Incident Thermal Radiation through Duct Shield and Cooling Time of Mirror

Yusuke SAKAKIBARA (ICRR)

2011.8.4 LCGT f2f meeting

Incident Thermal Radiation through Duct Shield

Purpose of duct shield

- Thermal radiation from opening of 900 mm in diameter

$$P_0 = \epsilon\sigma T^4 A = 29.2\ \mathrm{W}$$

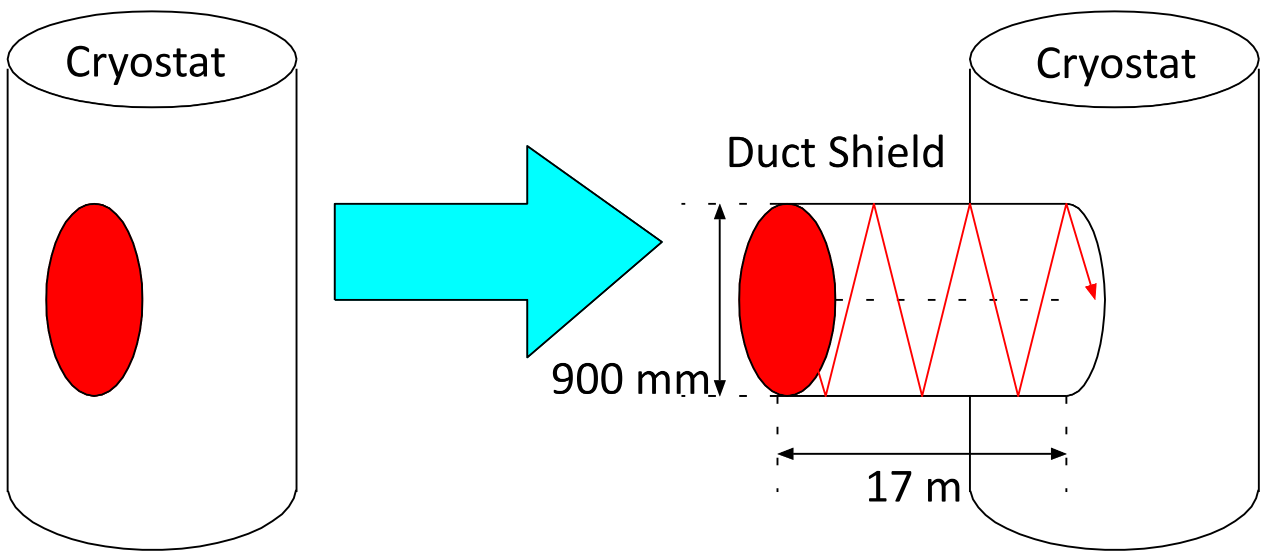
$\epsilon = 0.1$: Emissivity of duct (SUS)

σ: Stefan-Boltzmann constant

$T = 300\ \mathrm{K}$

A: Area of opening

- Cooling power 3.6 W at 4 K (4 pulse tube cryocoolers of 0.9 W at 4 K)
- Thermal radiation can be decreased if solid angle reduces
- Thermal radiation reflected by metal shield pipe
  - Problem experienced in CLIO $P/P_0 = 0.213 \quad P = 6.22\ \mathrm{W}$



Reducing thermal radiation by baffles

- Incident thermal radiation calculated using ray trace model by counting up number of reflections

$$\frac{P}{P_0} = \int R^{N(\theta)} \frac{d\Omega}{2\pi} = \int_0^{\pi/2} R^{N(\theta)} \sin\theta d\theta$$

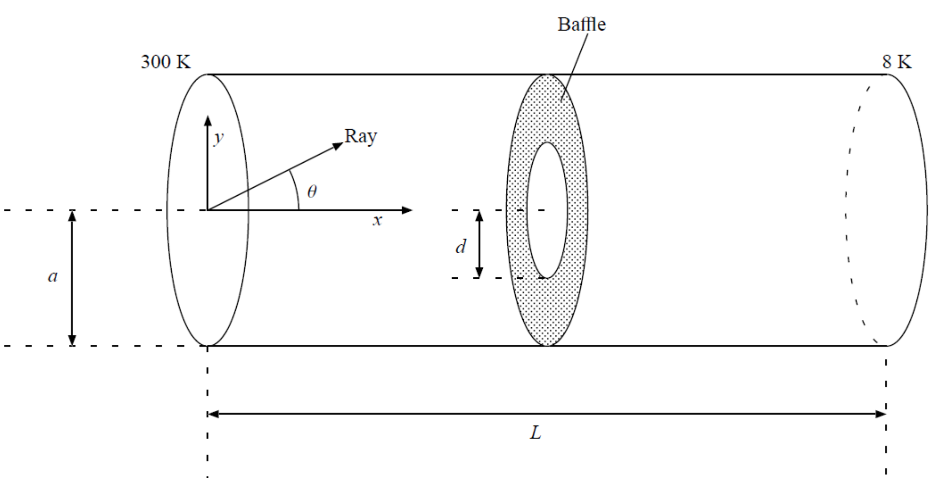
$P_0 = \epsilon\sigma T^4 A = 23.1$ W

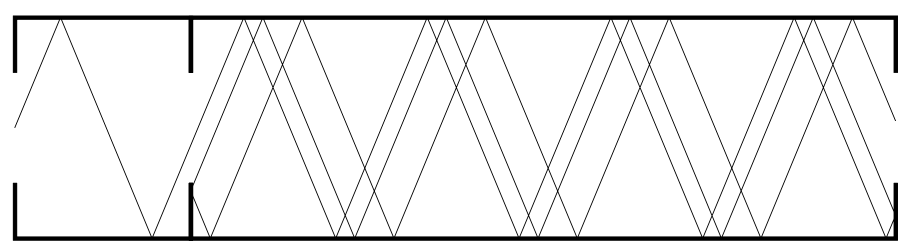
$A = \pi d^2$: Area of baffle opening

$N(\theta)$: Number of reflections

$R = 0.94 \pm 0.02$: Reflectivity of duct and baffles

(Aluminum of A1070 measured at 10 um, 80 K)



