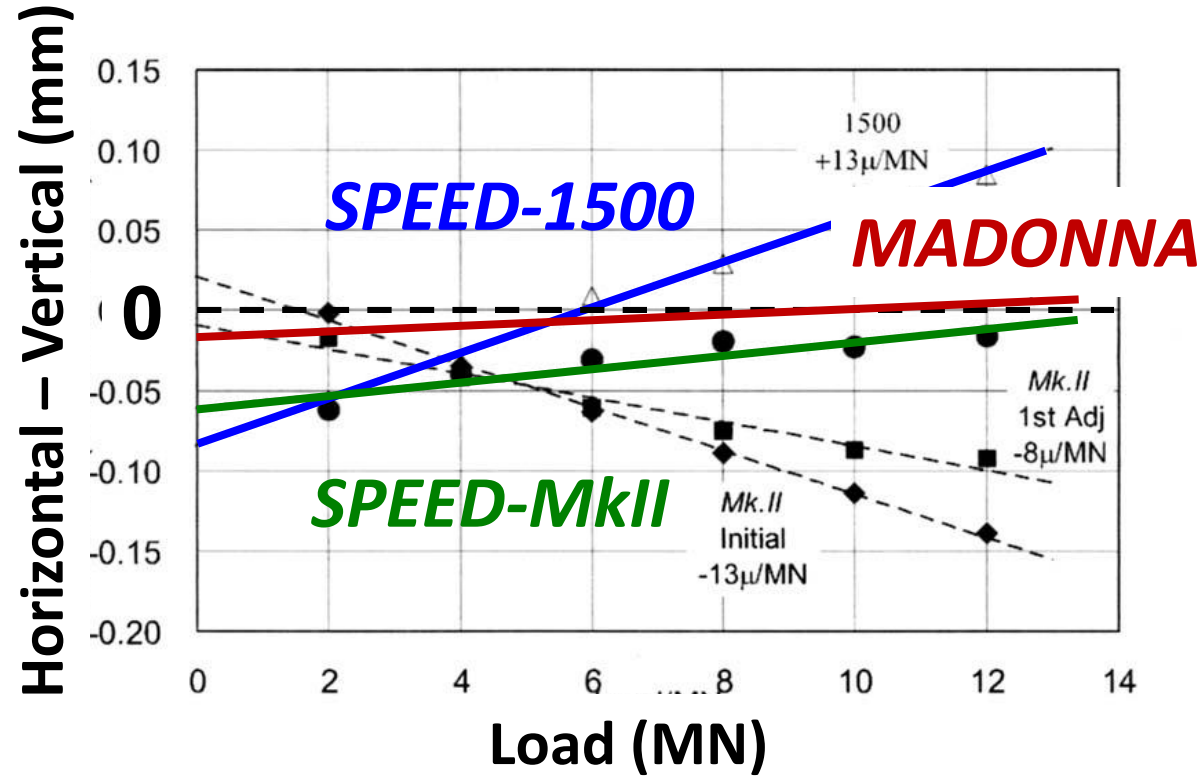
DIA type MA (e.g. SPEED-1500)



