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Thermal Diffusivity of Electron Irradiated Tungsten Small Disk

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Thermal diffusivity in Tungsten materials

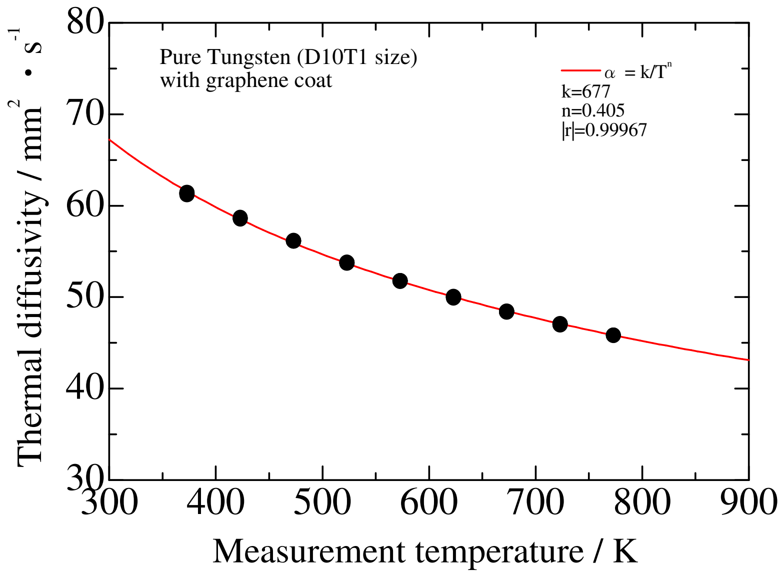
Thermal diffusivity in Metal / Ceramics

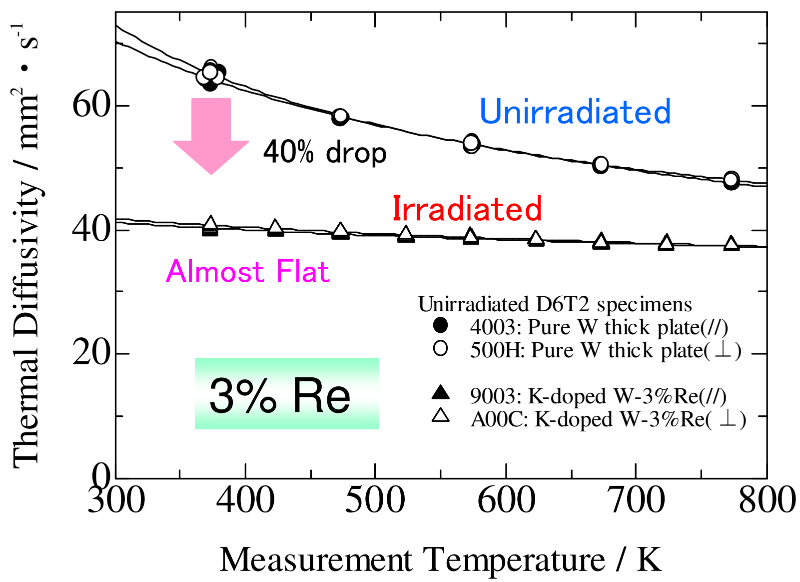
In Tungsten, heat is mainly carried by electron like typical metals, but about 1/3 of heat is carried by phonon like ceramics (at room temperature).

In ceramics, high temperature increase phonon-phonon scattering and thermal diffusivity α is described as $\alpha = a/T^n$, where unirradiated specimens show n = 1 and irradiated them show n < 1.

Unirradiated pure tungsten showed n~0.4 with the same function.

Furthermore, fusion neutron induces transmutation element such as Rhenium or Osmium that reduce thermal diffusivity drastically.





RB-19J Irradiation in PHENIX Project

In light water fission reactor, most neutrons are moderated to thermal neutrons that gives larger amount of transmutations than the fusion reactor at the same irradiation induced damage.

W → Re, Os

Thermal diffusivity change;

In the PHENIX project, irradiation in HFIR have been performed with the **Gadolinium** thermal neutron shield.

Compare with rapid irradiation without Gd shield is important.

