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Overview of thermal radiative properties of materials for cryogenics

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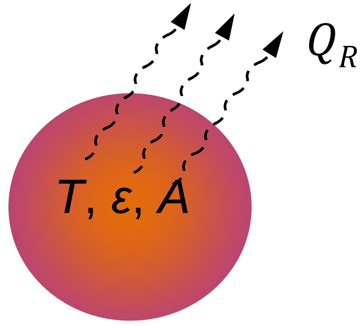
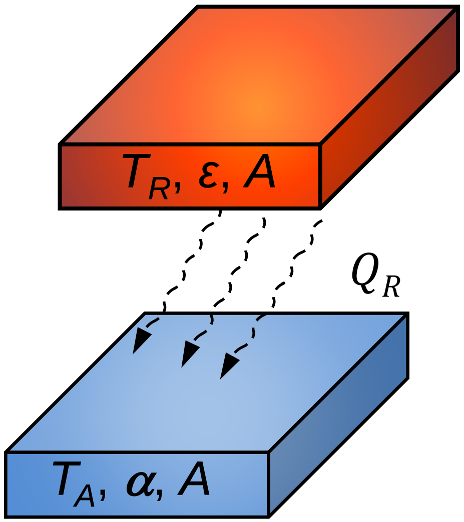
Thermal radiation

Power radiated from a body: Stefan–Boltzmann law: $Q_R = A\varepsilon T^4$ [W]
A: area of the object [m²]
ε: total hemispherical emissivity (real object: > 0% and <100%) [1]
T: temperature of the object [K]
σ: the Stefan-Boltzmann constant [$W \cdot m^{-2} \cdot K^{-4}$]



Heat transfer between two objects (our measurements):
ε: total hemispherical emissivity
T_R: radiator temperature
α: total hemispherical absorptivity
T_A: absorber temperature
Q_R: radiative heat flow
Mutual emissivity ε_{RA} ≈ total hemispherical emissivity or absorptivity

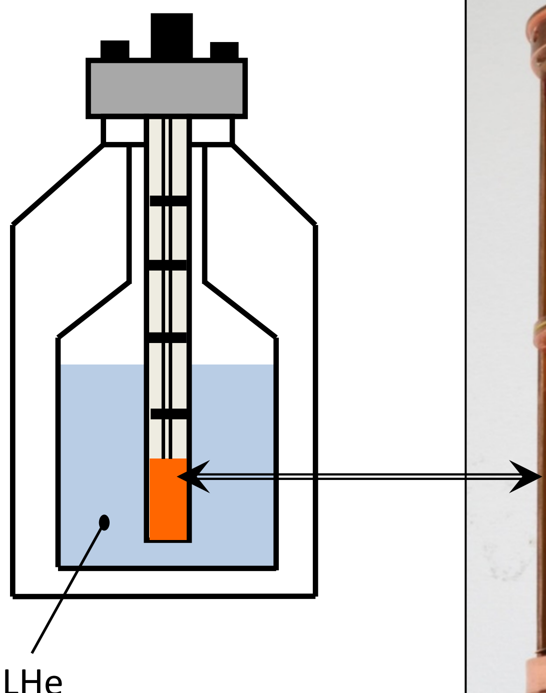
$$\varepsilon_{\mathrm{RA}}(T_R, T_A) = \frac{Q_R}{A\sigma(T_R^{\,4} - T_A^{\,4})} \approx \varepsilon(T_R) \text{ or } \approx \alpha(T_R)$$

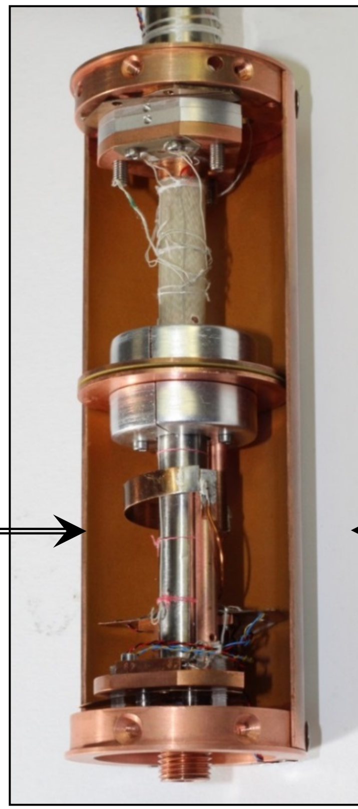


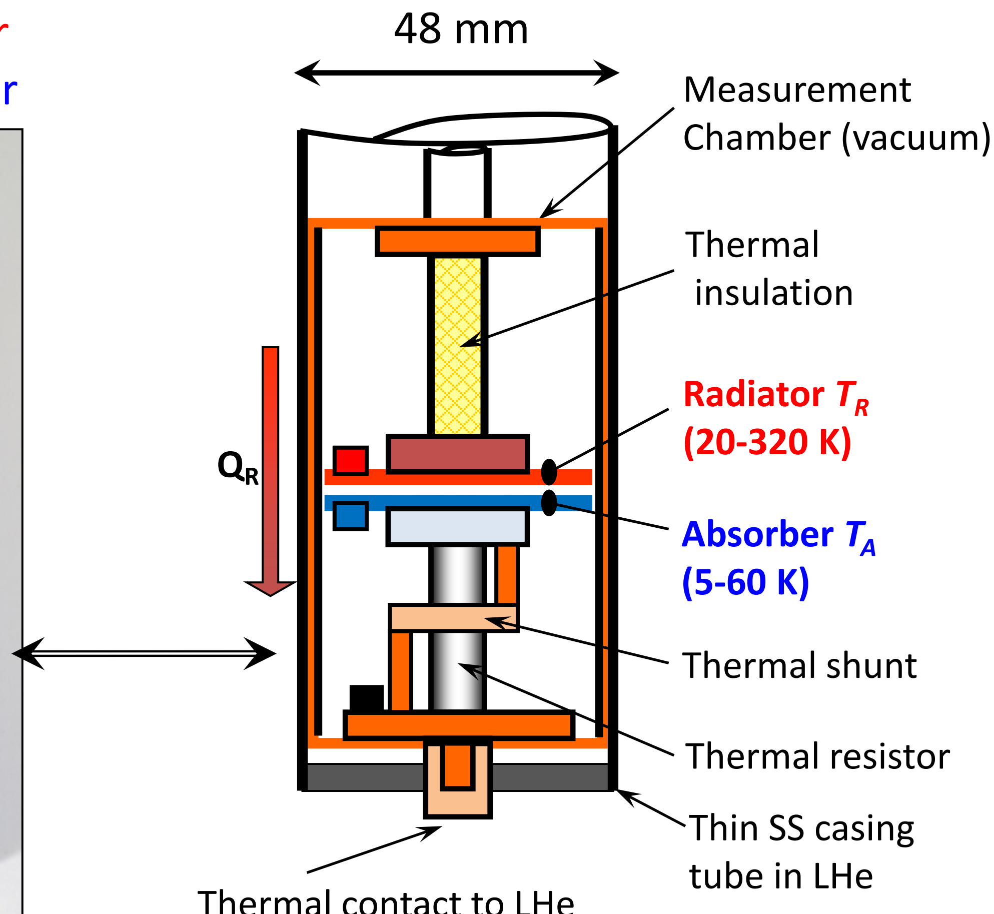
Králík T, et al. 2016. Metrologia. 53(2), 743-753.