Further improvement

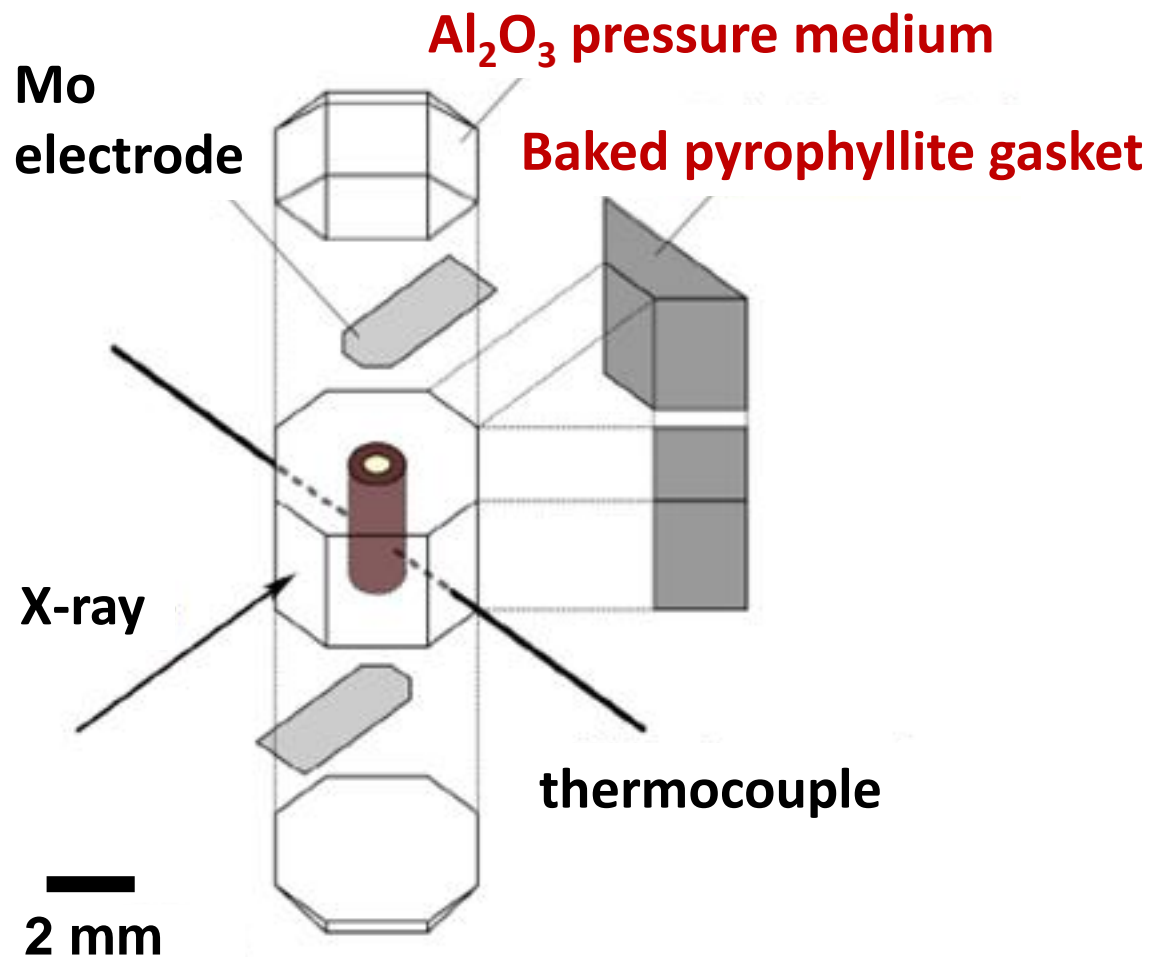


MADONNA-1500



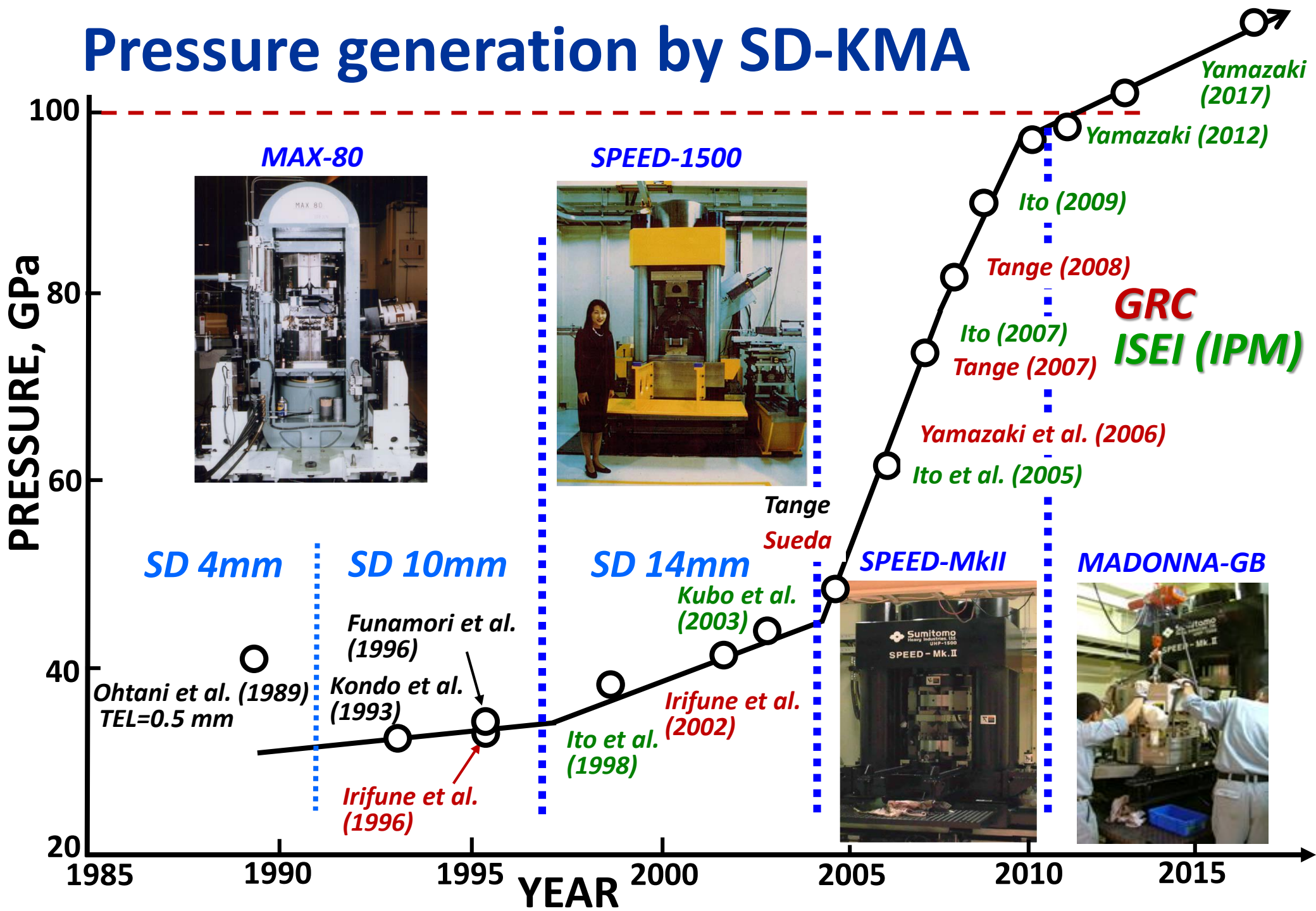
Irifune, Rev. High Press. Sci. Tech. (2010)

Cell assembly for SD-KMA

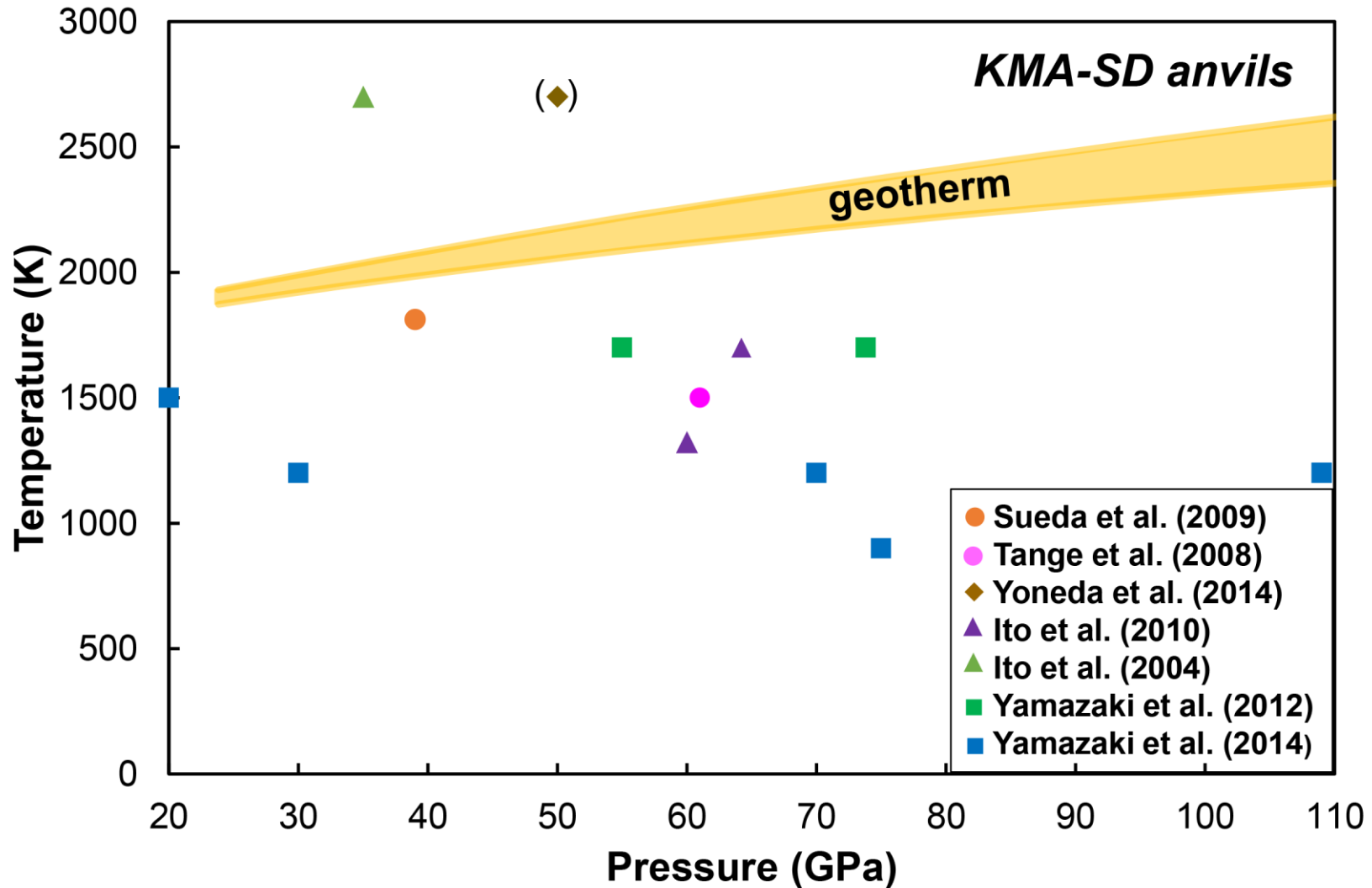


Tange et al., High Press. Res. (2008)

