Abnormal grain growth induced by a fusion relevant magnetic field at high temperature

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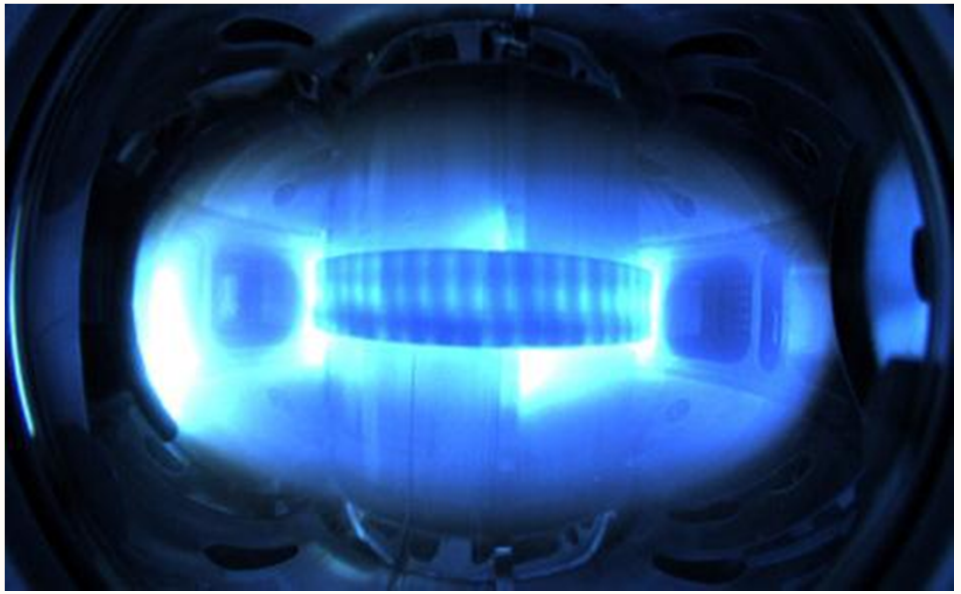
Magnetic confinement – fusion

Materials challenges

- Radiation damage
- Sputtering
- blistering
- Low induced radioactivity
- High thermal heat fluxes



Magnetic confinement

High temperature

High magnetic field

Facing Plasma Materials: Tungsten

Ductile to brittle transition
Melt

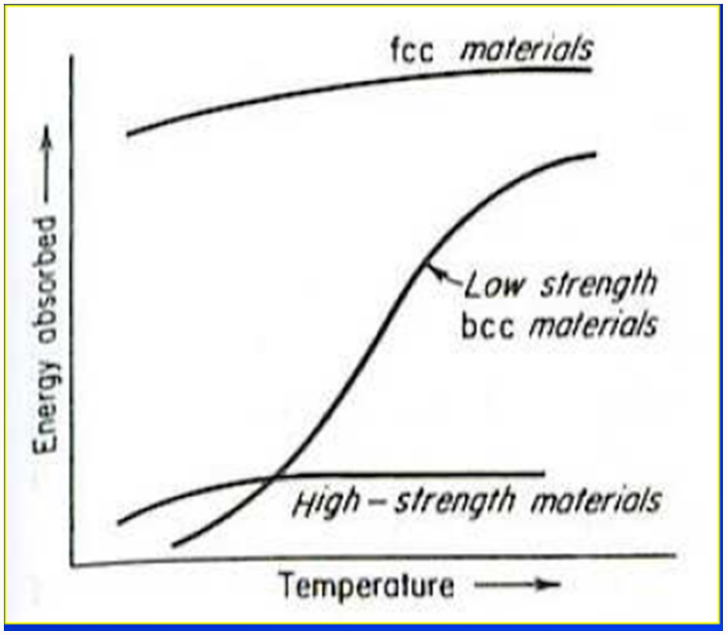
H.Bolt et al. / Journal of Nuclear Materials 307–311 (2002) 43–52

Effect of crystal structure and grain size on DBTT

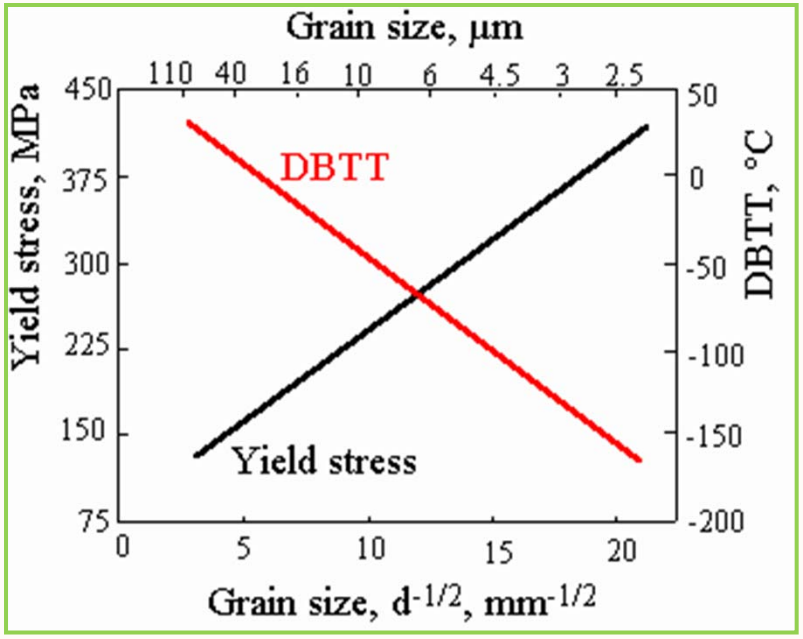
Pure tungsten(BCC)