Measurement method

- First measurements in 1986. Q_R from flow of the evaporation of a LN2.
- New apparatus 2003-2019 (successively improved):
  - Q_R from ΔT on thermal resistor.
  - I. sample; II. opposite surface: „black“ **reference surface**
  - Emissivity (ε): sample as Radiator
  - Absorptivity (α): sample as Absorber







Apparatus in a Dewar vessel / *Photography of opened chamber* / *Scheme of the measurement chamber*

Database of emissivities and absorptivities

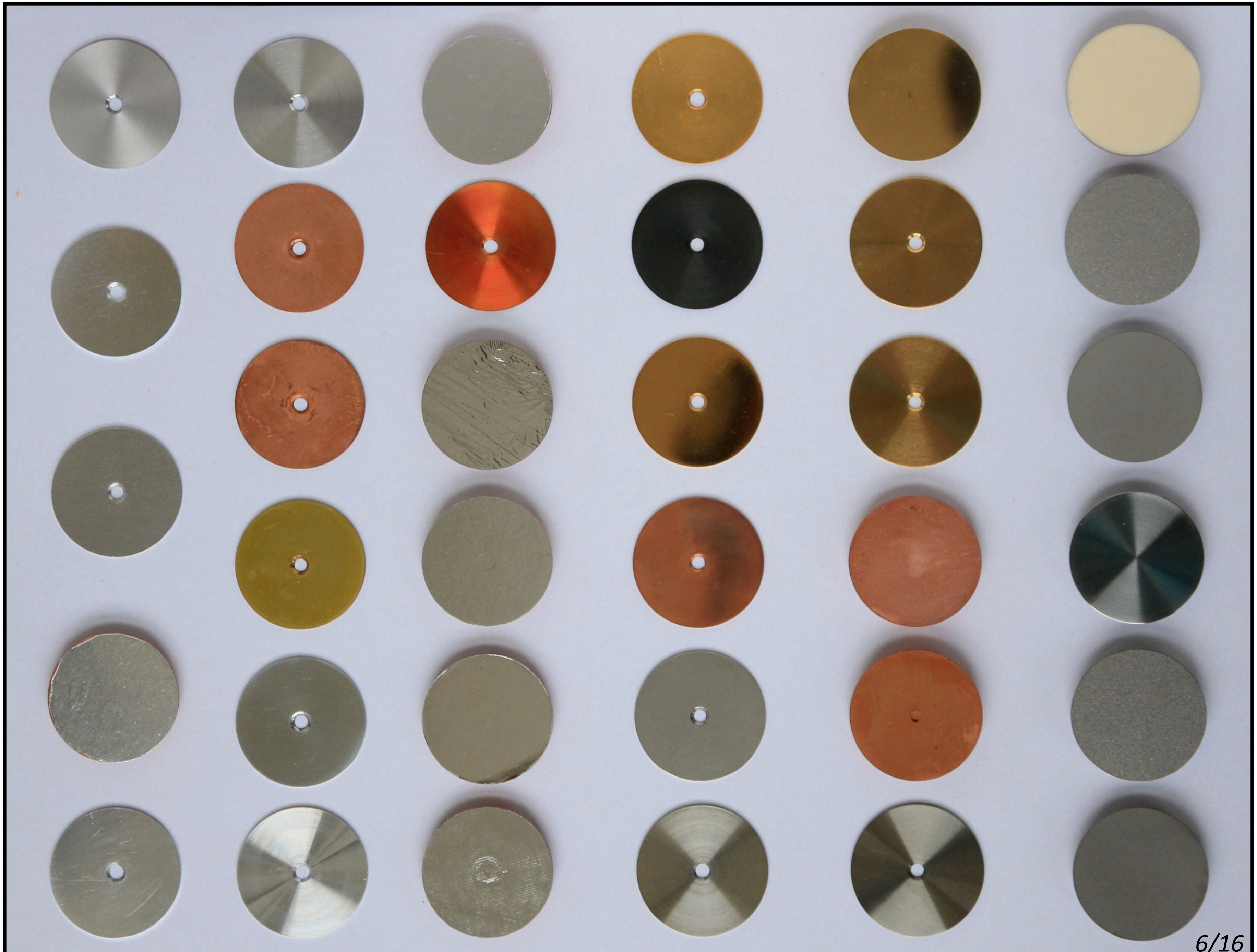
Article: Frolec, J., Králík, T., Musilová, V., Hanzelka, P., Srnka, A., Jelínek, J., 2019. A database of metallic materials emissivities and absorptivities for cryogenics. Cryogenics 97, 85-99. **DOI:** *10.1016/j.cryogenics.2018.12.003*

Related database: https://data.mendeley.com/datasets/z8t423rwwd/2; **DOI:** *10.17632/z8t423rwwd.2*