Pressure generation by SD-KMA

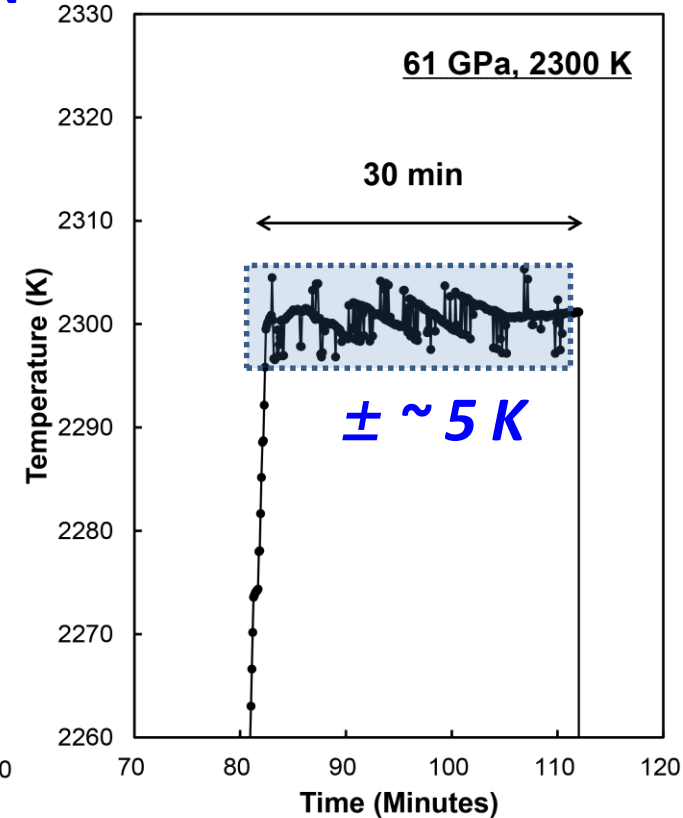
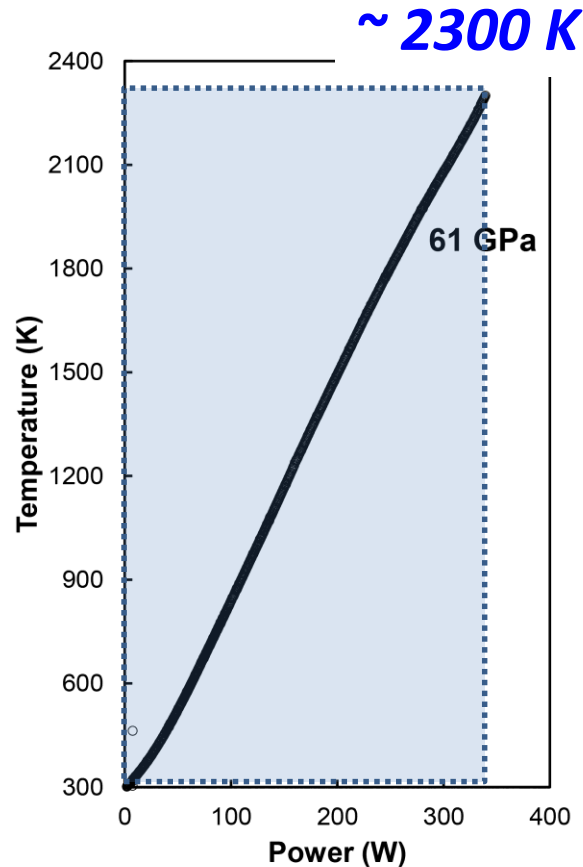
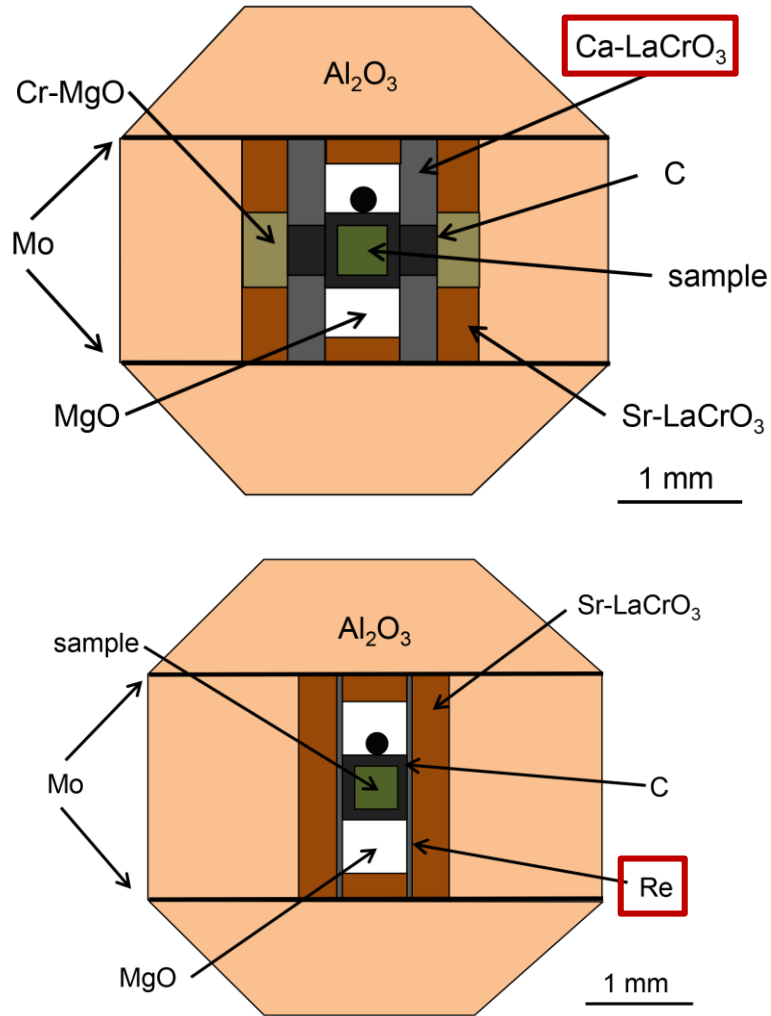