- *BCC structure metal experience ductile to brittle transition temperature(DBTT)*

  Slip system numbers increase from low to high temperature



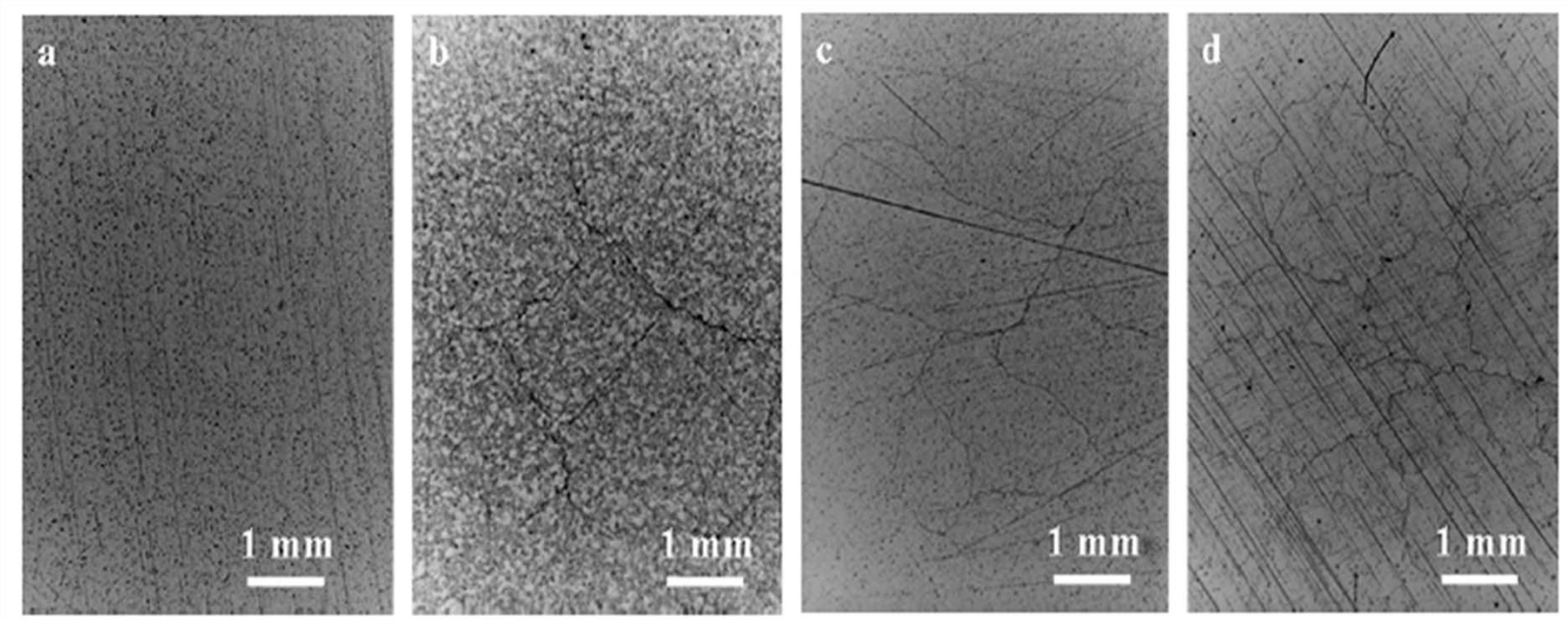
Crystal structure



Grain size

- *Reducing grain size increases toughness, decreases DBTT*
- *Effect of specimen orientation*

Effect of recrystallization on DBTT



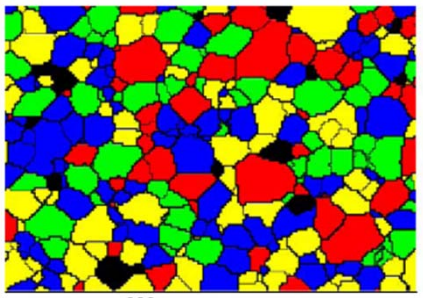
Surface morphology observed by optical microscope after single pulse of 0.33 GW/m2 for 5 ms on (a) sintered W as-received; (b) sintered W recrystallized; (c) deformed W as-received and (d) deformed W recrystallized.

Recrystallization caused clearly degradation of thermal shock resistance

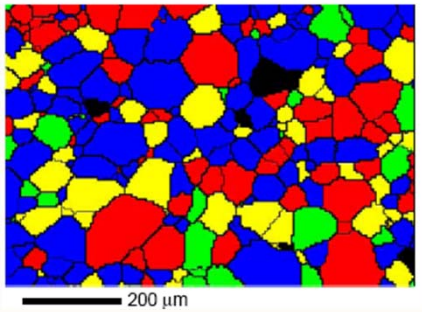
Increasing grain size primary cracks and second cracks?

