Shape effects of forsterite particles on infrared spectra

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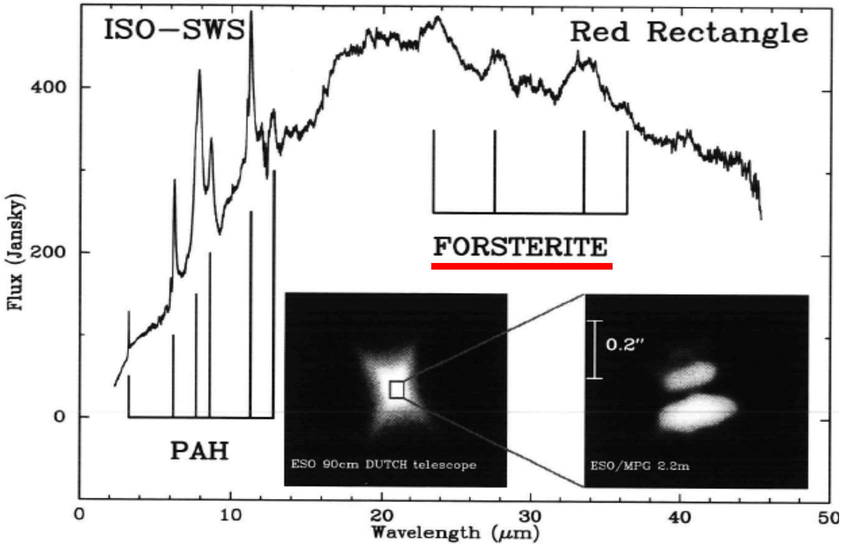
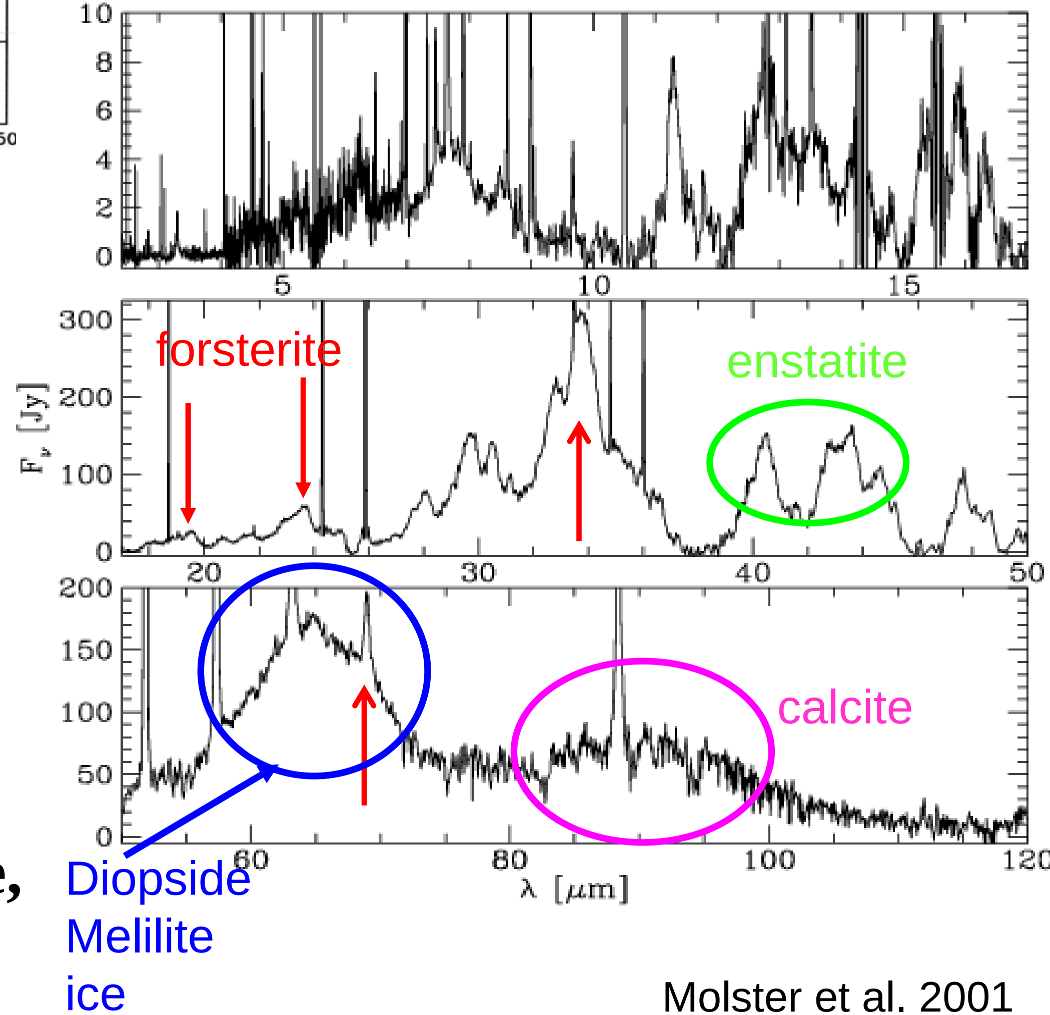
Waters et al.
(1998, Nature 391)