HT generation in SD-KMA

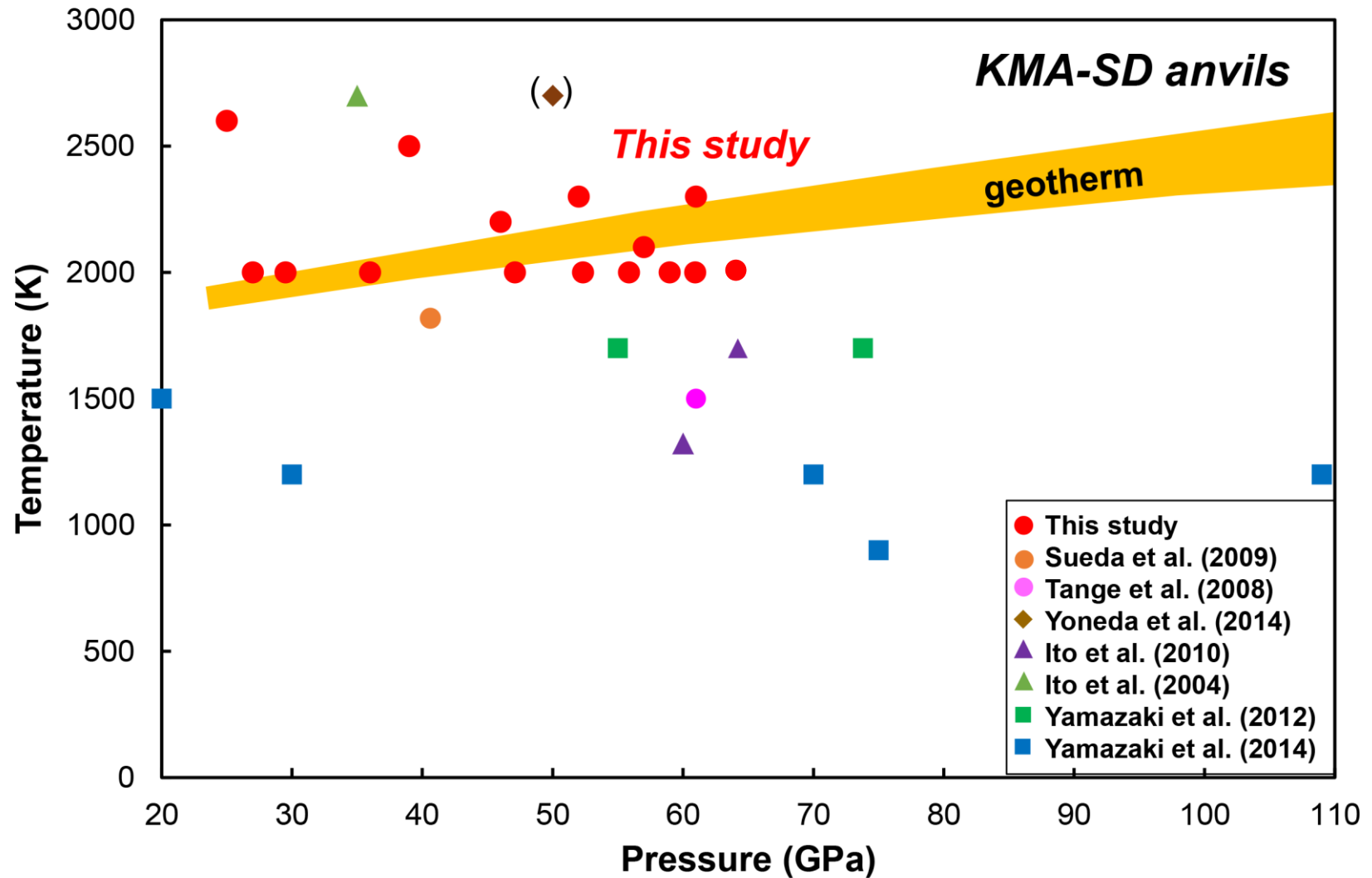


Courtesy of T. Arimoto

Generation and stability of HT in SD-KMA

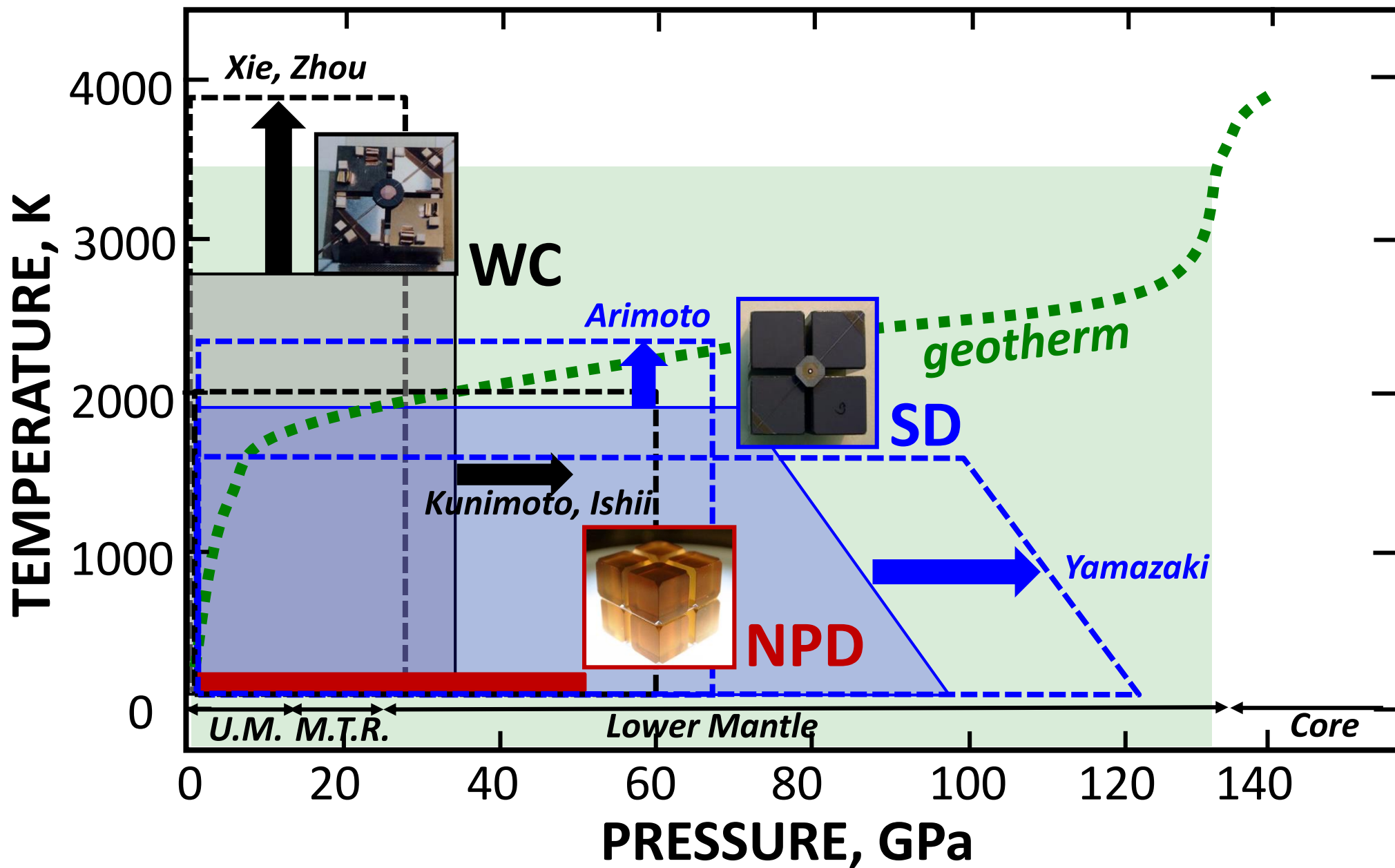


HT generation in SD-KMA

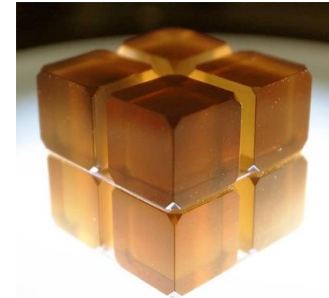
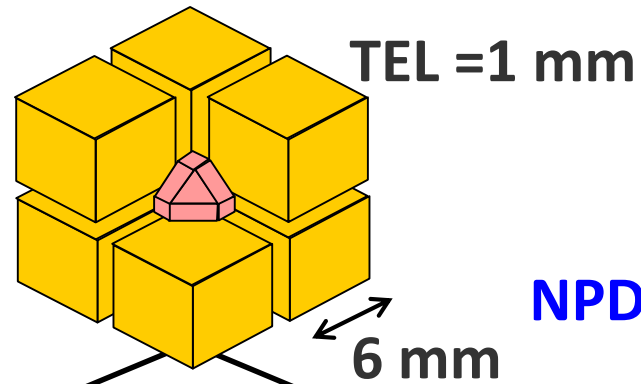
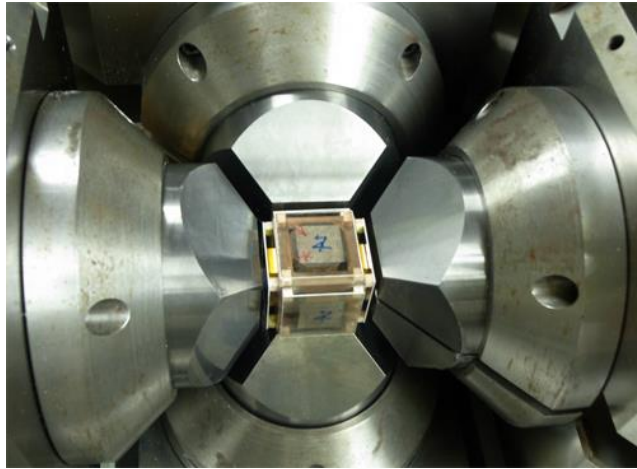