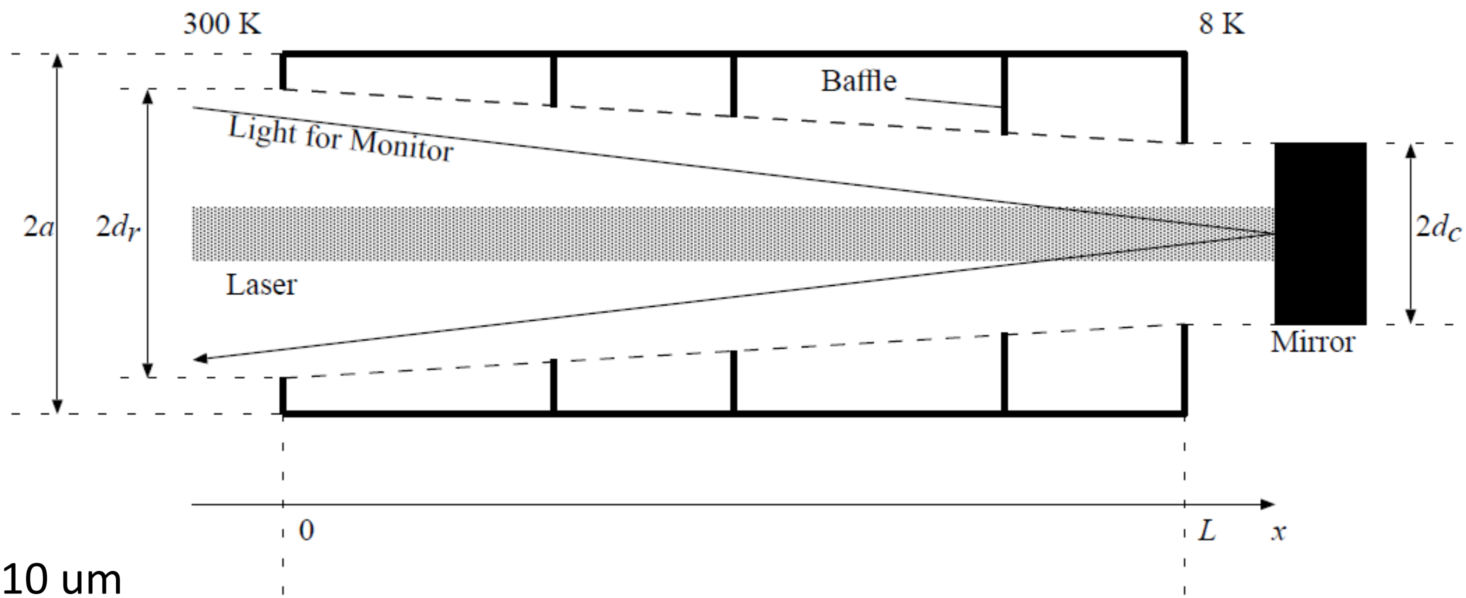


Calculation of incident thermal radiation

- Apertures of baffles change linearly

$L = 17$ m

$2a = 900$ mm, $2d_r = 800$ mm, $2d_c = 250$ mm



R=0.94 at 10 um

Position of baffles x/L	P[W]
No baffle	6.22
$0, \frac{8}{16}, \frac{9}{16}, \frac{10}{16}, \frac{14}{16}, 1$	0.0992