I. Uytdenhouwen et al. / Journal of Nuclear Materials 363–365 (2007) 1099–1103

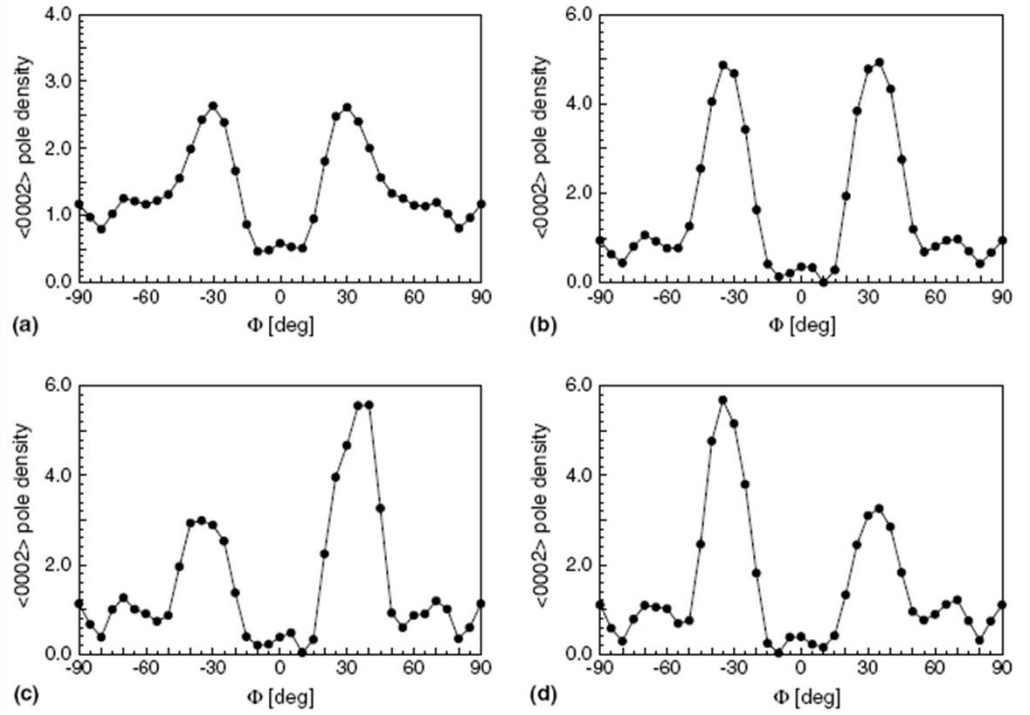
Effect of high magnetic field on recrystallization



Without a magnetic field



With a magnetic field

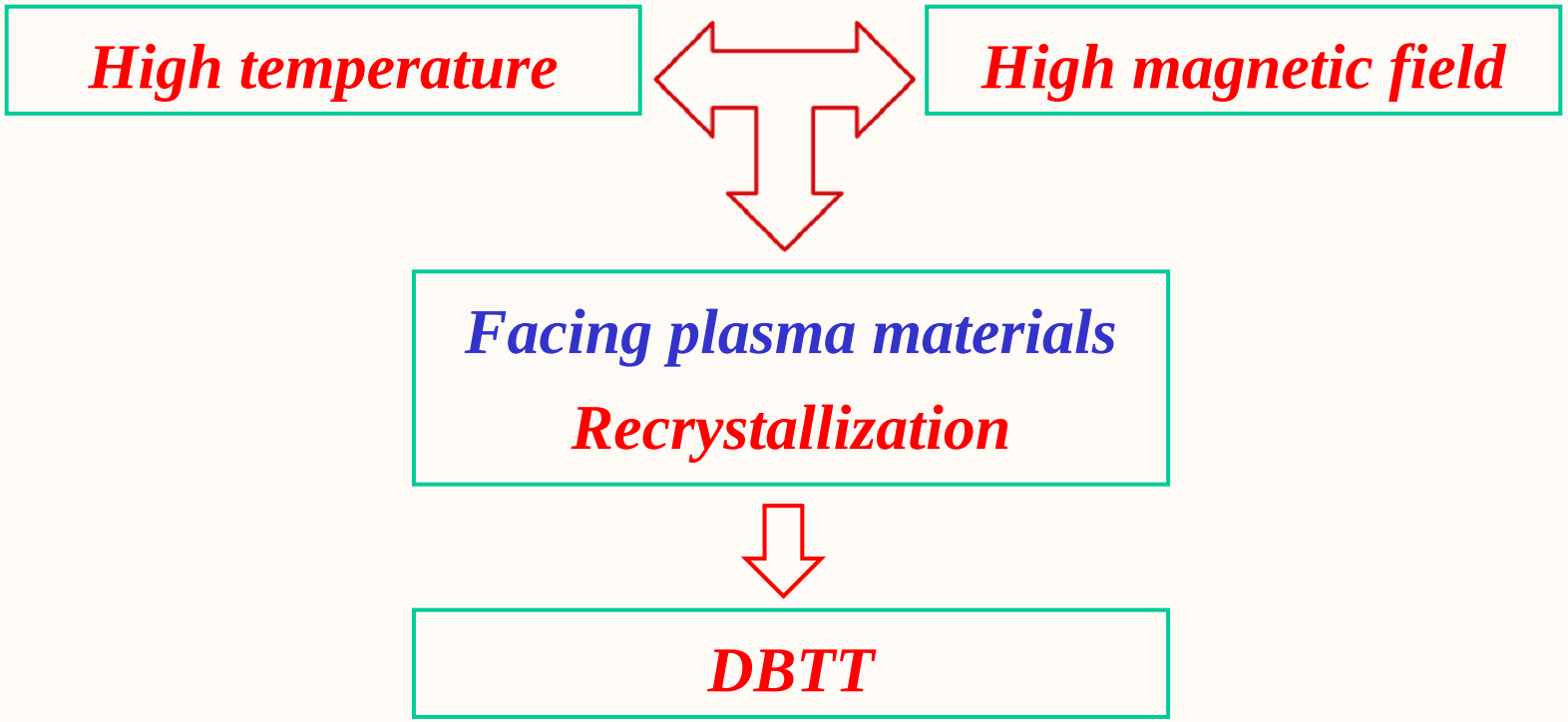


<0002> pole density along TD: (a) for 82%-rolled paramagnetic a-Ti sheet samples; (b) after annealing at 750 °C, after annealing in the field at 750 °C with TD; (c) tilted at 30°; (d) tilted at 30°