SAMPLE SPECIFICATION			
CATEGORY	MATERIAL	PURITY / STANDARD / THICKNESS	
Bulk material:	Stainless steel	Type 304	
Coating:	N/A	N/A	
	DESCRIPTION		
Treatment of bulk material:	finely turned on a lathe		
Surface treatment:	sand blasted with corundum (grit size approx. F22)		
Surface characteristics:	Ra = 3.06 um; Rz = 17.56 um		
Comment:	N/A		
Sample already presented in:	N/A		
Date of record entry:	17.07.2018		
Sample No. :	92/1		
MEASURED DATA			
Sample at the position of (measured quantity):	radiator (emissivity)		
radiator temperature [K]	absorber temperature [K]	quantity value [%]	Uncertainty (absolute) [%]
20.0	4.26	5.83	2.88
25.0	4.26	8.12	1.39
30.0	4.27	9.69	0.98
35.0	4.27	11.04	0.90
40.0	4.28	12.22	0.91
50.0	4.31	13.97	0.98
60.0	4.36	15.51	1.06
70.0	4.46	16.99	1.15
80.0	4.60	18.33	1.24
90.0	4.81	19.47	1.31
100.0	5.11	20.74	1.39

Measured materials overview

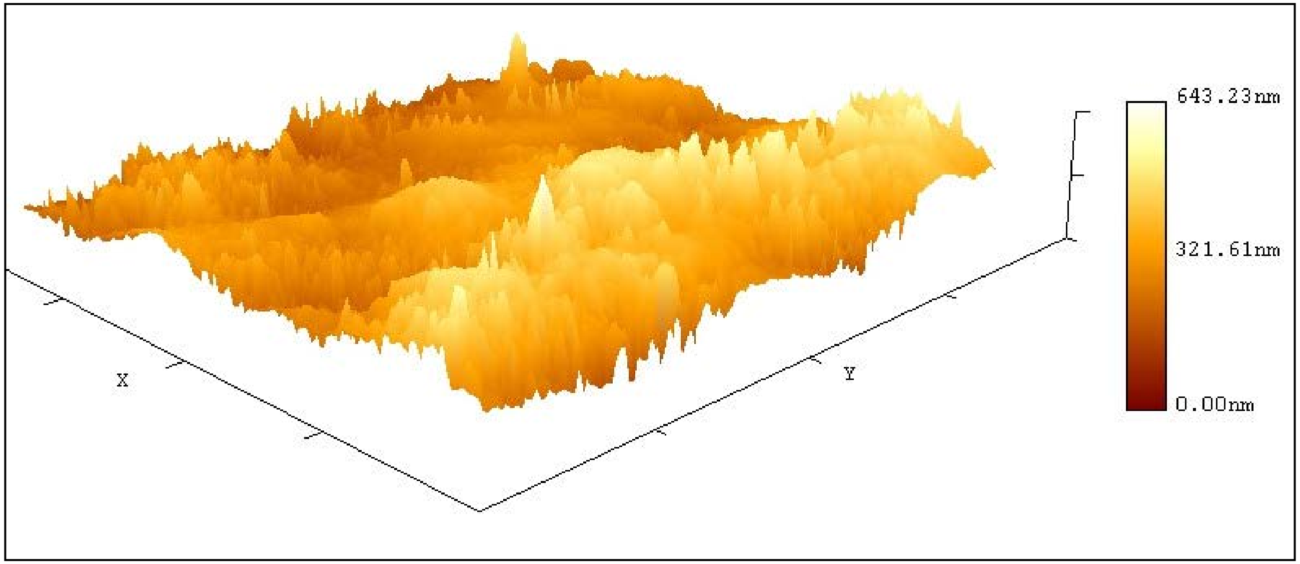
First treatment	Final treatment	*Al*	*Cu*	*AlCu4Mg* (Duralumin)	*Ti-6Al-4V*	Stainless steel	*Cu-Zn* brass	*Al* foil	Polyester + *Al*	Al_2O_3
N/A	Unfinished	x				x		x	x	x
N/A	Abraded	x								
N/A	Etched		x							
N/A	Finely turned	x	x	x	x	x				
Mechanically polished	*Au* galvanically		x							
Finely turned	*Au* galvanically				x					
N/A	Chemically polished	x	x				x			
Chemically polished	Ice layer	x								
Vacuum annealed	Chemically polished	x								
Mechanically polished	Chemically polished		x							
Etched	Chemically polished		x							
N/A	Mechanically polished	x	x							
Lapped	Mechanically polished		x							
Mechanically polished	Diamond-like carbon deposition		x							
Finely turned	Sand blasted (finely)				x	x				
Finely turned	Sand blasted (coarsely)				x	x				
Chemically polished	Sputtered *Au*		x							
Finely turned	Vacuum annealed		x							