Location: RB-19J

Dose: 0.2~0.7 dpa, 4 cycles

4.7×10^{18} n/m^2·s (E > 0.1 MeV) and
9.5×10^{18} n/m^2·s (E < 0.5 eV)

→ Shielded to about 1/100

Temperature regions

550℃, 850℃, 1050℃

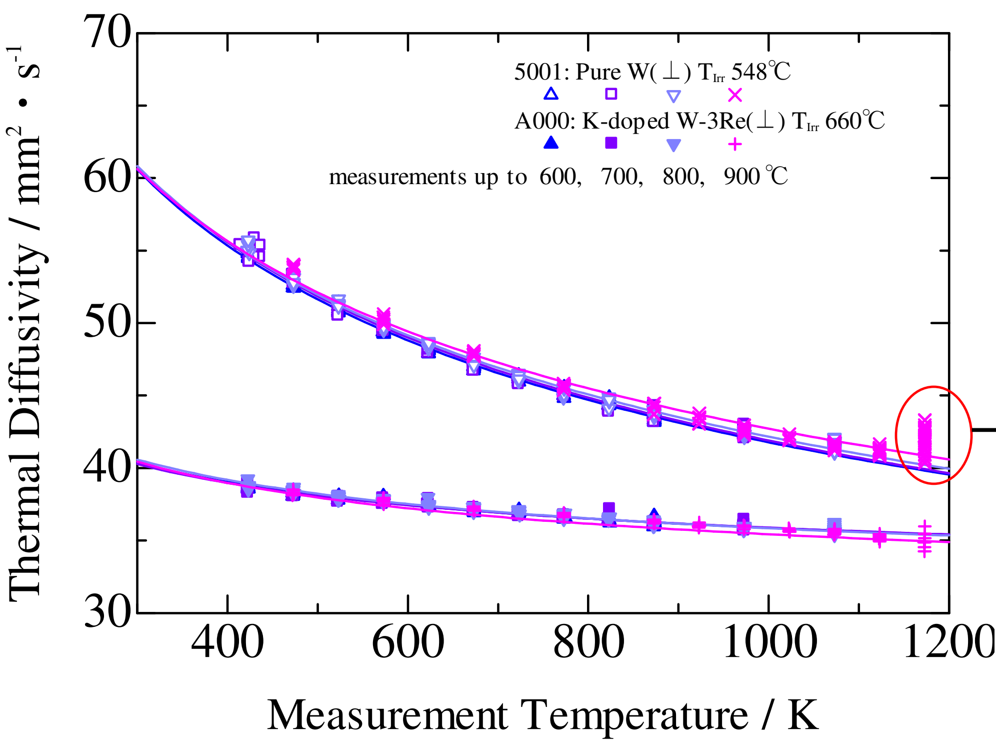
Separate effect of lattice defects from transmutations.

Electron conduction

Phonon conduction

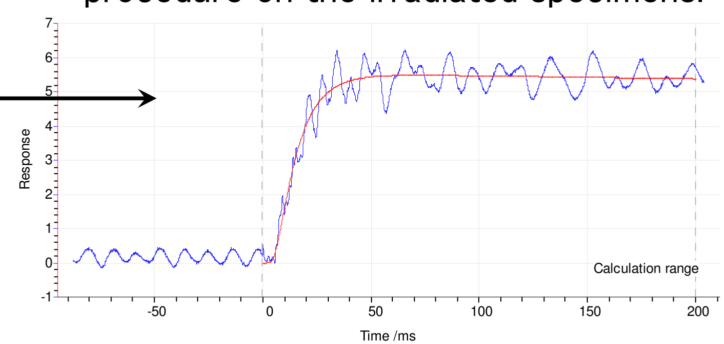
The Oscillation problem at high temperature measurement with LFA-467

In order to evaluate the recovery behavior by annealing at high temperature, we attempted to evaluate isothermal annealing effect as well as isochronal annealing by repeating the measurement every minute for one hour at the target temperature, then lowering the temperature and evaluating the temperature dependence again.