- *Grain size increases with a high magnetic field*
- *This effect is due to an additional driving force for grain growth arising in the magnetic field by the anisotropy of the magnetic susceptibility of Ti.*

D.A. Molodov, A.D. Sheikh-Ali / Acta Materialia 52 (2004) 4377–4383

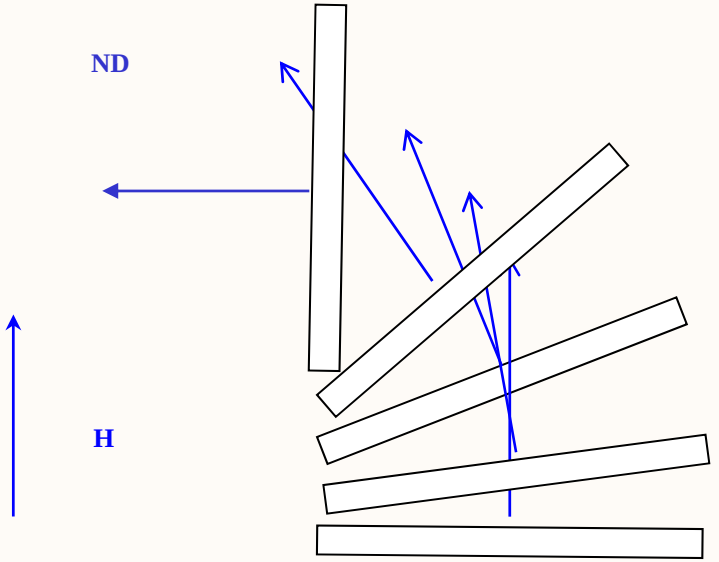
Motivation


High temperature
High magnetic field
Facing plasma materials
Recrystallization
DBTT

Experiments

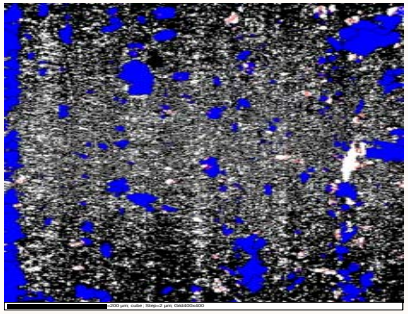
- *Strength of high magnetic field (10T) diameter(150mm)*
- *Vacuum furnace 1000°C*
- *Experimental materials pure Nickel*

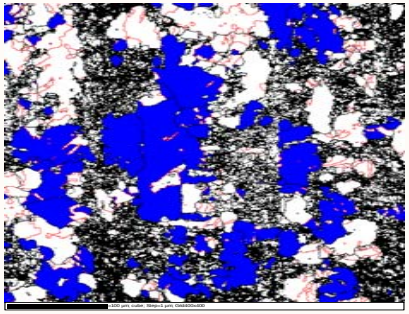
Simulator for PFM under high magnetic and temperature field (SIMATE)



Sample direction along high magnetic field direction

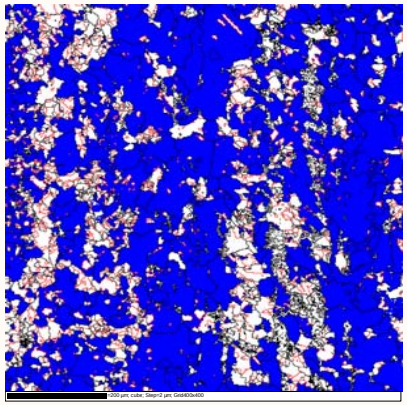
Recrystallization in high magnetic field

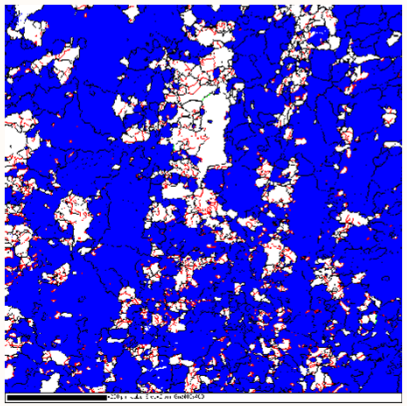




5 minutes

17 ^{o} 31 ^{o}





120 minutes

17 ^{o} 31 ^{o}

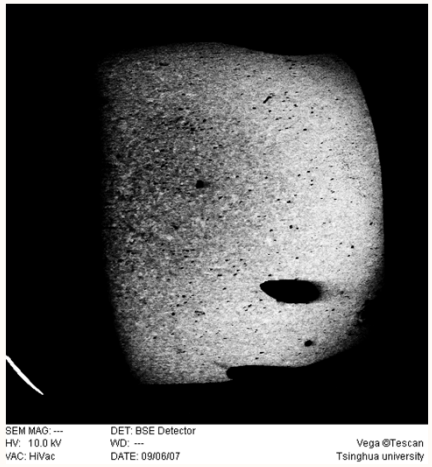
OIM picture of sample with different angles between sample and magnetic field direction after annealing at 300 ^{o}C

Blue : cube ; white : others orientation ; black : deformation ; red : twin grain

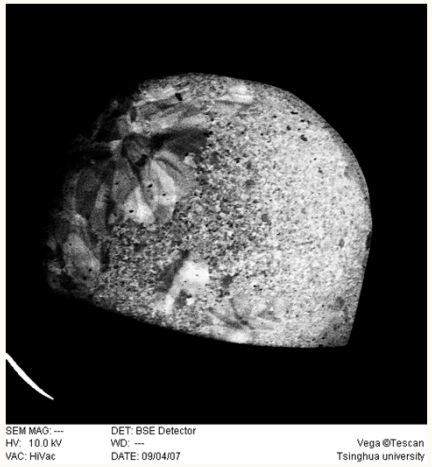
<111> direction (17 ^{o}) is aligned parallel to the magnetic field direction

Smaller grain size!