Results – factors determining emissivity and absorptivity

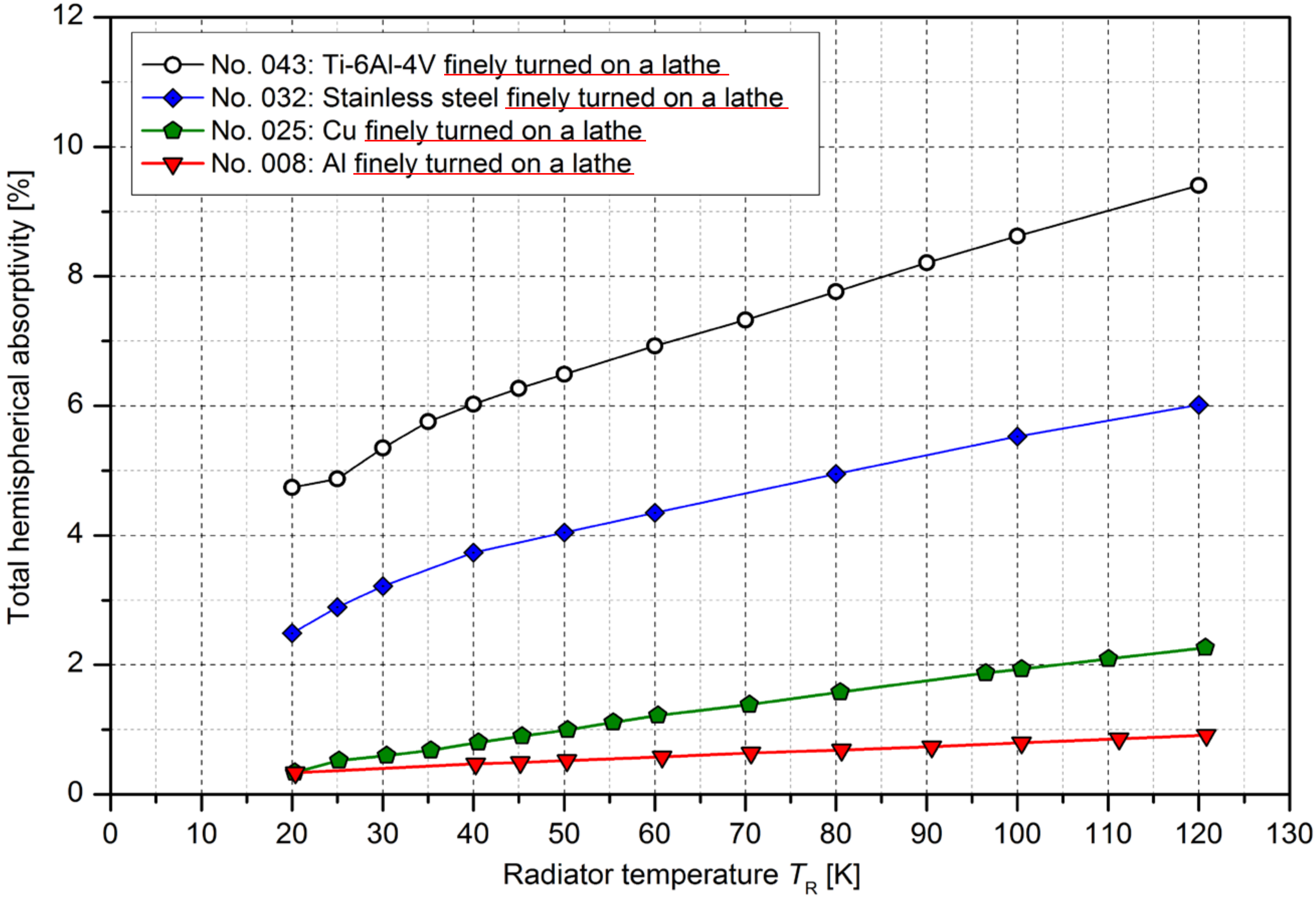
TRP are highly sensitive to the state of the material near the surface (thermal radiation interacts with very thin surface layer - tens of nm)

1) Surface material and its purity
2) Temperature
3) Surface finish - mechanical working / chemical treatment
4) Contamination of the surface
5) Aging