R=0.94±0.02

Worse case

R=0.96 P=0.172 W

Better case

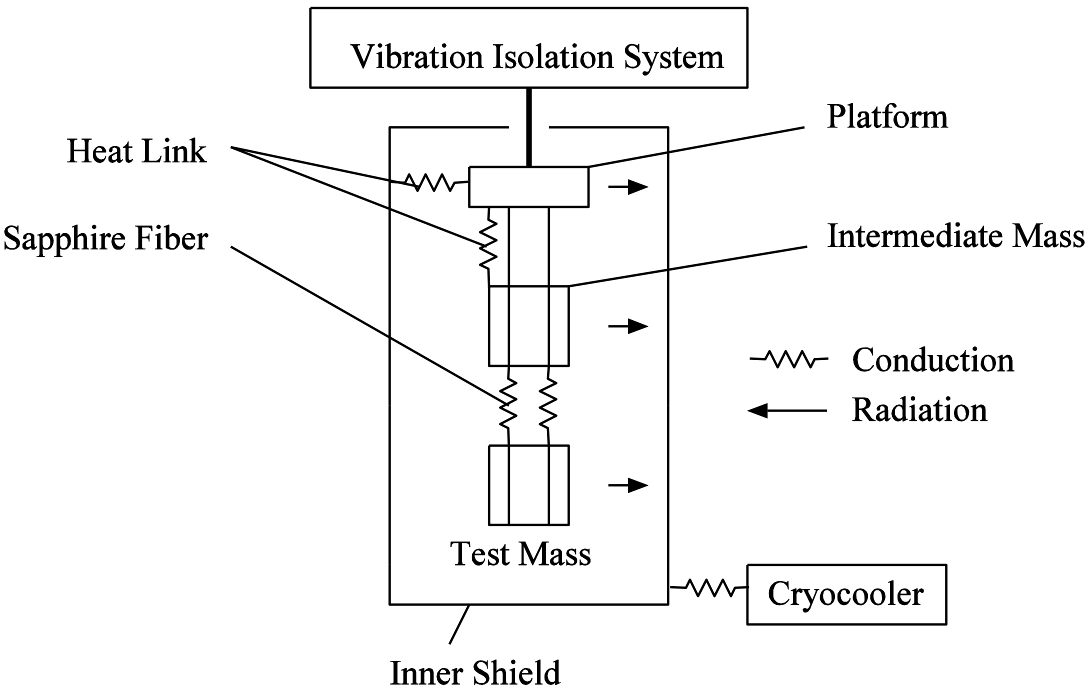
R=0.92 P=0.0615 W

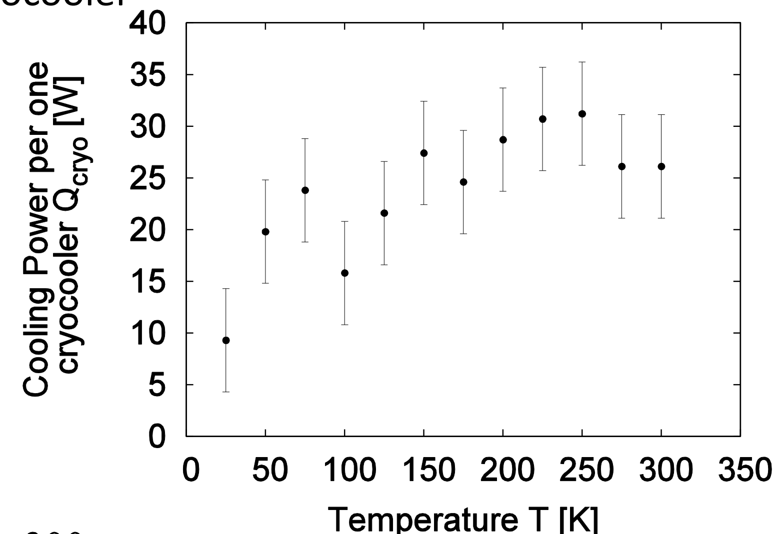
Thermal radiation can be sufficiently reduced by baffles

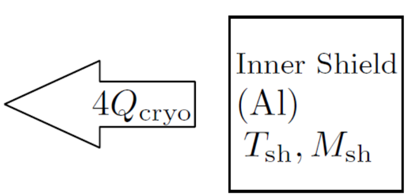
Cooling Time of Mirror

Cooling of inner shield

- Model is constructed to estimate initial cooling time
- Heat is transferred by conduction in sapphire fibers and heat links and radiation
- Inner shield of 410 kg is connected to the 2nd stages of 4 cryocoolers
  - Cooling power is derived from test result of LCGT cryocooler