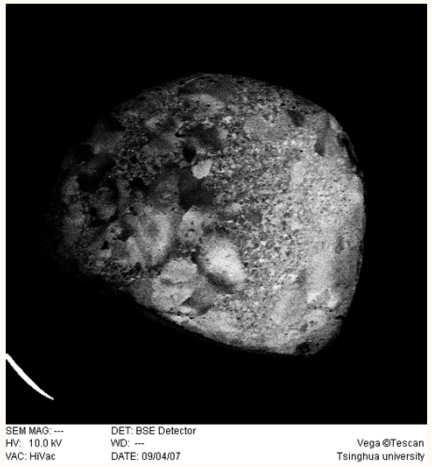
Abnormal grain growth in high magnetic field(600 °C)



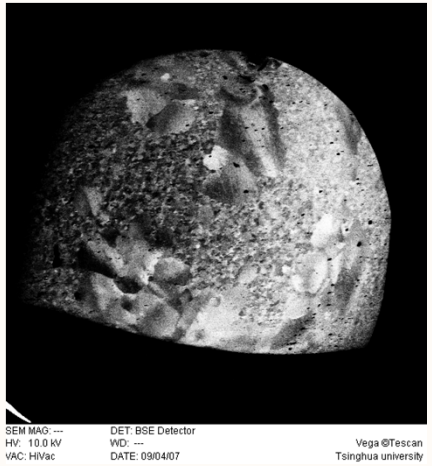
0T



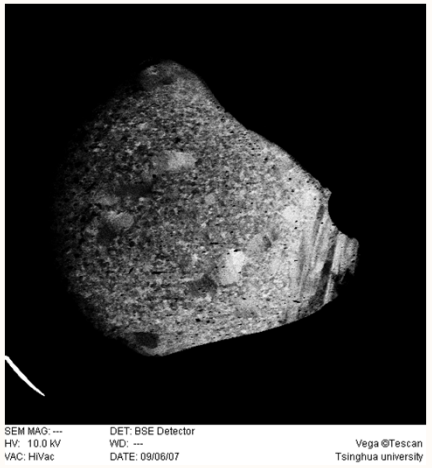
0 degree



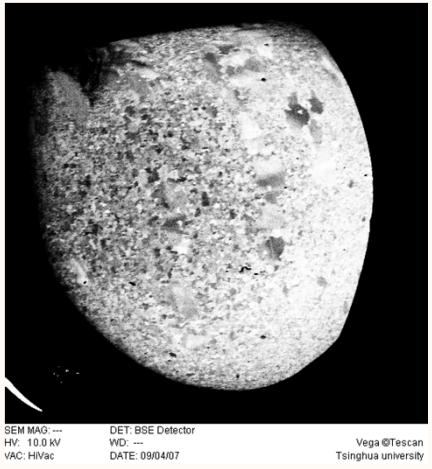
17 degree



24 degree

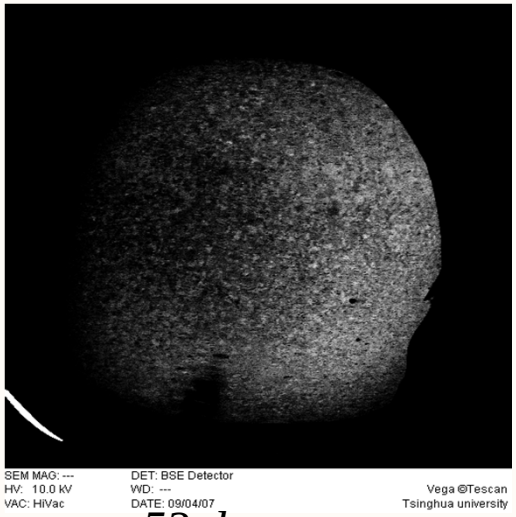


31 degree

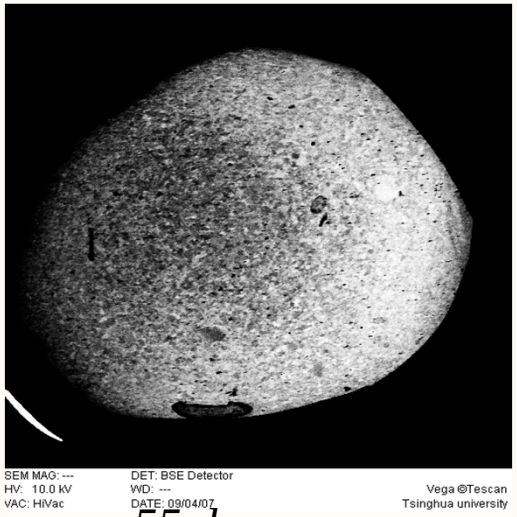


45 degree

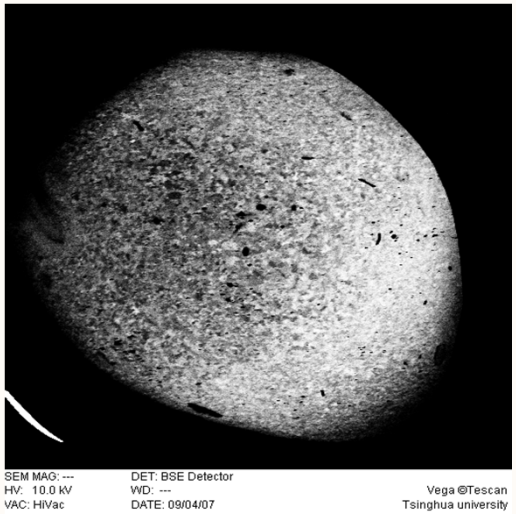
Normal grain growth in high magnetic field(600 °C)