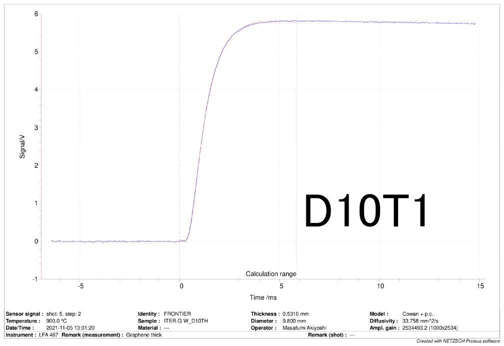


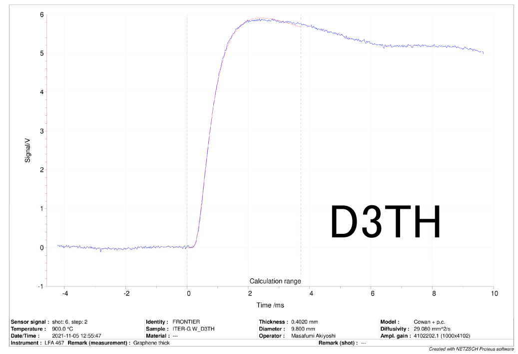
- The annealing at 800℃ showed no recovery on the specimens irradiated at 548℃ or 660℃.
- The measurement at 900℃ showed cyclic noise on the IR signals, that is said the Oscillation problem.

Therefore, we stop the annealing procedure on the irradiated specimens.



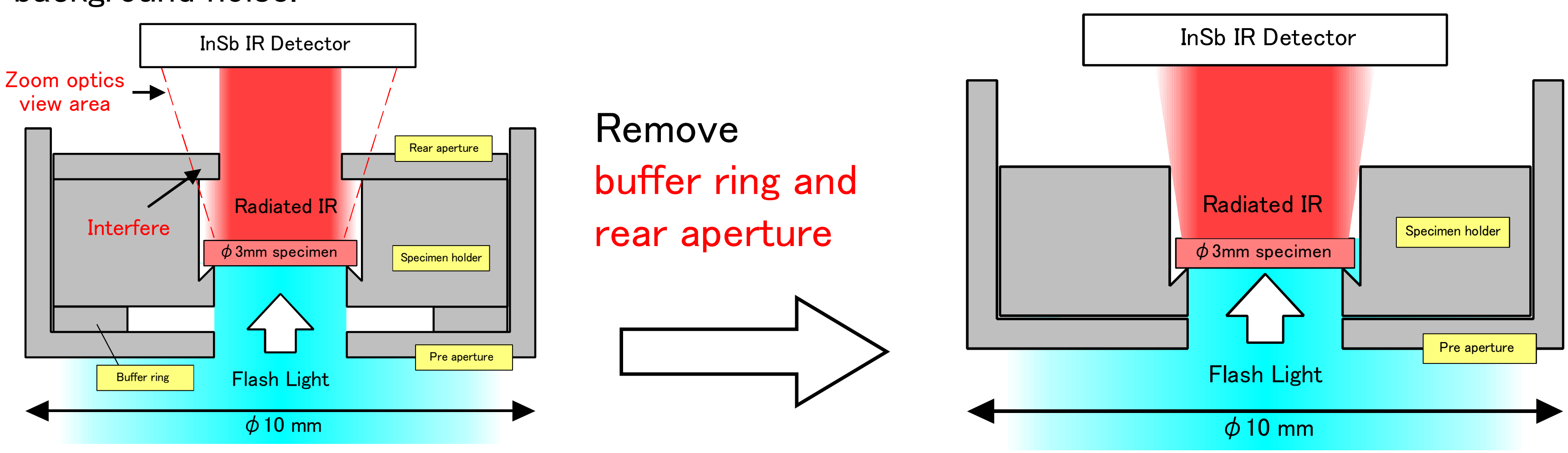
D3TH Miniature Specimen Holder





The Netzsch LFA-467/467HT is equipped with a zoom optics system, an optical system for a sensor that measures infrared radiation emitted from the back side of the specimen, allowing measurement of small specimens.