Courtesy of T. Arimoto

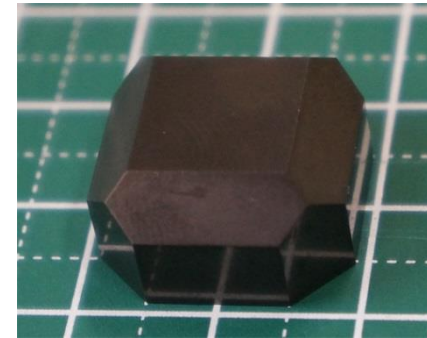
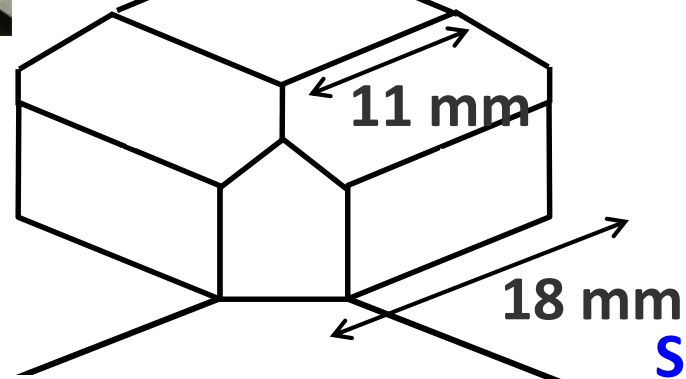
HPT generation in KMA