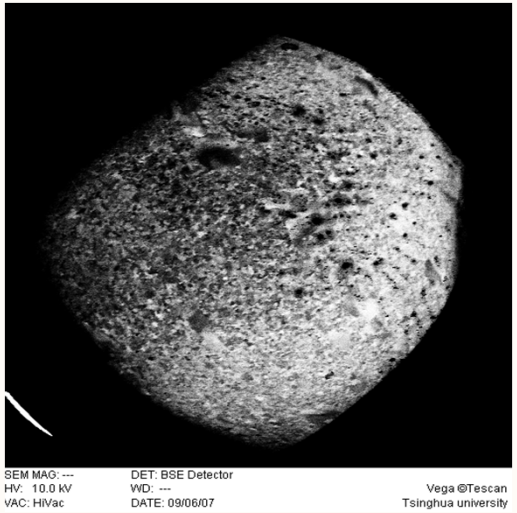
53 degree



55 degree

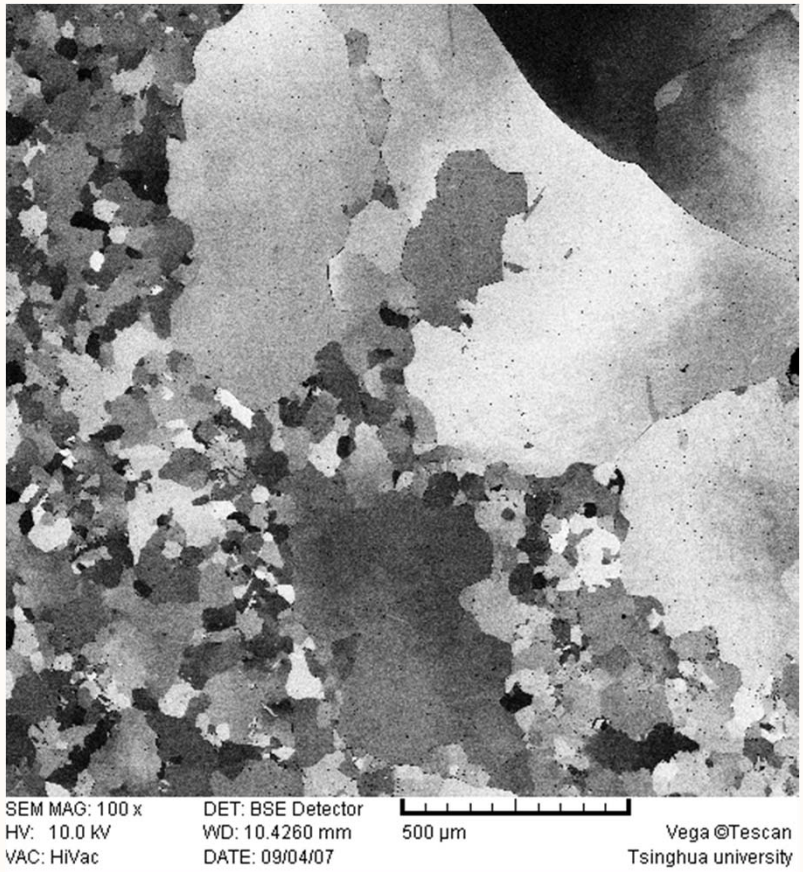


58 degree

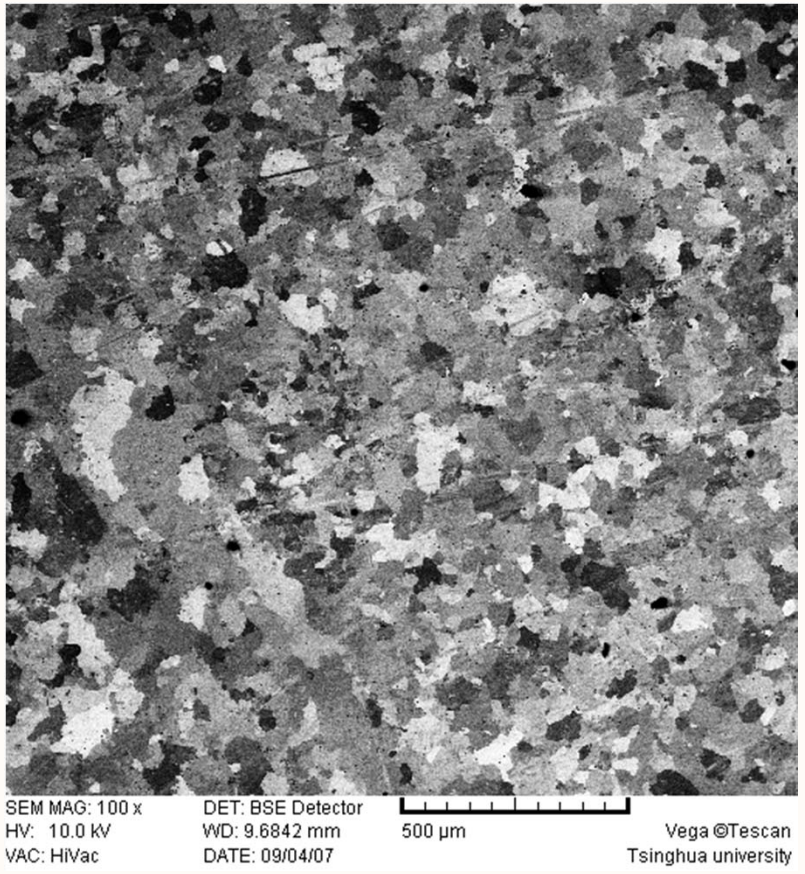


90 degree

Normal grain growth without high magnetic field(600 °C)