ISO observation
In circumstellar

NGC 6302



Molster et al. 2001

Many sharp peaks were detected

↓

Compare with laboratory data (absorption of particles, reflectance)

↓

Identified as minerals forsterite, enstatite, diopside, melilite, calcite, ,,,,,,

Infrared Absorption of dust (fine particles) depend on

- **size**
- **composition (olivine, pyroxene,,,,,)**
- **shape (Fo)**
- **coagulation (aggregate)**
- **temperature (cooling at RT, 200K, 100K, 50K, 20K, 8K)**
- **crystallinity (degree of crystallinity)**
- **medium (KBr, PE)**

we investigate about forsterite particles on the shape and coagulation

(Koike et al. 2010, Koike et al. in preparation)

forsterite : Mg_2SiO_4

Sample Preparation for Forsterite Mg_2SiO_4 particles

$Mg(OH)_2$ + SiO2
(Mg / Si = 2 / 1)

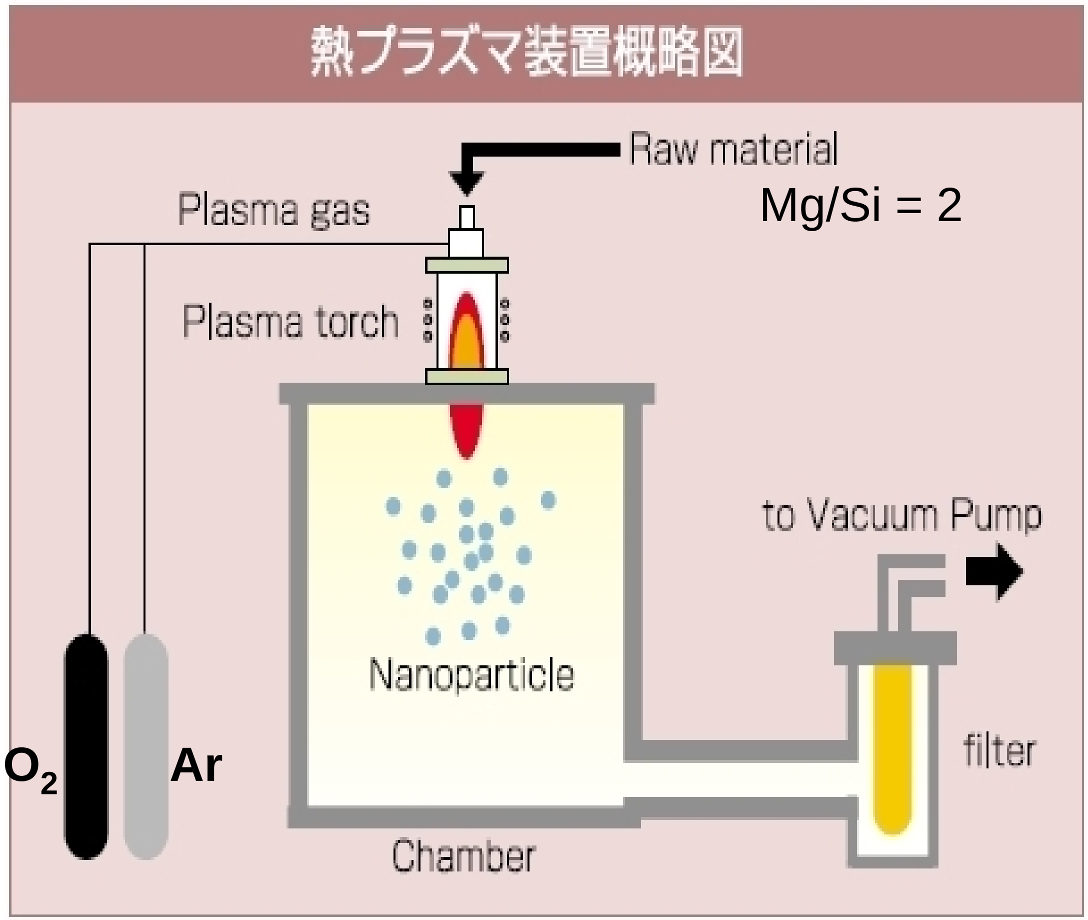
evaporation & condensation

commercial products in plasma method

spherical amorphous particles

annealing and crystallization

spherical, and irregular forsterite particles



@ Nisshin Engineering Inc.