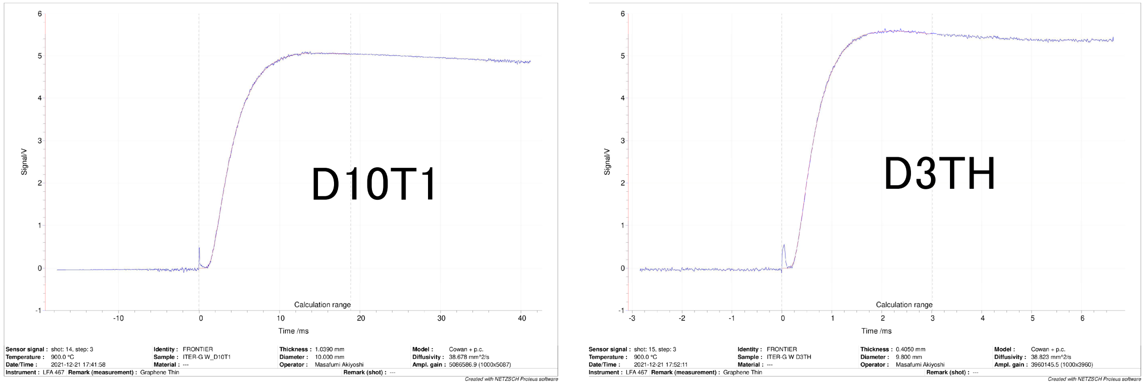
In the measurement of D10T1 and D3TH Pure W samples at 900℃, oscillations occurred only in the D3TH sample, even though the measurement range by zoom optics was the same ϕ2.8 mm. This is thought to be because the sample holder used to measure the D3TH sample interfered with the zoom optics optical system, limiting the amount of infrared light entering the sensor, resulting in a lower signal-to-noise ratio that caused the oscillations to become apparent due to background noise.

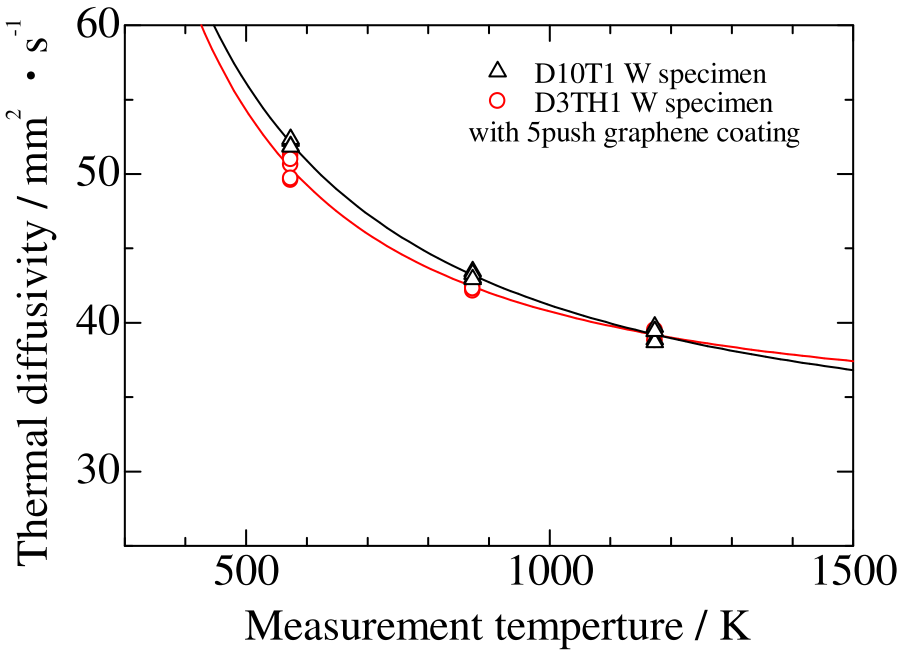


FIX the oscillation problem

Pure W polished samples were sparsely (5 push) graphene-sprayed and measured under rare gas purification and ultra-high purity Ar gas flow (200 ml/min) conditions.