With high magnetic field(45 degree)

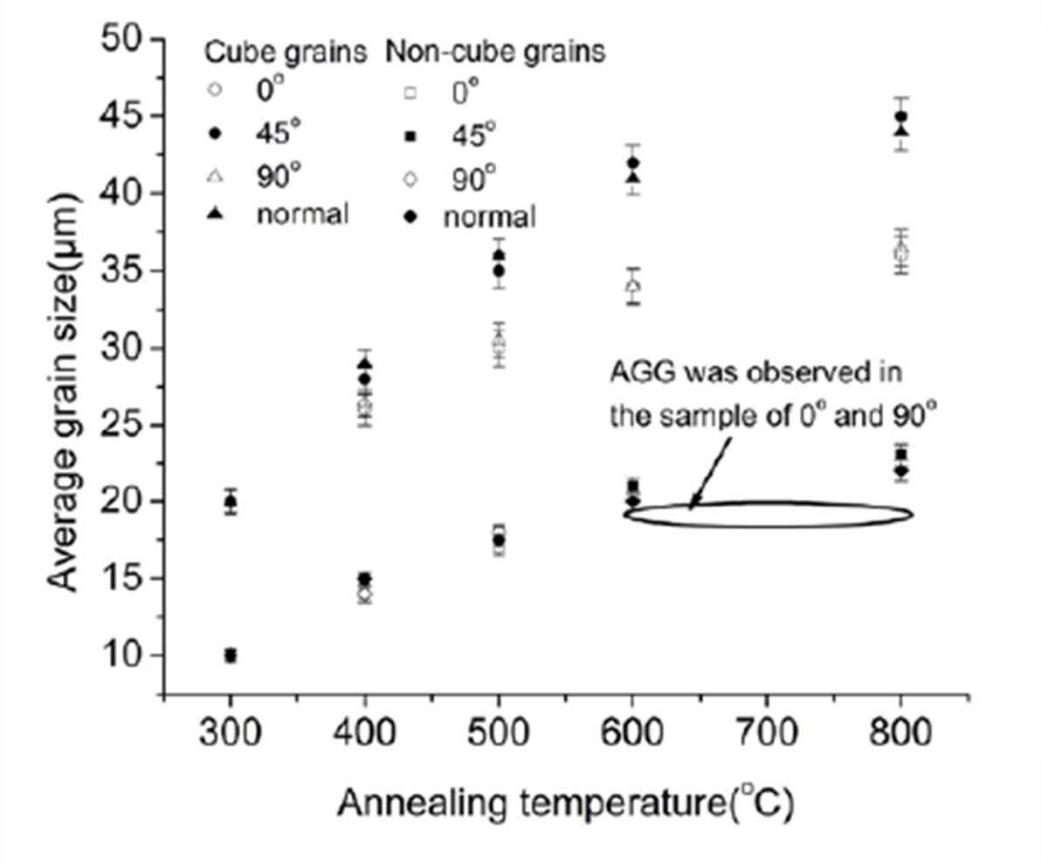


Without high magnetic field

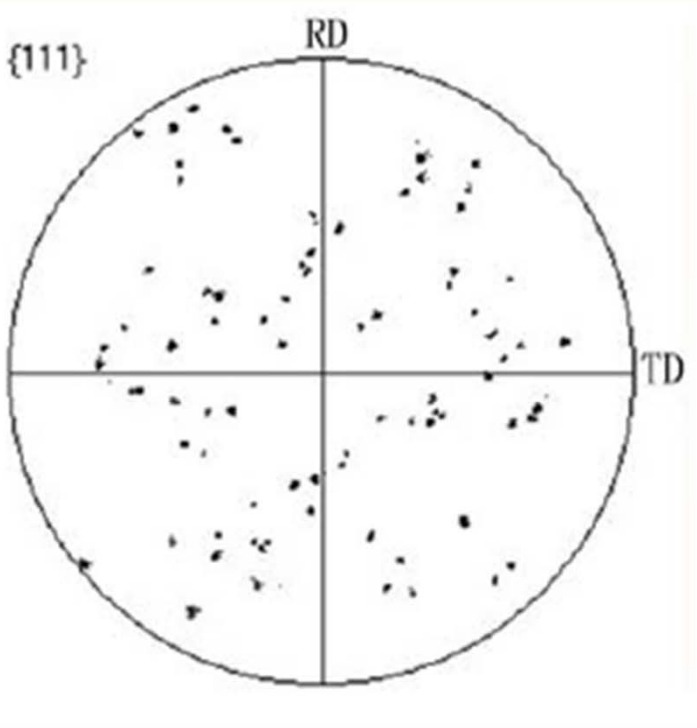
Up to now, abnormal grain growth without high magnetic field for Nickel

Impossible happen!