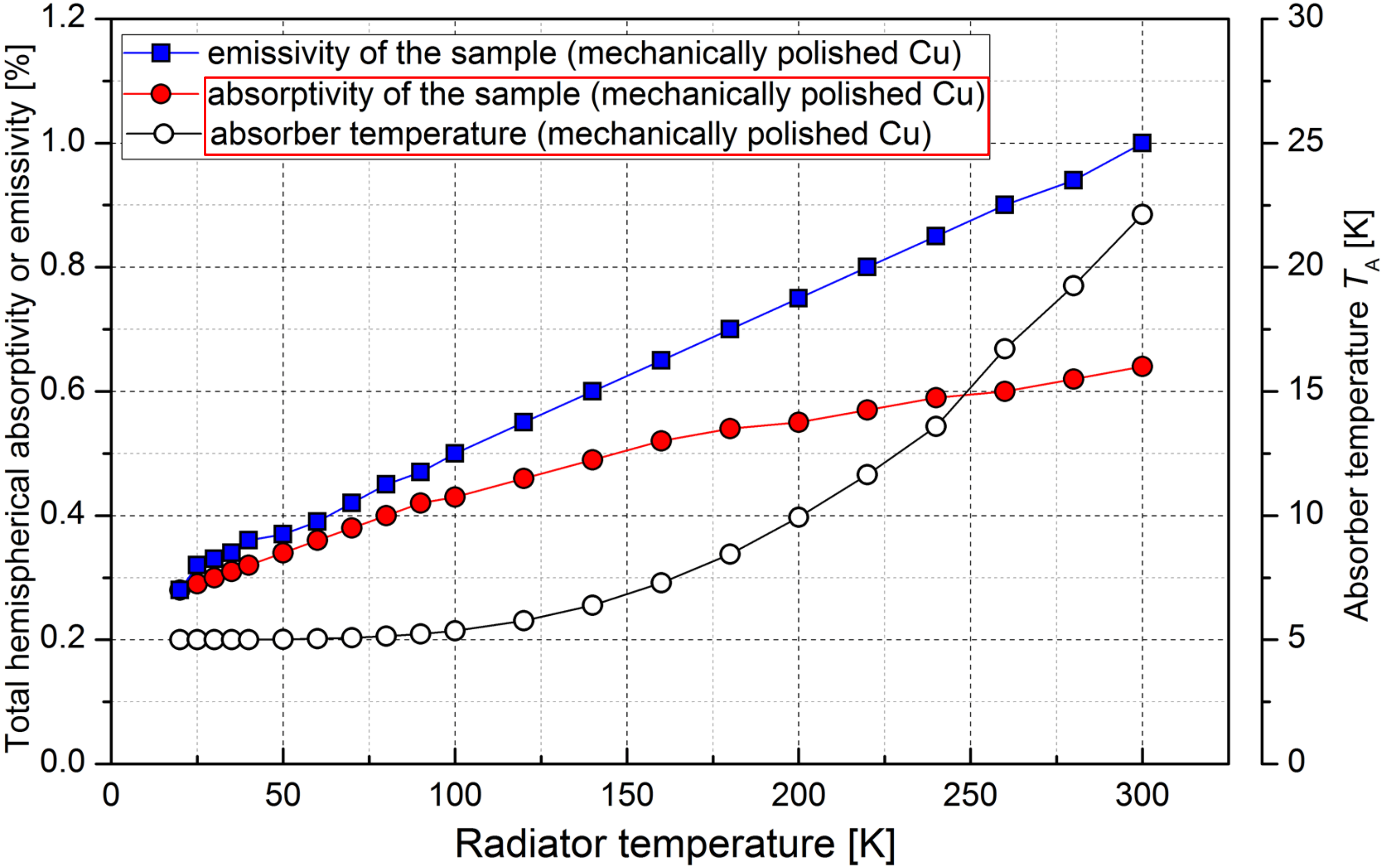
AFM image of our copper sample

Surface material and its purity

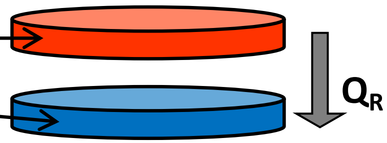


- *Identical surface finish* x *different material*

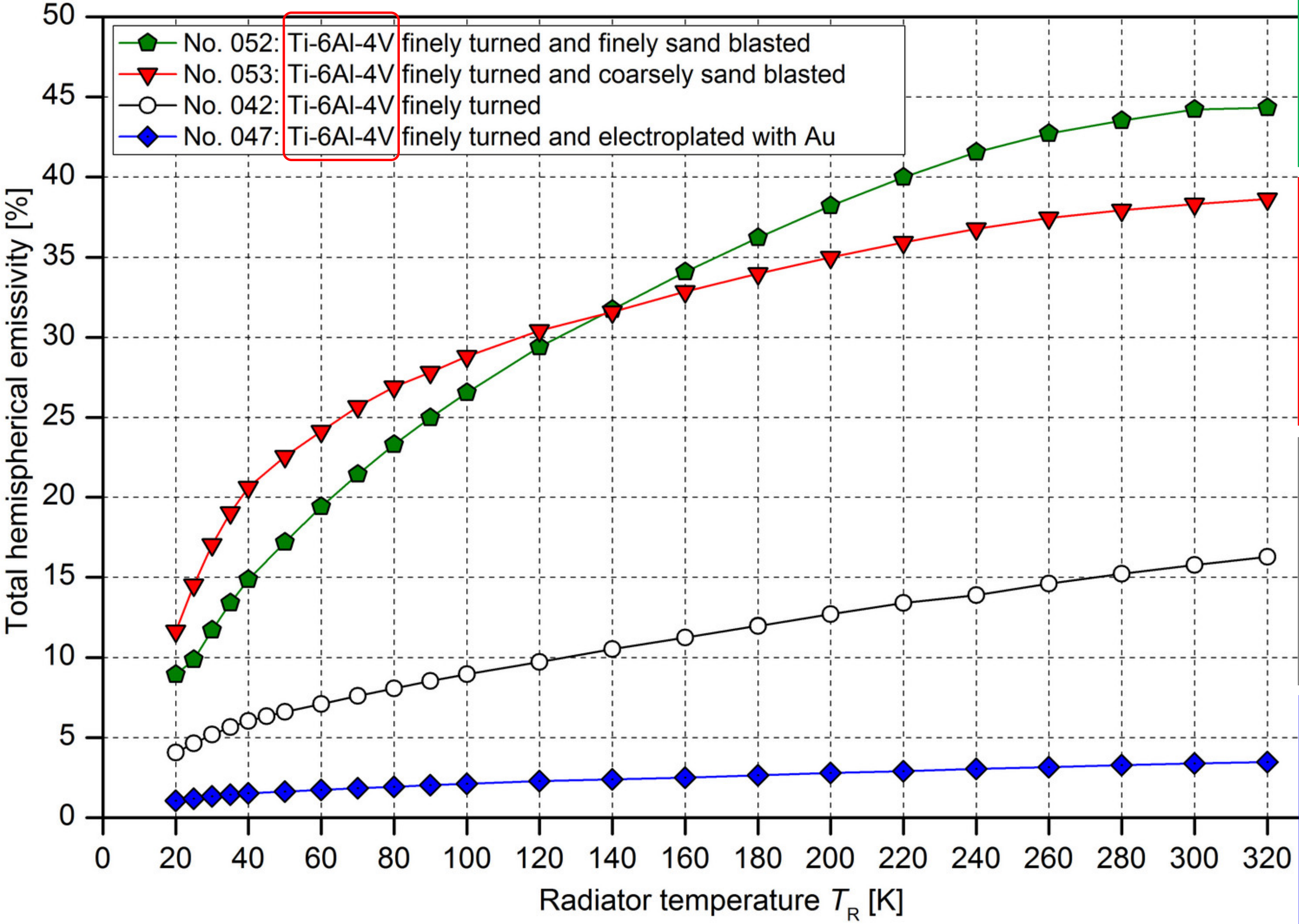
Temperature

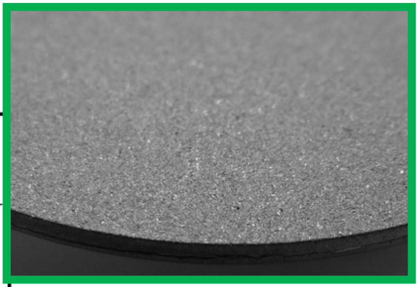


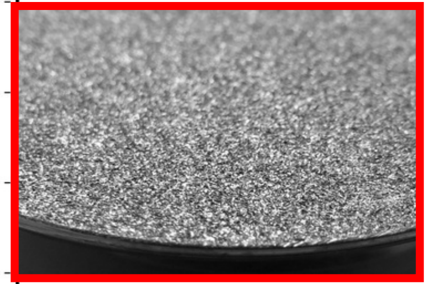
- *Emissivity – sample at radiator temperature*
- *Absorptivity – sample at absorber temperature*