KMA using NPD anvils

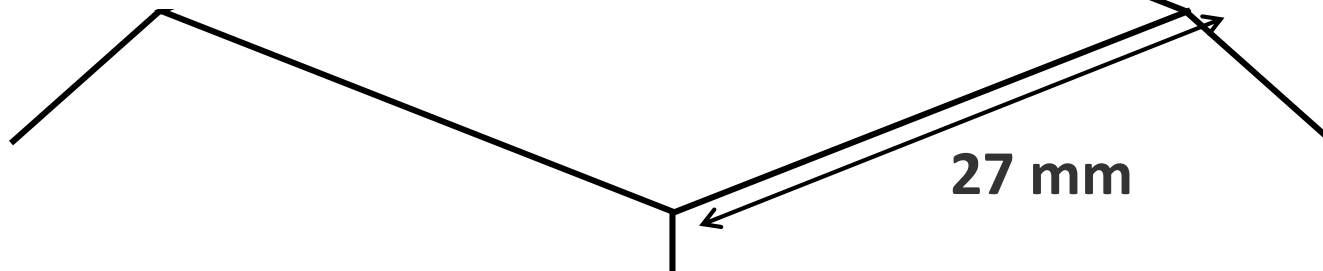


NPD third-stage anvil

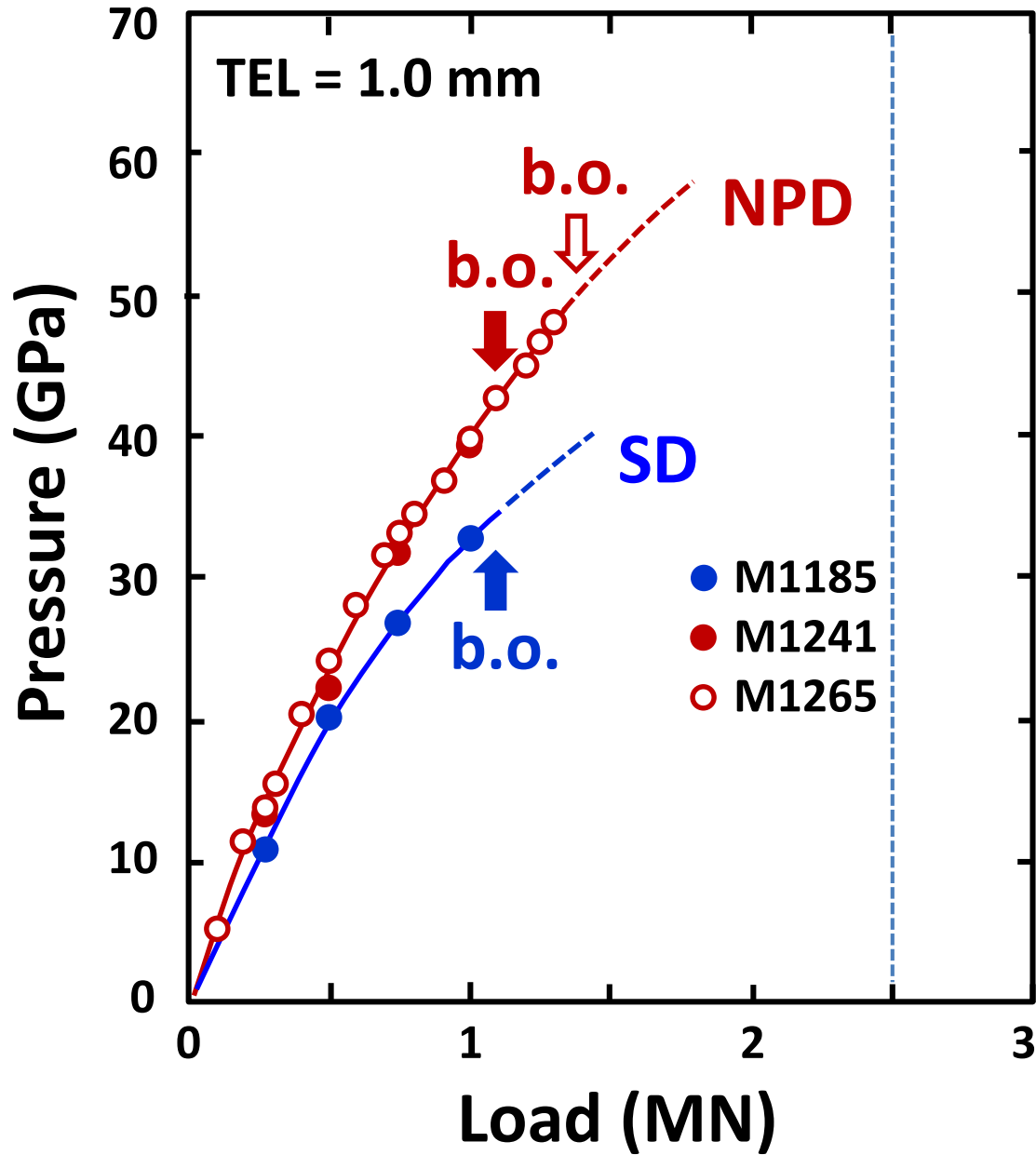


SD second-stage anvil

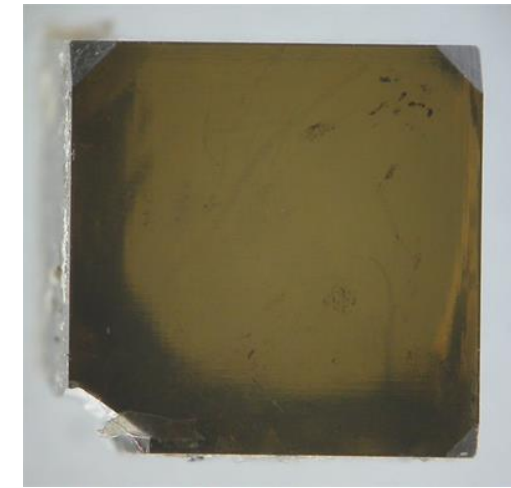
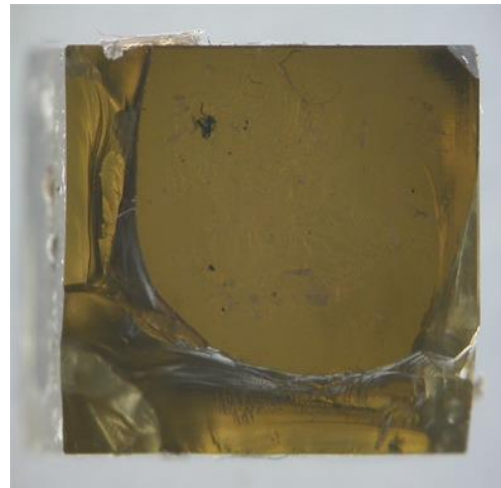
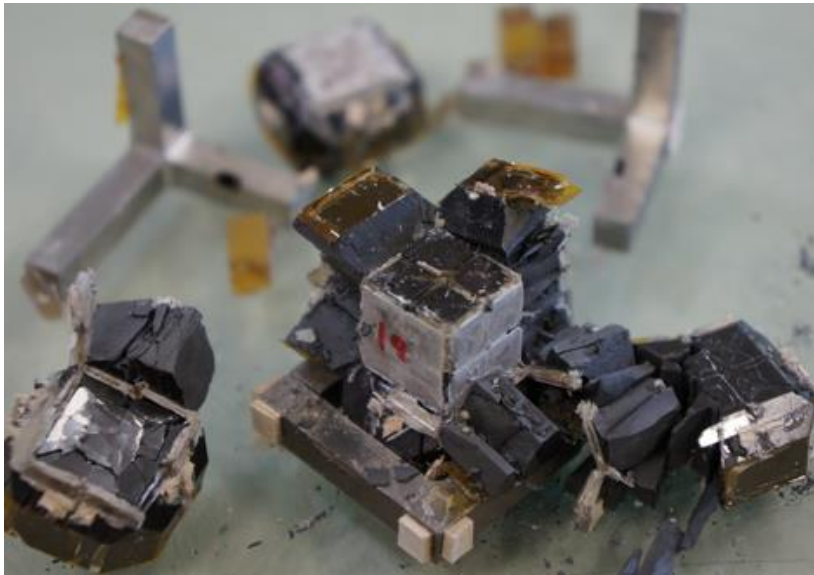
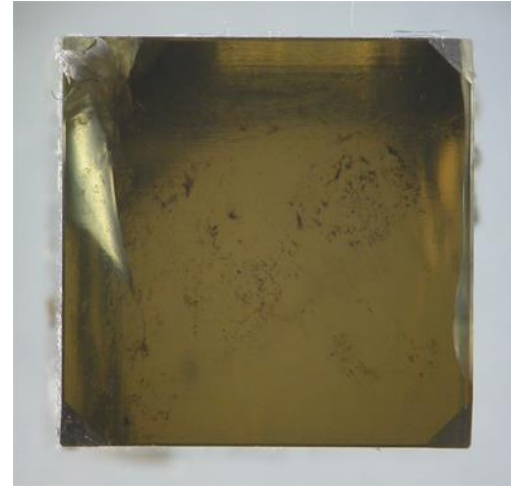
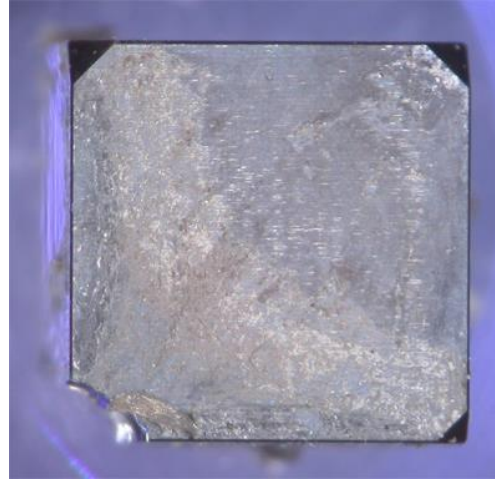
WC first-stage anvil