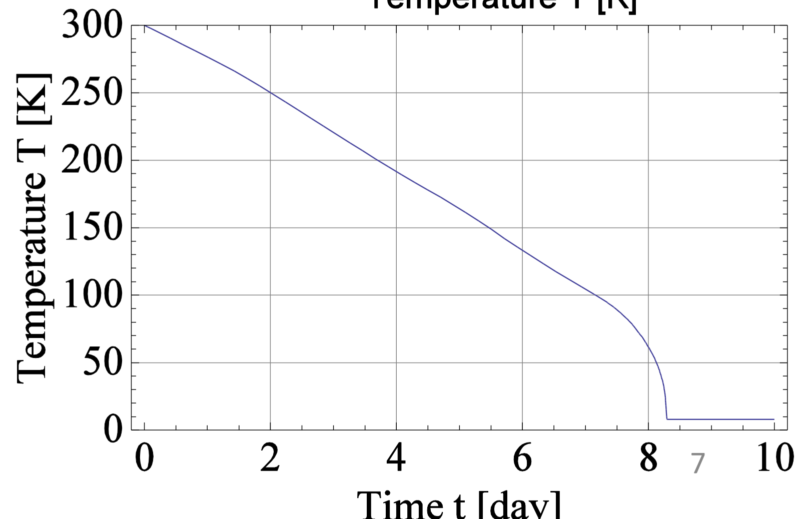




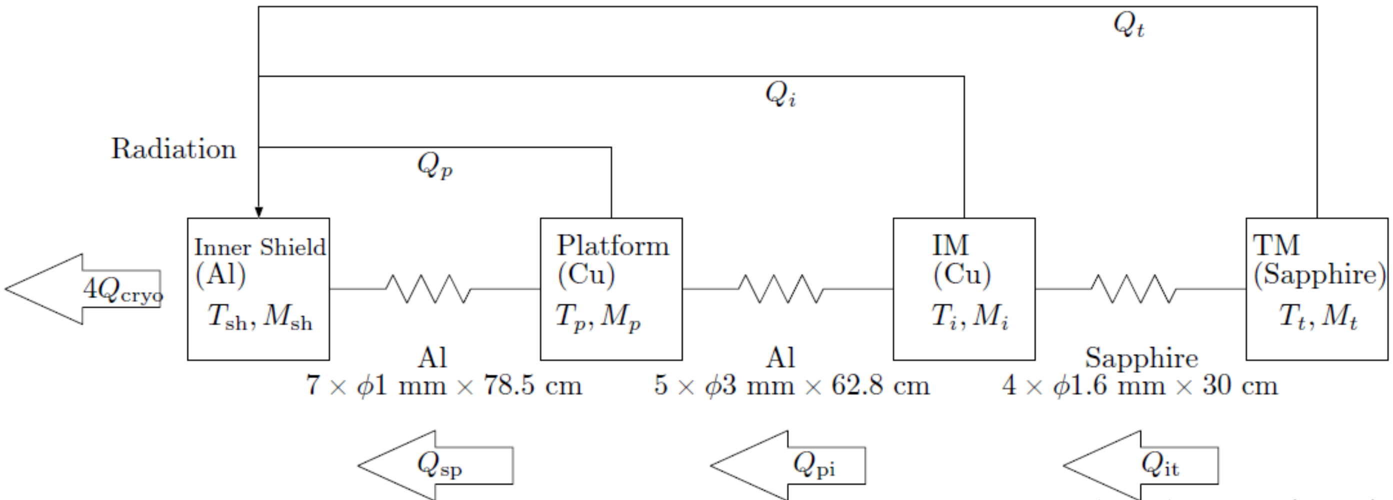


$$\frac{dT_{sh}}{dt} = -\frac{4Q_{cryo}(T_{sh})}{M_{sh}C_{Al}(T_{sh})}$$

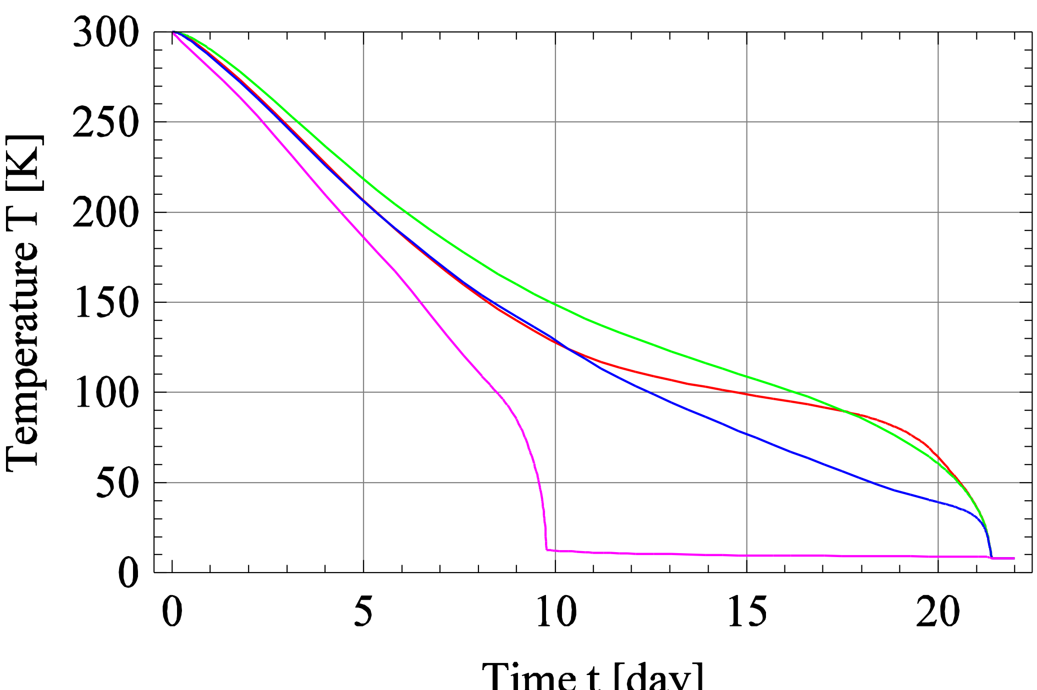
Suspension system is excluded in this case

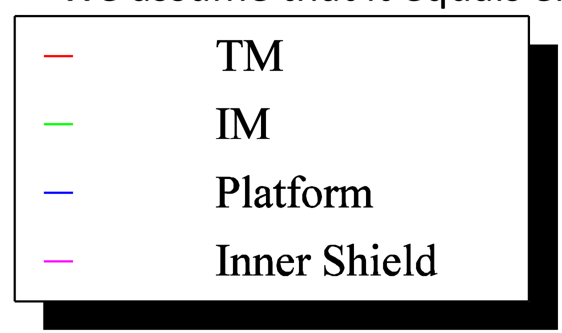


Increased radiation by DLC coating



- Increased radiation by platform, intermediate mass, and inside of inner shield coated with DLC (Diamond Like Carbon)
- Absorptivity of DLC at 10 um is 0.41 (cf. emissivity of Cu and Al is 0.03)
  - We assume that it equals emissivity