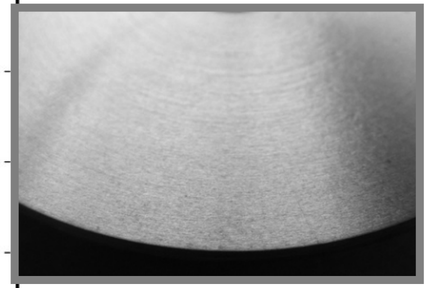


Surface finish (I) - emissivity of titanium alloy



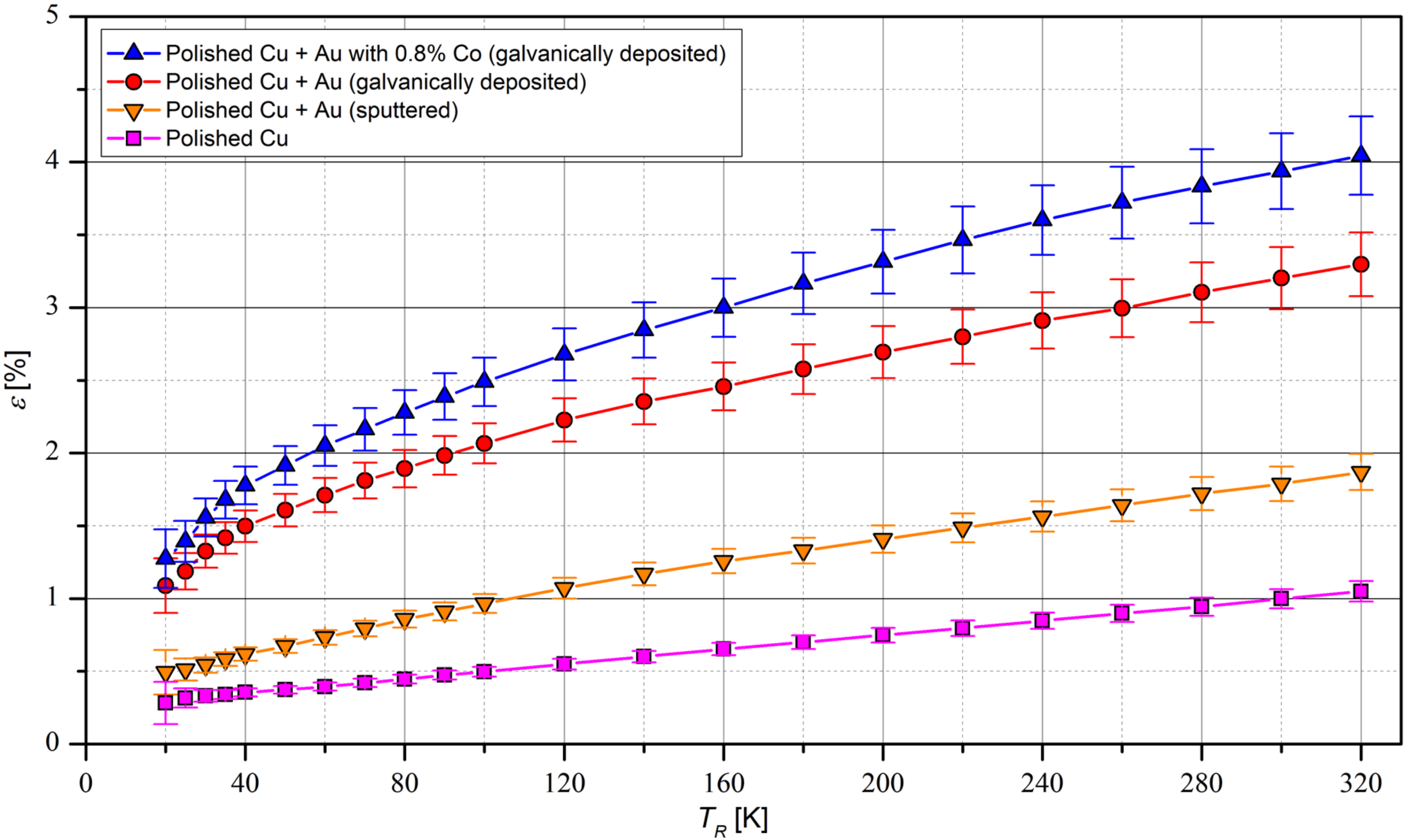






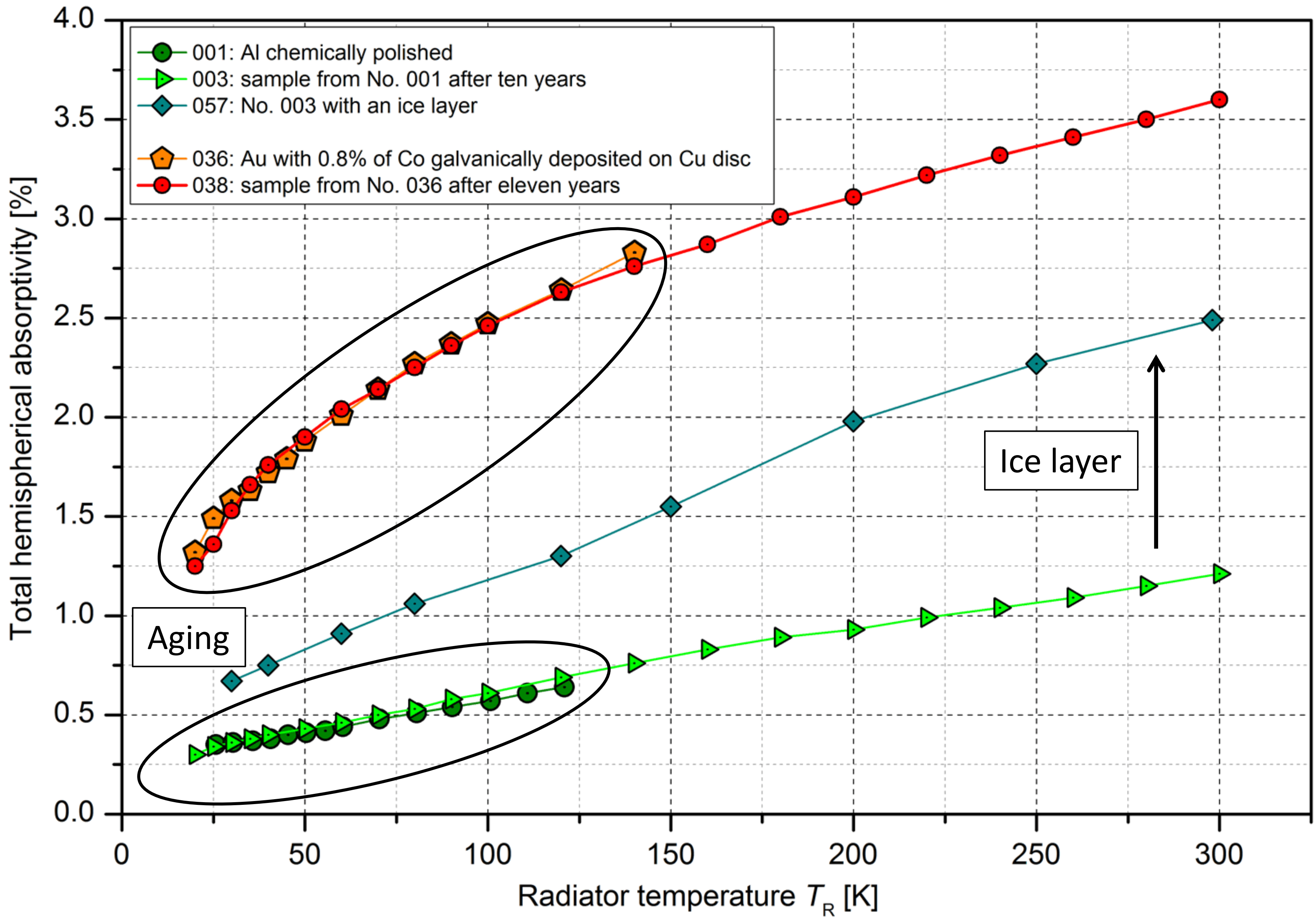
- *Identical material* x *different surface finish*