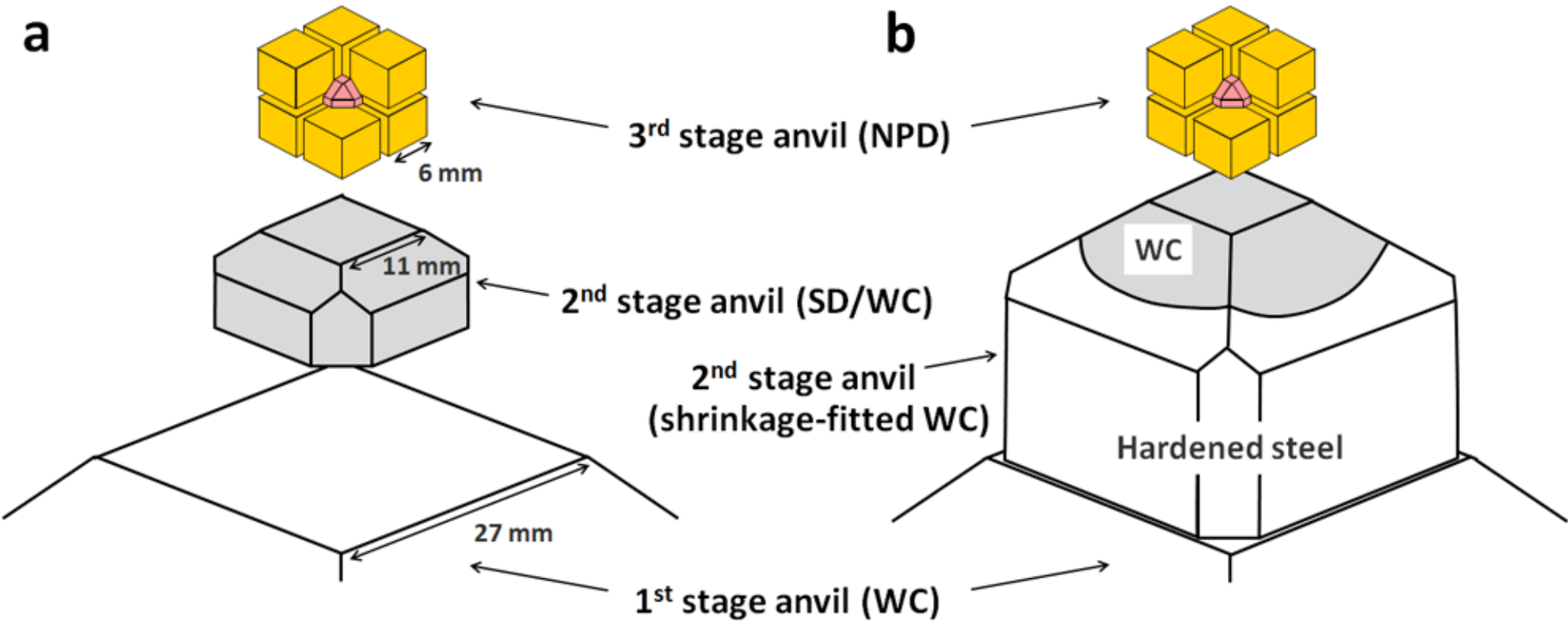
Initial attempts



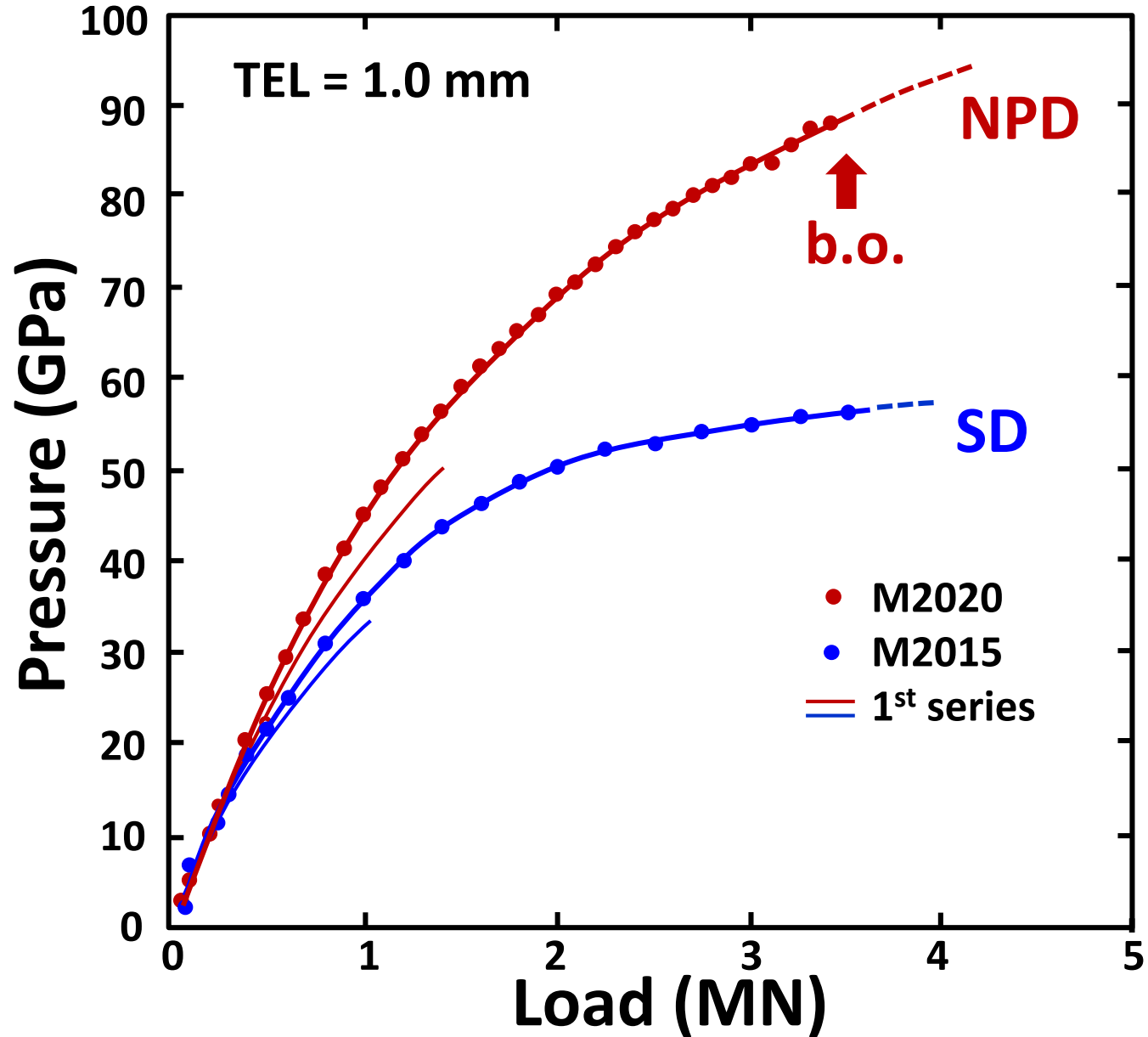
Recovered SD and NPD anvils



Replacement of second-stage anvils



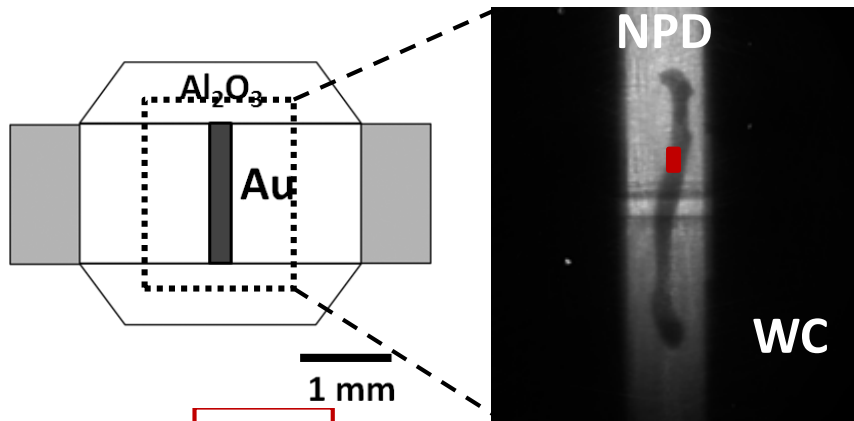
NPD vs SD anvils



Kunimoto, Irifune et al., C. R. Geosci. (2018)