Infrared spectra of annealed forsterite particles

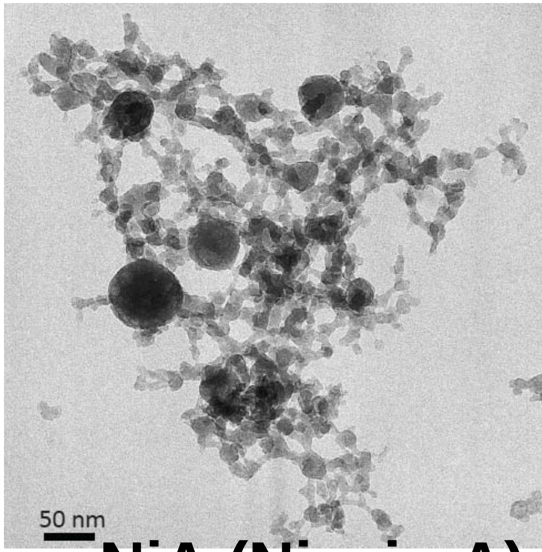
Starting products

original amorphous of Nissin products (by XRD)

NiA average size 11 nm : coagulated

NiB average size 80 nm : isolated

↓ **annealing at various temperature**

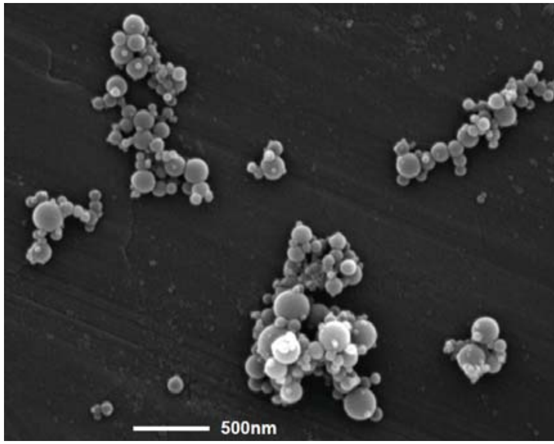


NiA (Nissin A)

shape ー depend on annealed temperature

NiA spherical and coagulated → irregular shape

NiB spherical → irregular shape



NiB (Nissin B)

how to change infrared spectra

(KBr & PE) (in wide wavelength region)

○ 11 μm, 33 μm band

○ 69 μm band

Condition for annealing of amorphous products (NiA & NiB)

Low temperature
≦ 1200 ℃

NiA

	550℃	600℃	650℃	700℃	800℃	1000℃	1100℃	1150℃	1200℃
3h									○
24h	○	○	○	○	○	○	○	○	
48h				○					