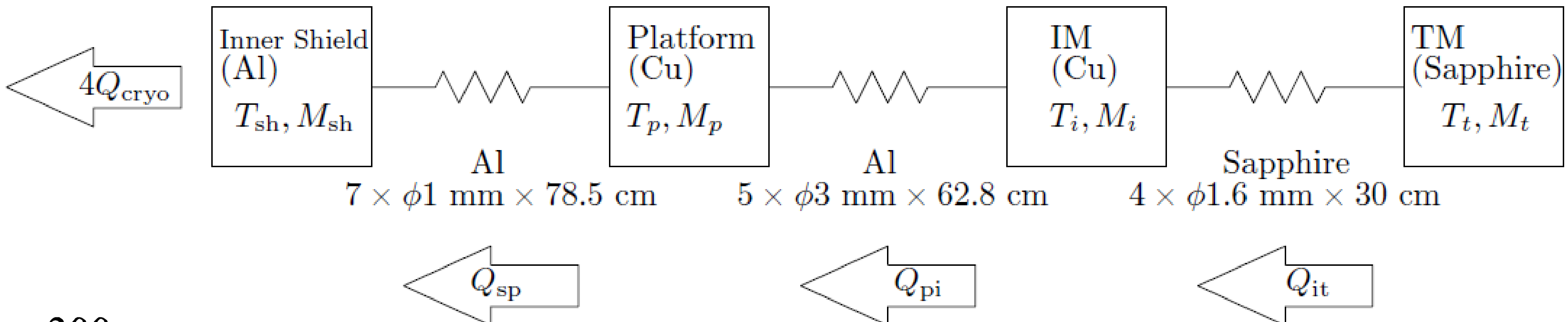
Summary

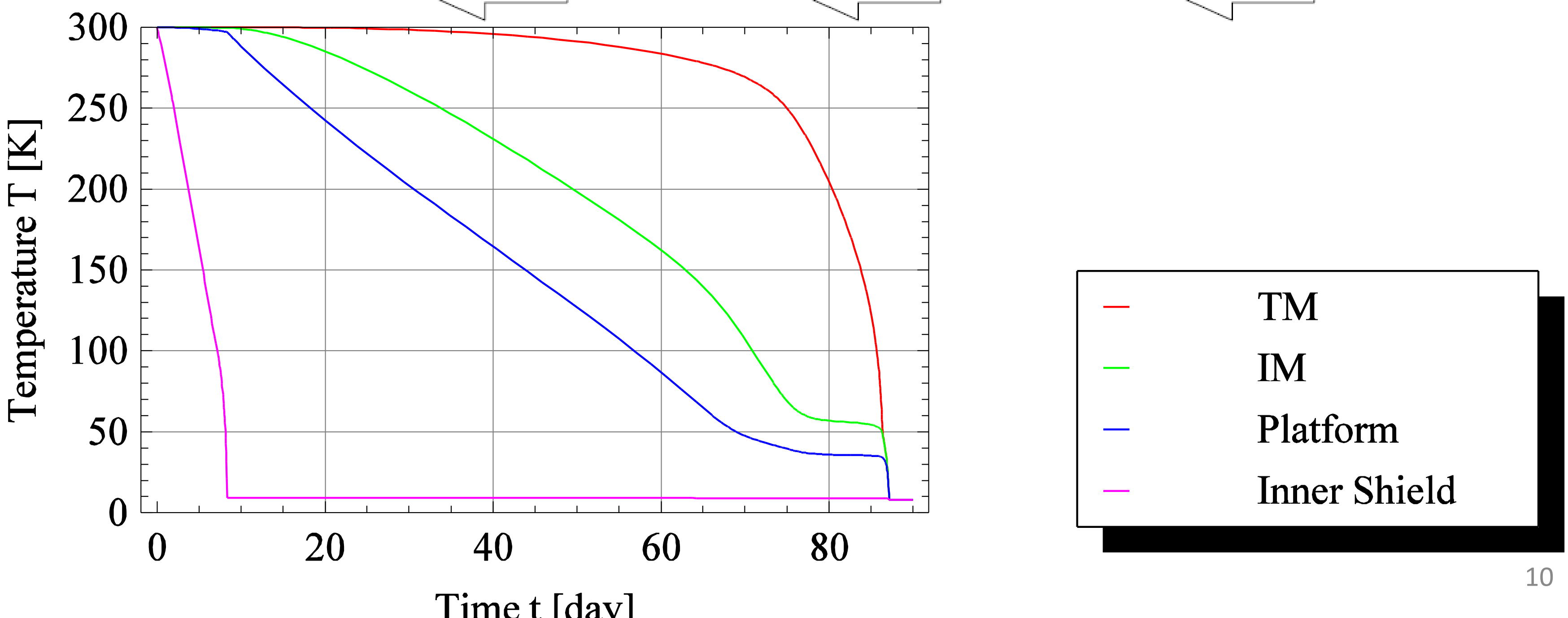
- Thermal radiation through duct shield can be sufficiently reduced by baffles
  - 200 mW (100 mW x 2 duct shields)

- It takes 20 days to cool down mirror with DLC coating
  - Research for high emissivity coating is now underway

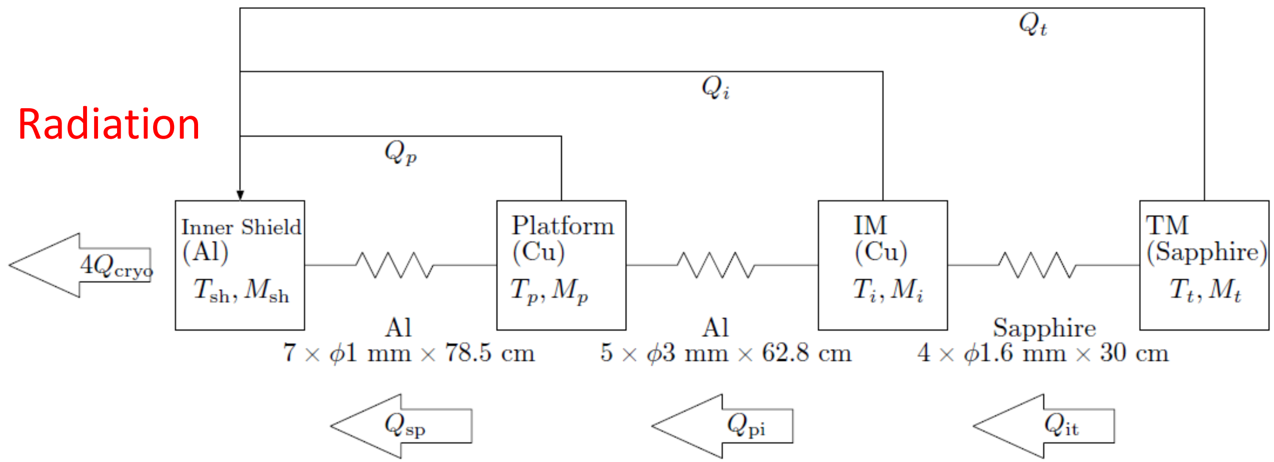
Appendix(Conduction cooling of suspension system, No radiation)