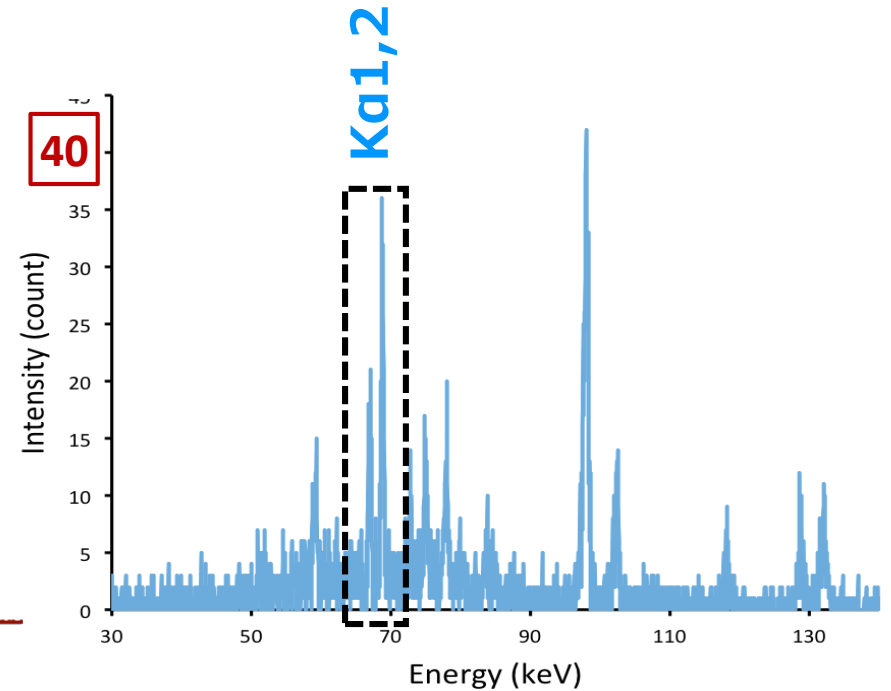
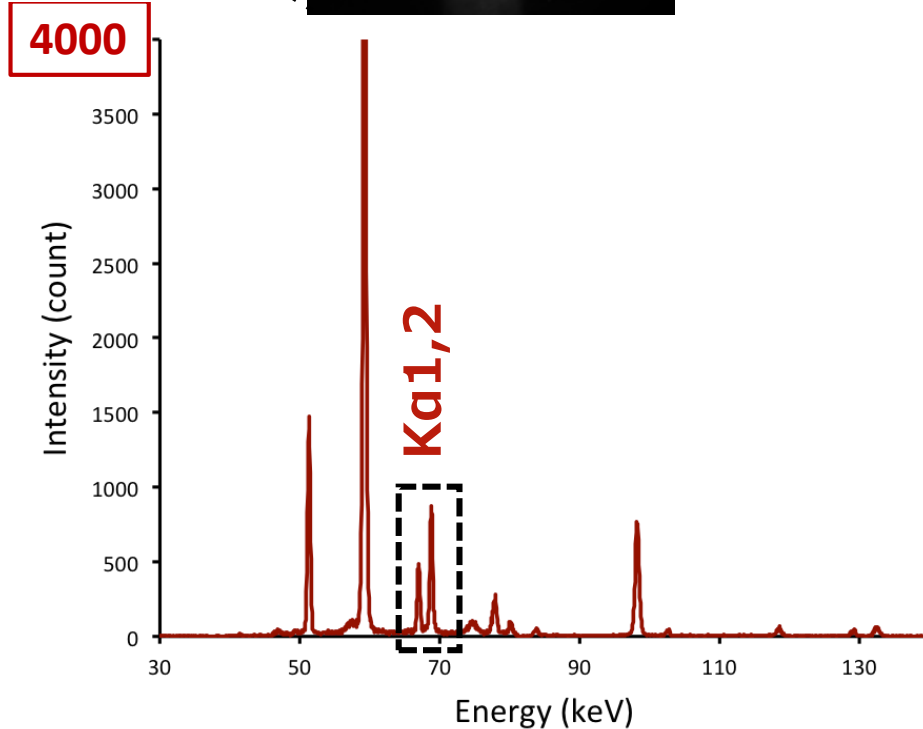
XRD profiles through NPD and SD anvils

NPD anvil



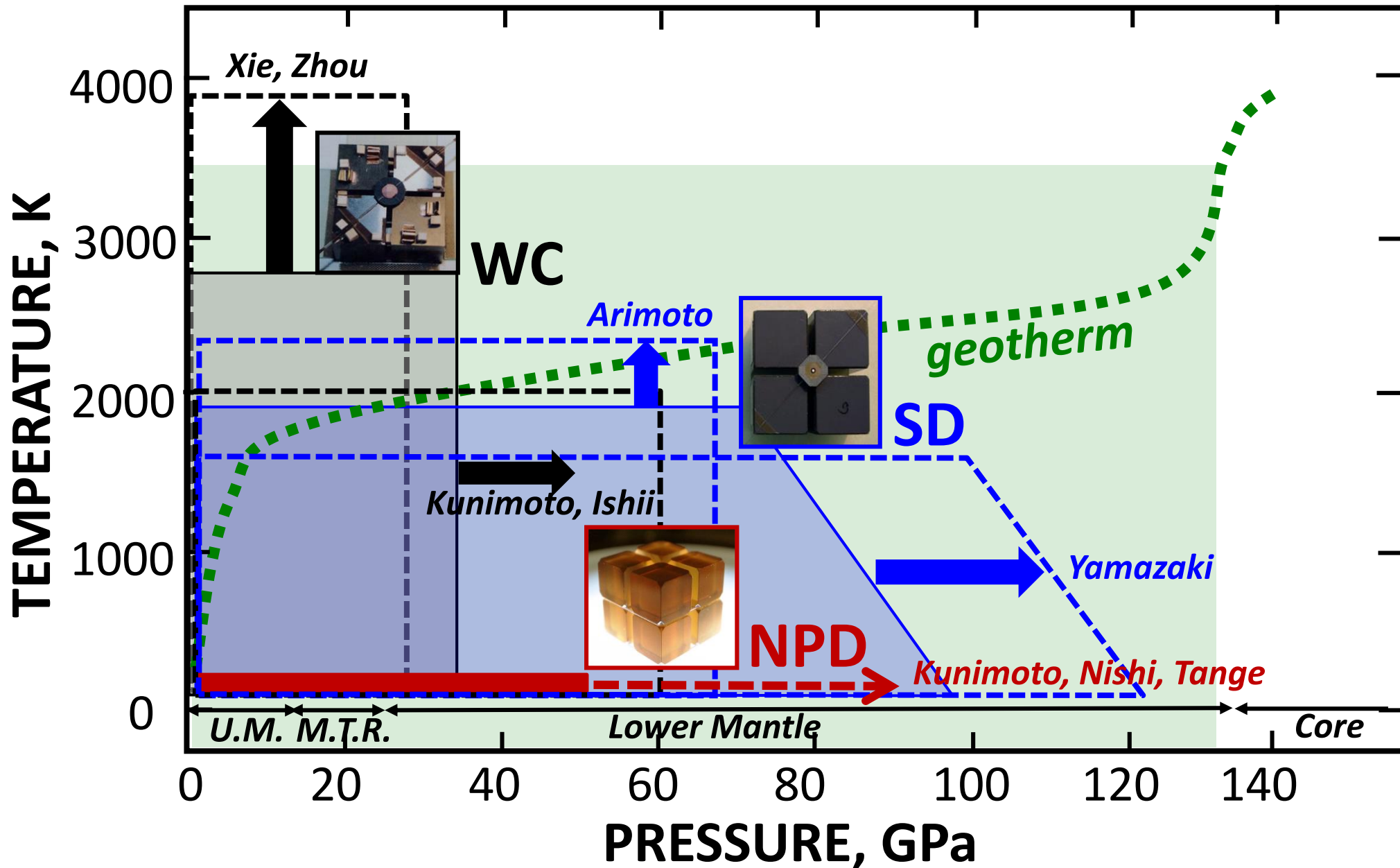
sample: Au
slit : h0.05 mm × v0.1 mm
acquisition time: 180 sec.

SD anvil



Kunimoto, Irifune et al., C. R. Geosci. (2018)

HPT generation in KMA



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1st International Symposium on NPD, Matsuyama, March 2019

special volume of HPR (deadline, Oct. 2019)

Thank you!

We are looking for 2 post-docs at GRC

- co-sponsored by ELSI, Tokyo Inst. Tech.**
- from later this year for ~2.5 years**
- geo-science oriented HP scientists**
- foreign and/or female scientists**
- You can use NPD as many as you want!**