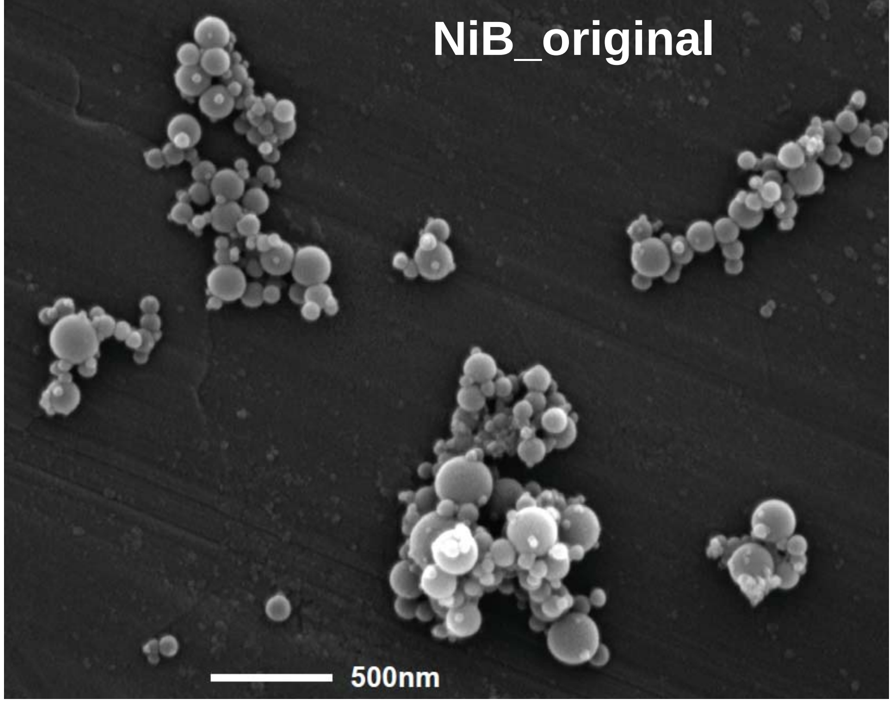
NiB

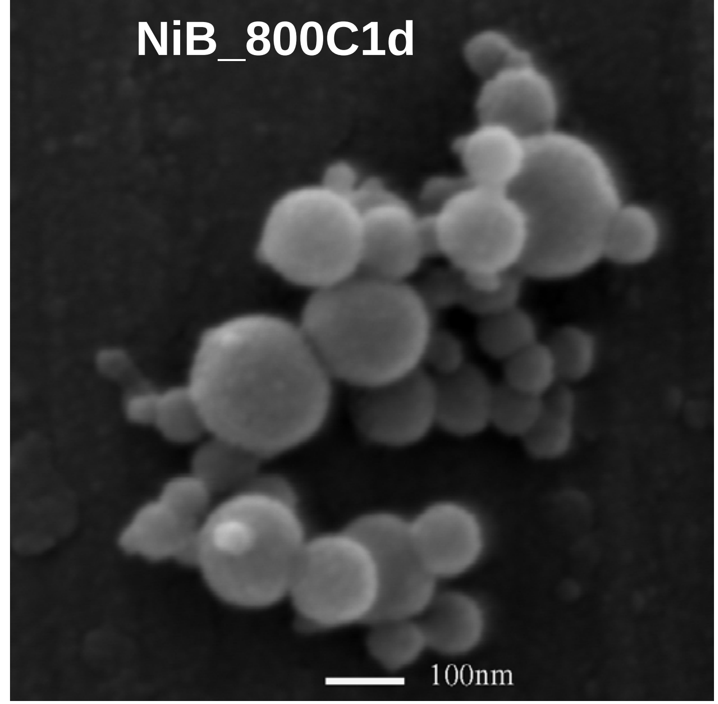
	600℃	650℃	700℃	800℃	1100℃	1130℃	1150℃	1200℃
6h					○			○
24h	○	○	○	○		○	○	○

High temperature
≧ 1200 ℃

	Annealing temperature ℃	Annealing time h	protoenstatite (by XRD)
NiA	1200	3	
	1300	3, 16, 18, 60, 96	16 – 96 h
	1400	3	3 h
	1500	2,3,4,10,14.3, 45.5	2 – 45.5 h
	1600	3	
NiB	1500	3	
	1600	3	