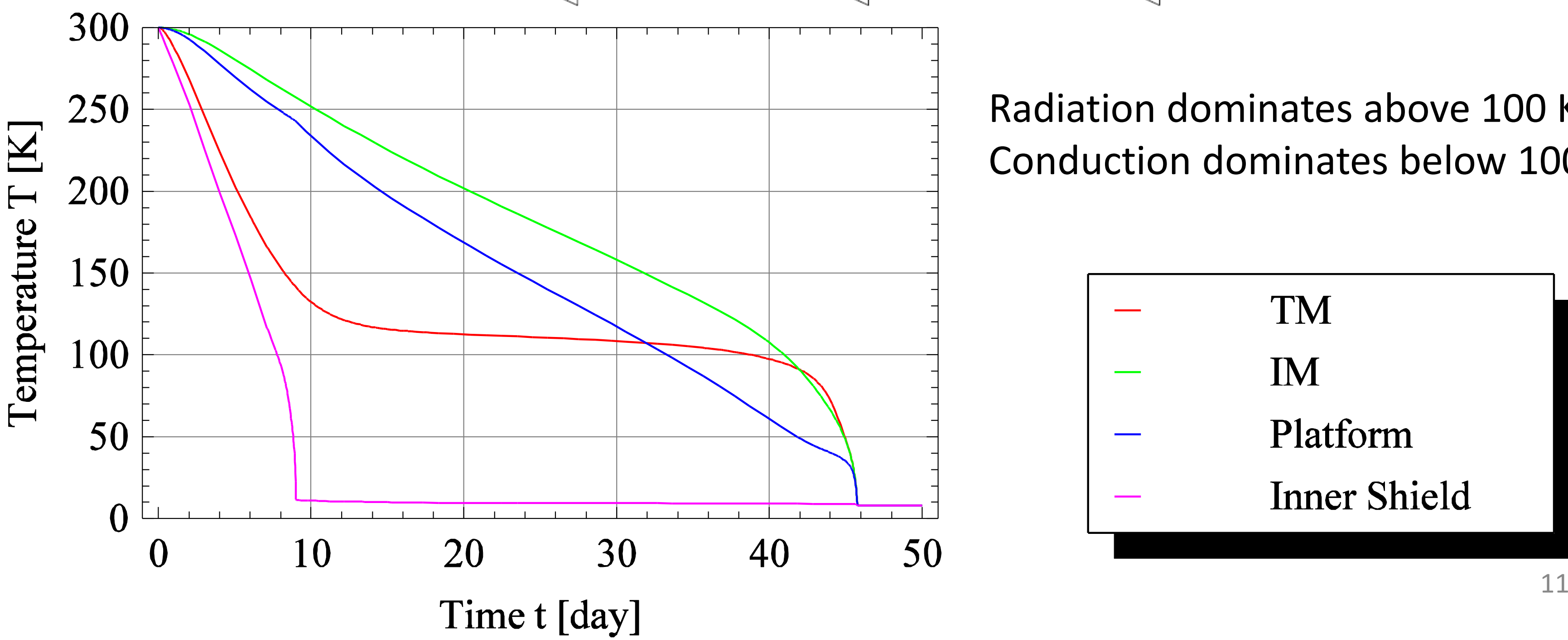
- Thermal conductivity of heat links or sapphire fibers limits cooling time