Surface finish (II) - emissivity of gold layers

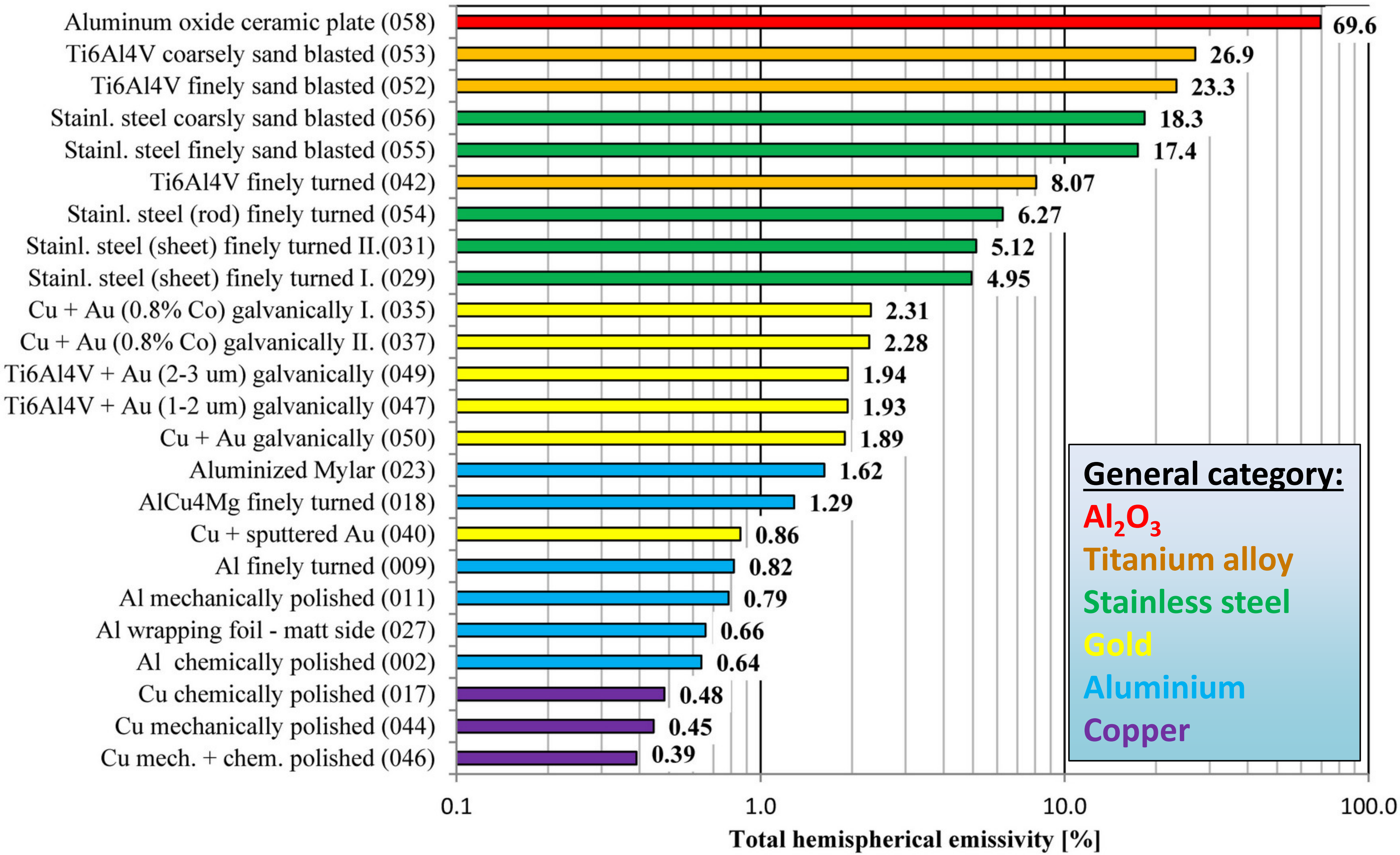


- *Gold deposition method & purity*

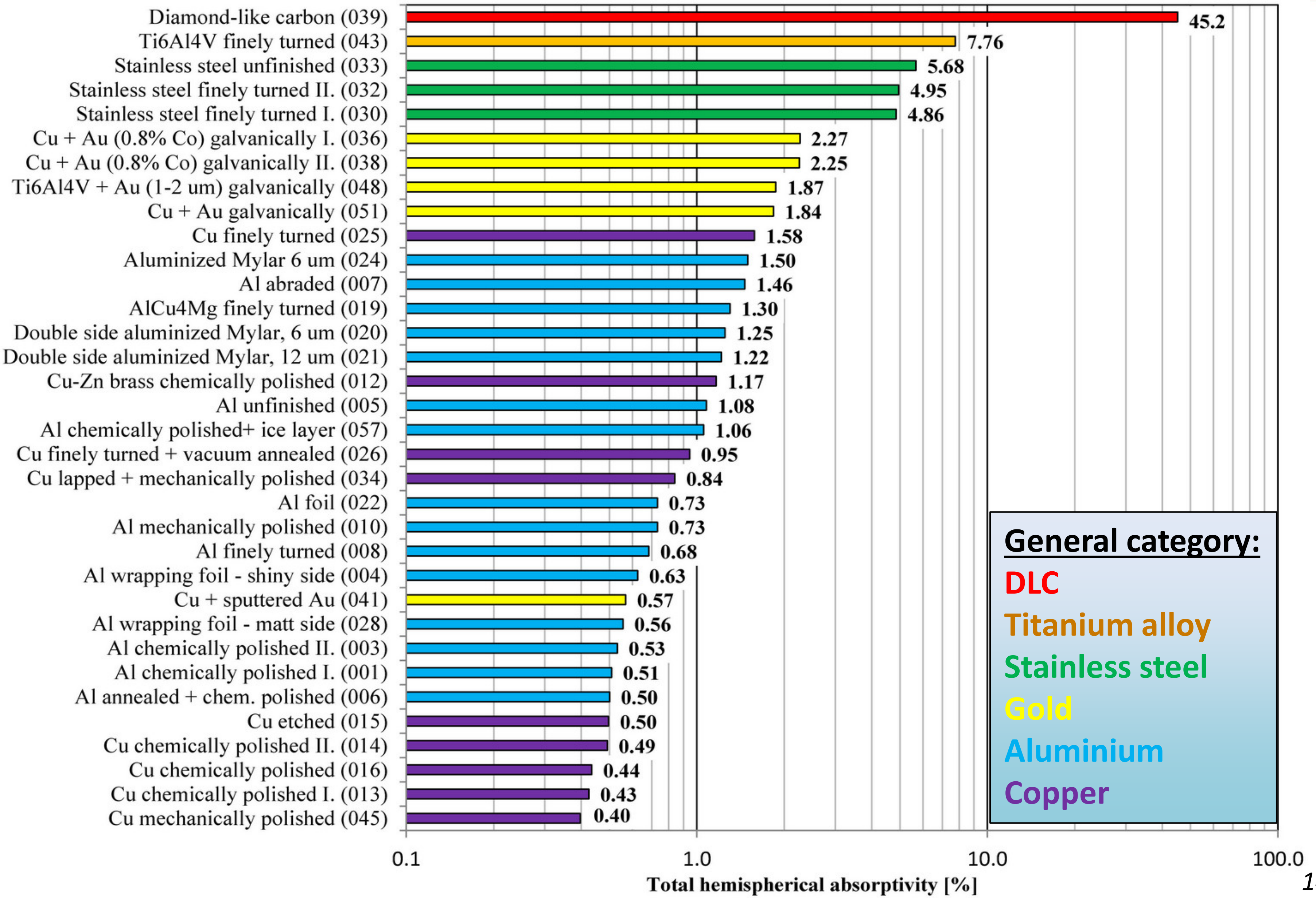
Surface contamination



Emissivity at 80 K (temperature of the sample)



Absorptivity at 80 K (temperature of the radiator)



Conclusions (I)

- Thermal radiative properties - ***ε*** and ***α*** - of metals generally depend on the ***T* of the material** and on the ***T* of the source of thermal radiation.**

- **Both *ε*** as well as ***α*: highly sensitive to the state of the material near the surface.**

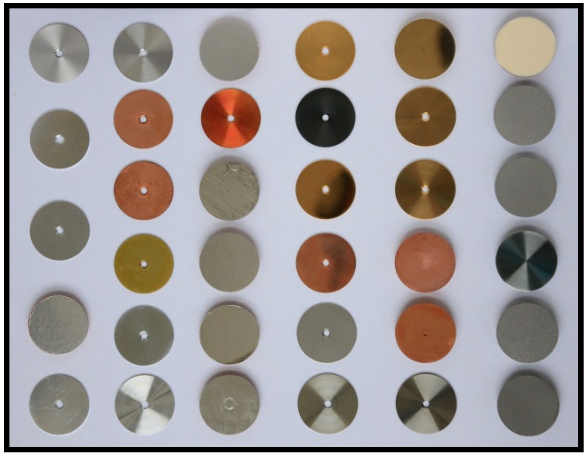
- **Surface finish: chemical treatment** (polishing, etching) usually provided surfaces with **lowest *ε*** / ***α***.

- **Surface contamination**: thin **layer of water ice**: possible **stronger influence** on the absorptivity, higher then the **natural oxide layer**.

- **Material purity:**
  - Significant difference in high purity **Au** vs. **Au** with 0.8% of Cobalt
  - Cu or Al with technical purity are satisfying; **very pure material is not effective** to reduce ***α*** (calculated absorptivity of Cu - ASE theory).

Conclusions (II)

Comprehensive **database** of thermal radiative properties (ε, α):



- 58 measurements of 45 different samples
- temperature dependences (plots & numbers)
- mostly metallic materials with different surface finishes
- publicly available at:

https://data.mendeley.com/datasets/z8t423rwwd/2

DOI: 10.17632/z8t423rwwd.2

Values of α and ε for metallic samples at cryogenic temperatures:

- **below 1%** : can be achieved mainly on polished Al, Cu, (Au)
- **up to ≈ 10%**: most common (e.g. finely turned surfaces, alloys)
- **higher than 10%**: a special treatment (sandblasting, layers, ...)