Red: IR measured

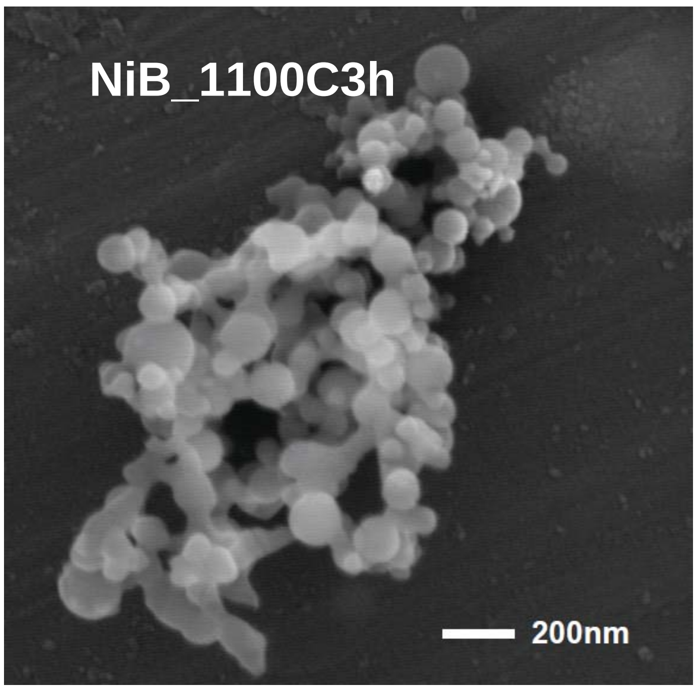


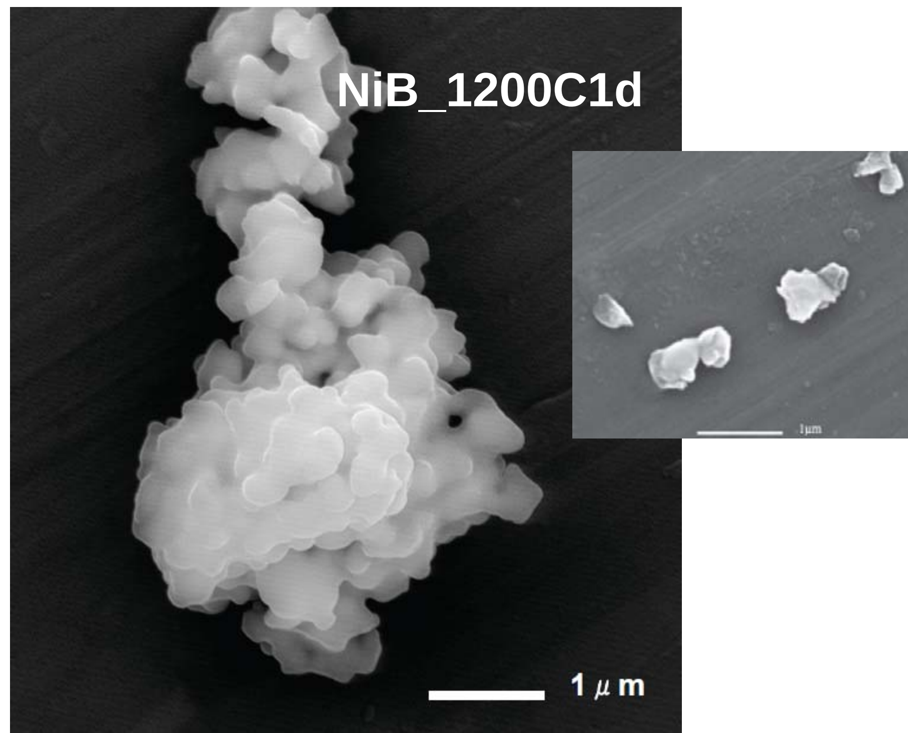


Single crystal

NiB_SEM

Spherical & isolate
↓
Irregular
↓
Plate-like including





NiA_TEM

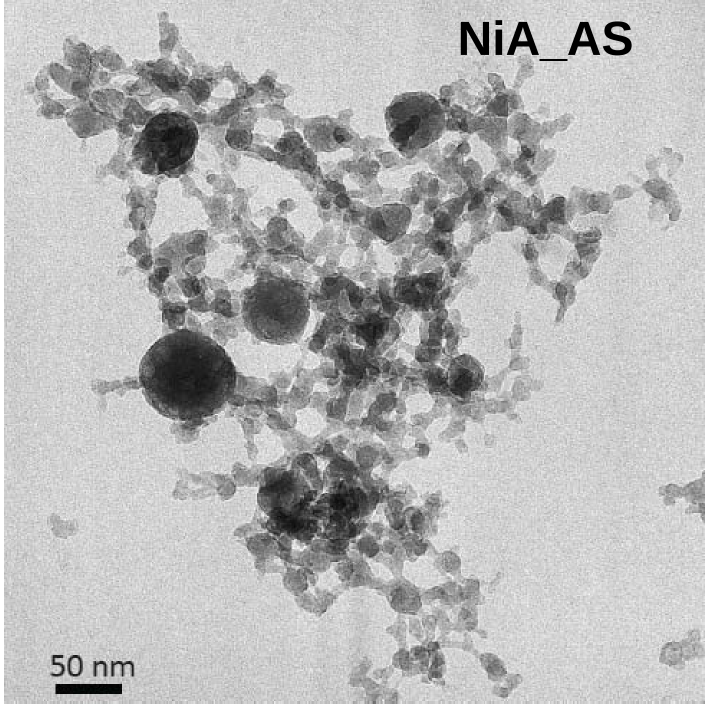
Spherical & Coagulation