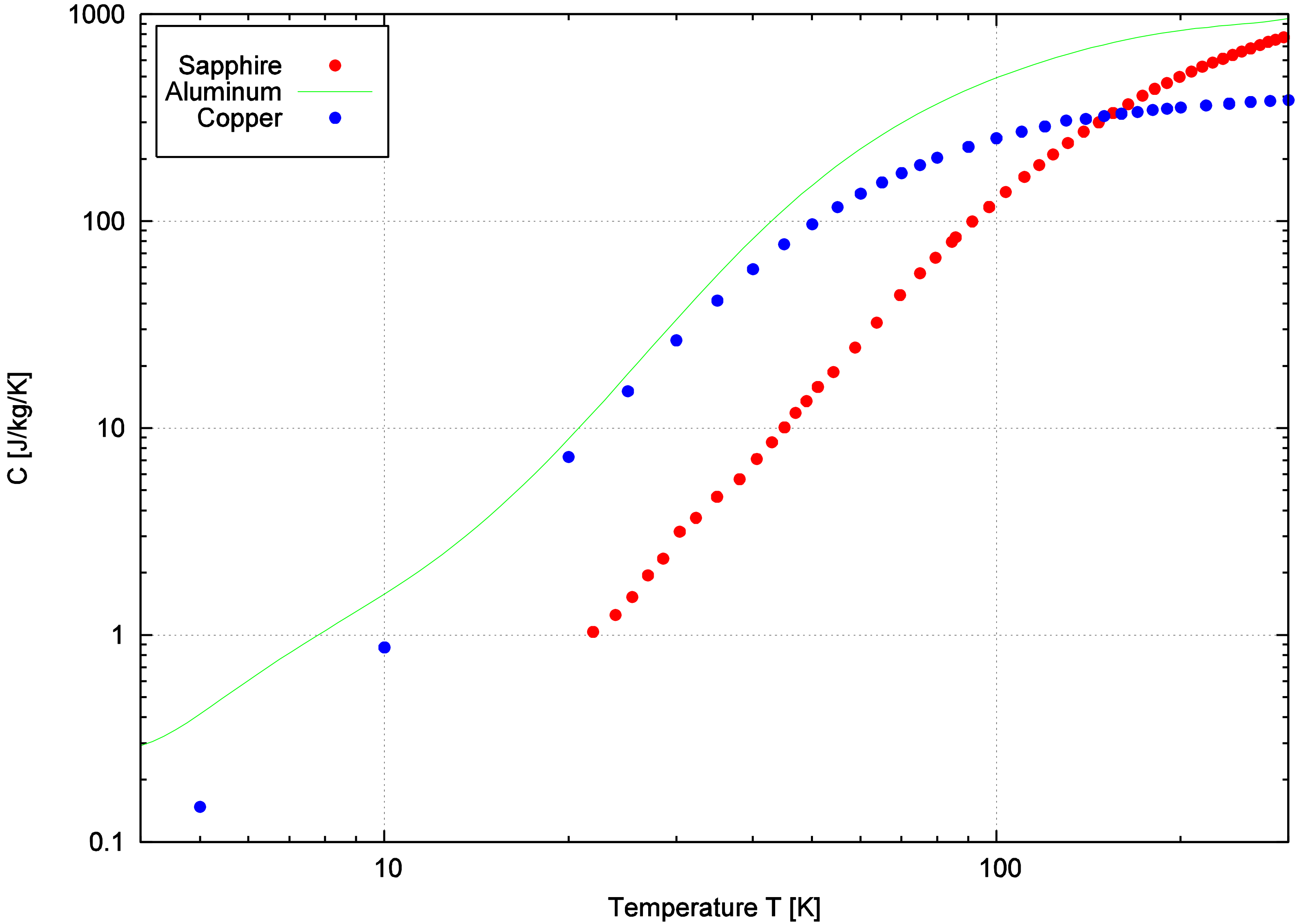
Appendix(Conduction and radiation cooling of suspension system)





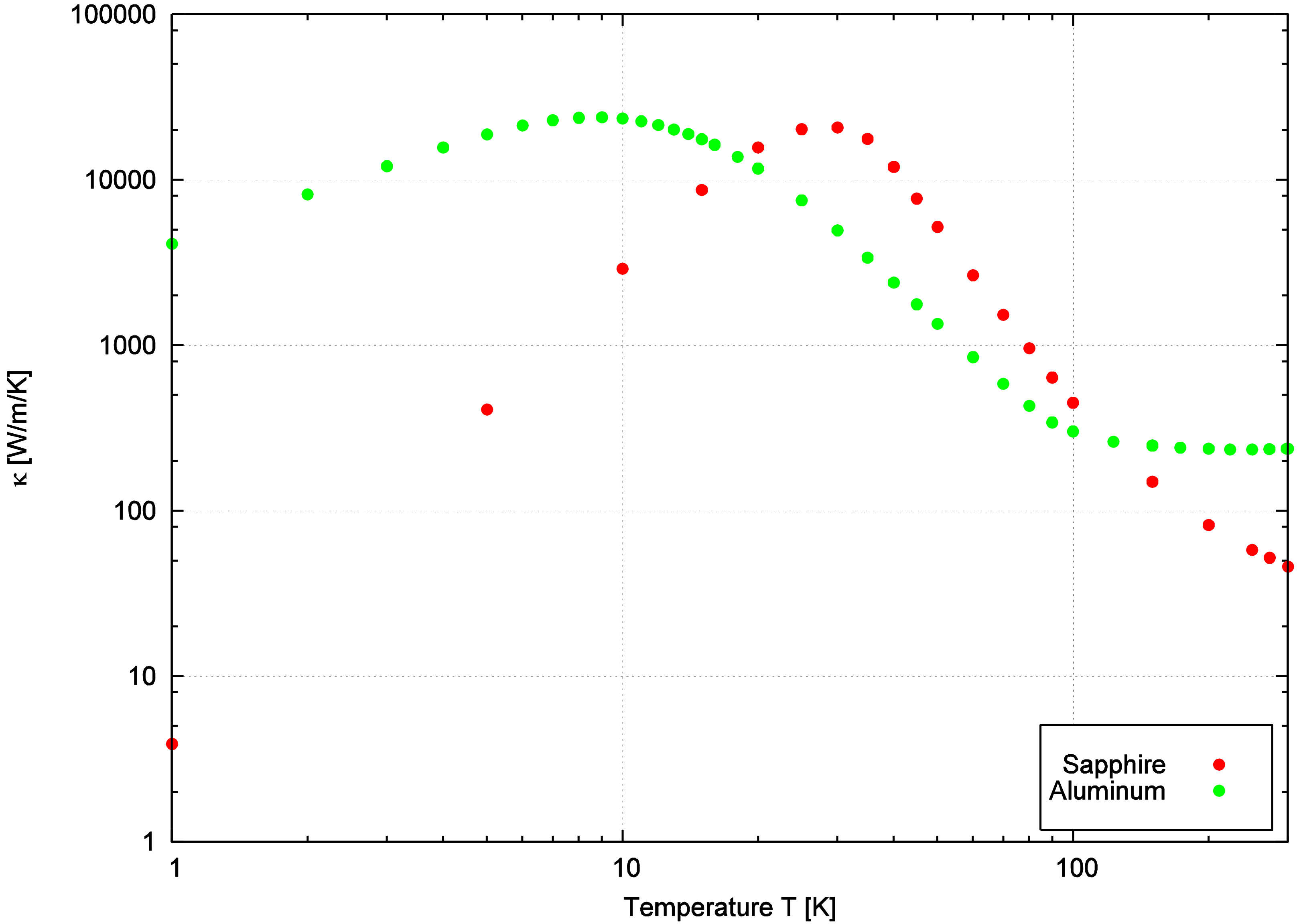
Radiation dominates above 100 K
Conduction dominates below 100 K