Annealing at different temperatures in high magnetic field



Grain sizes in different temperatures

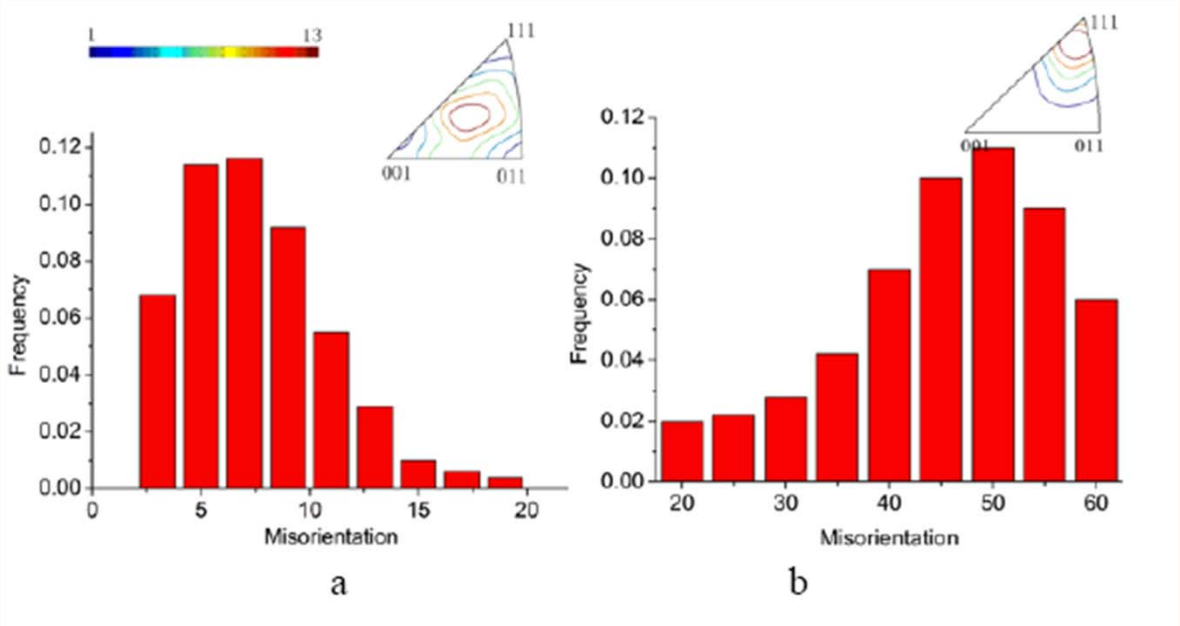


Orientation of abnormal growth grain

(random distribution)

- ***Abnormal grain growth is observed above 600 °C***
- ***Orientation of abnormal growth grain is random distribution***

Misorientation of grain boundary



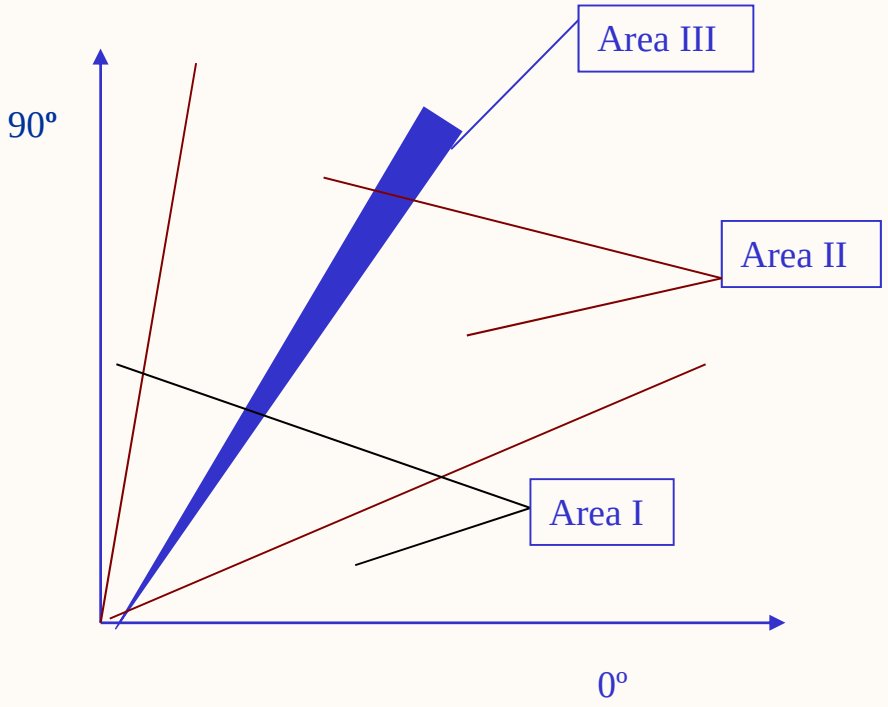
Misorientation of grain boundary in high magnetic field

(a) cube-cube grain; (b) cube-non cube grain; (c) cube-abnormal growth grain

- ***Misorientation of cube –cube grain*** ***Low angle boundary***
- ***Misorientation of cube –noe cube grain*** ***High angle boundary***
- ***Misorientation of cube –abnormal growth grain*** ***High angle boundary***

Increase DBTT Harmful!

Recrystallization in different angles



- *Area I: start to recrystallize*
- *Area II: partly recrystallized*
- *Area III: fully recrystallized*

Conclusions

- *Comparing with conventional heat treatment, high magnetic field heat treatment increases cube orientation grain and reduces grain size.*
- *Effect of high magnetic field depends on the angle between sample and magnetic field direction.*
- *Annealing at high temperature under high magnetic field, abnormal grain growth of non cube grain is induced at small angles between sample and magnetic field direction.*
- *Anormal growth grain increases DBTT, which is harmful to the facing plasma materials.*

Thank you for your attention!