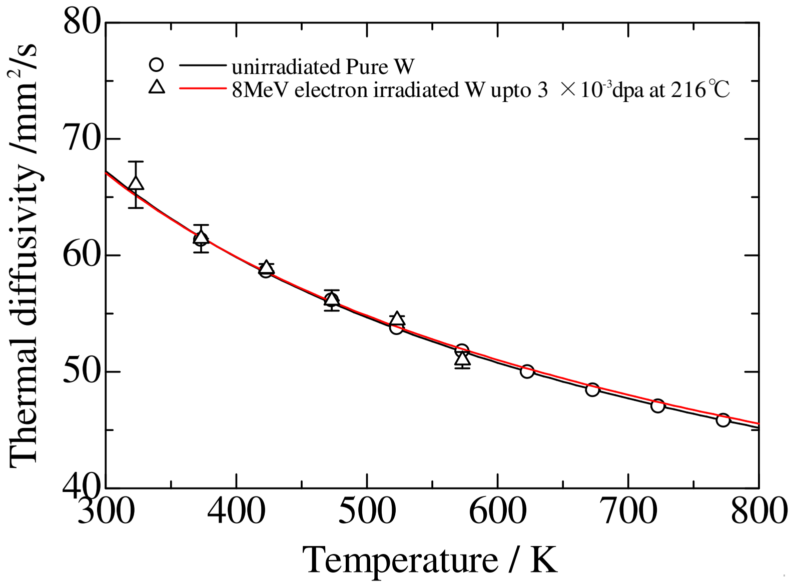
IR signals at 900℃ by LFA-467





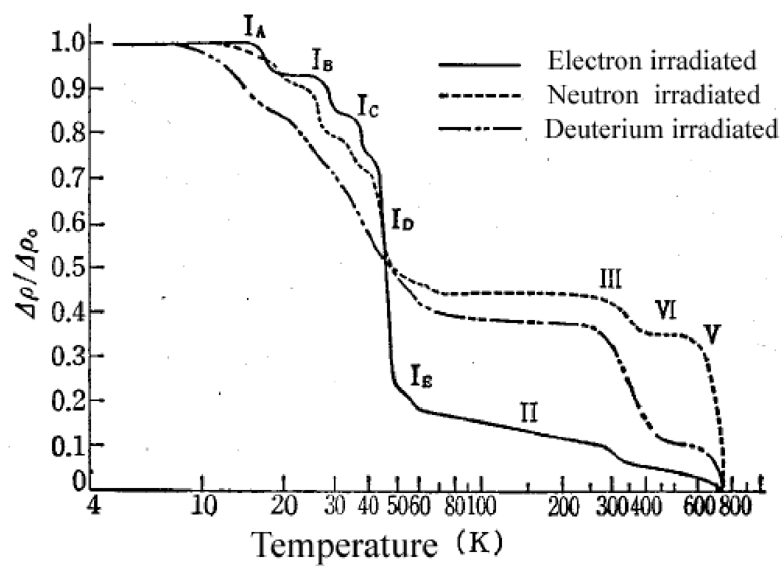
The D3TH sample did not show the oscillation up to 900℃, and showed thermal diffusivity measurements comparable to those of the D10T1 sample.

Thermal diffusivity of electron irradiated pure W



To clarify the lattice defect contribution, pure W specimens were irradiated by 8 MeV electron beams using KURRI-LINAC at 216℃ to 3.8×10^{23} electrons/m^2 that corresponding to 2.8×10^{-3} dpa. At these condition, ceramics material such as β-SiC showed obvious change in thermal diffusivity, but these specimens did not show decrease.

This result suggests that recovery after stage III in W is quite limited because no I-loops are induced in this specimen and most point defects have recovered below 300 K [1979Ishino]. In the case of pure Cu, stage III in electron irradiated specimen above 300 K is quite limited compared with neutron irradiated or deuterium irradiated specimens.



Recovery of electric resistivity in pure Cu irradiated by different source (detail is not given) [1979Ishino].

Estimation of thermal conductivity

From the experimental and calculation results in this study, the phonon contribution in thermal diffusivity is about $15 mm^2/s$ at room temperature for pure W and also W-5%Re.

The thermal diffusivity α is obtained by $\alpha = vl / 3$ (v: phonon velocity, l: phonon mean free path) and v = sqrt(E / ρ) (E: Young's modulus, ρ: density), so using E = 400 GPa and ρ = 19.25 g/cm^3, $v = 4.56 \times 10^3$ m/s and l is obtained as 9.87 nm (at higher temperature, this phonon mean free path is shorter).

It represent that large crystalline defect such as I-loops or grain boundary gives quite small contribution to thermal diffusivity in phonon conduction. There is no electric resistivity measurement at high temperature for neutron irradiated specimen, but annealing measurement in this study indicates that the effect of crystalline defect to electric resistivity seems to be limited too.

Then, only Re (and also Os) distribution (NOT only amount) is important to estimate thermal diffusivity in irradiated W and W-Re alloy.