Appendix (Heat capacity)



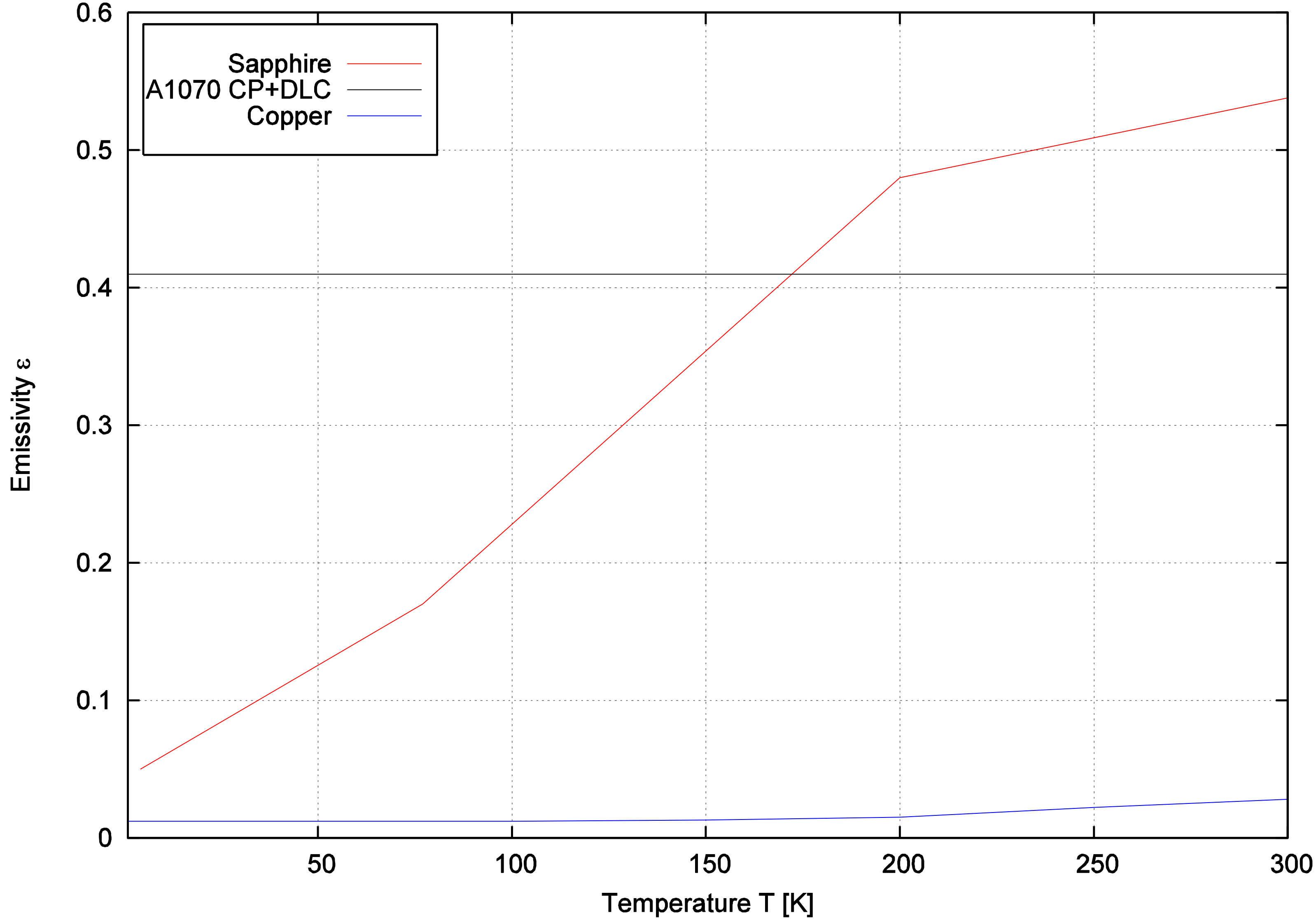
Sapphire: Y.S.Touloukian: "Thermophysical Properties of Matter Volume 5 Specific Heat Nonmetallic Solids," IFI/Plenum (1970)
Copper: AIST Network Database System for Thermophysical Property Data
Aluminum: NIST http://cryogenics.nist.gov/MPropsMAY/5083%20Aluminum/5083Aluminum_rev.htm

Appendix (Thermal conductivity)



Sapphire: Y.S.Touloukian: "Thermophysical Properties of Matter Volume 5 Specific Heat Nonmetallic Solids," IFI/Plenum (1970)
Aluminum: AIST Network Database System for Thermophysical Property Data

Appendix (Emissivity)



Sapphire: Y.S.Touloukian: "Thermophysical Properties of Matter Volume 5 Specific Heat Nonmetallic Solids," IFI/Plenum (1970)
Copper: Y.Sakakibara et al. TEION KOGAKU 2011;46