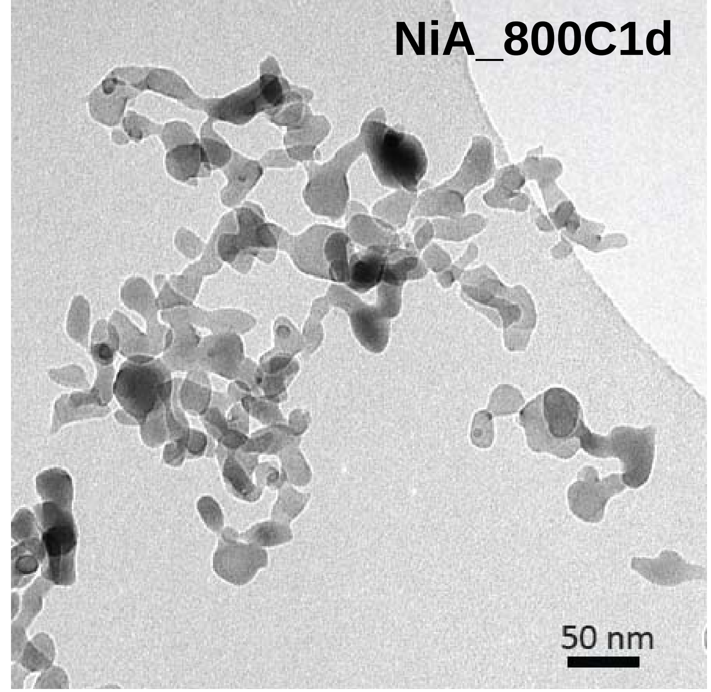
↓

Irregular

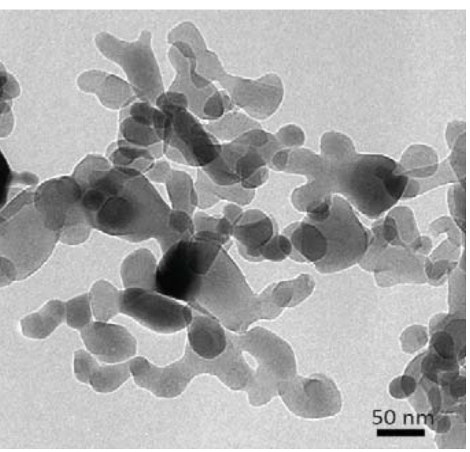
↓

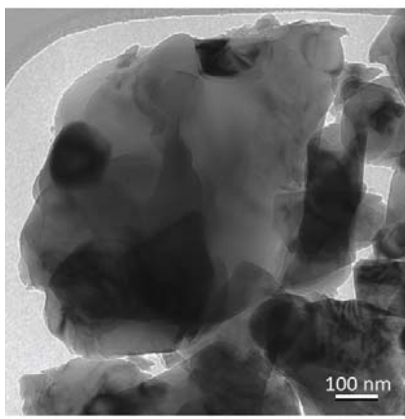
Plate-like including





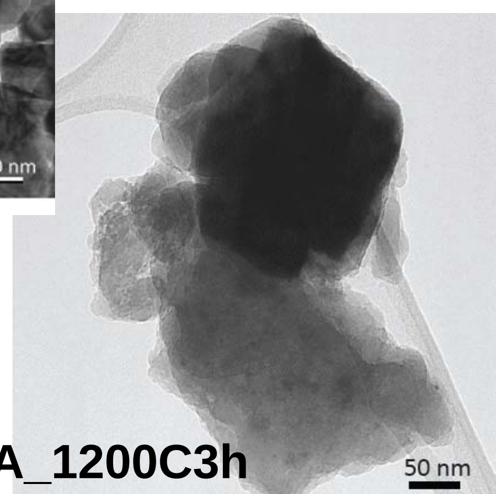
NiA_1000C1d





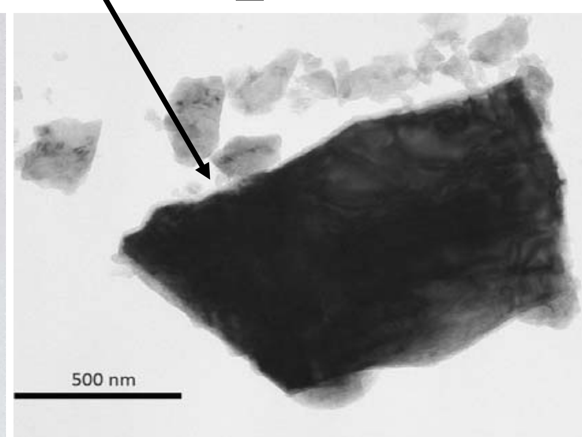
NiA_1150C1d

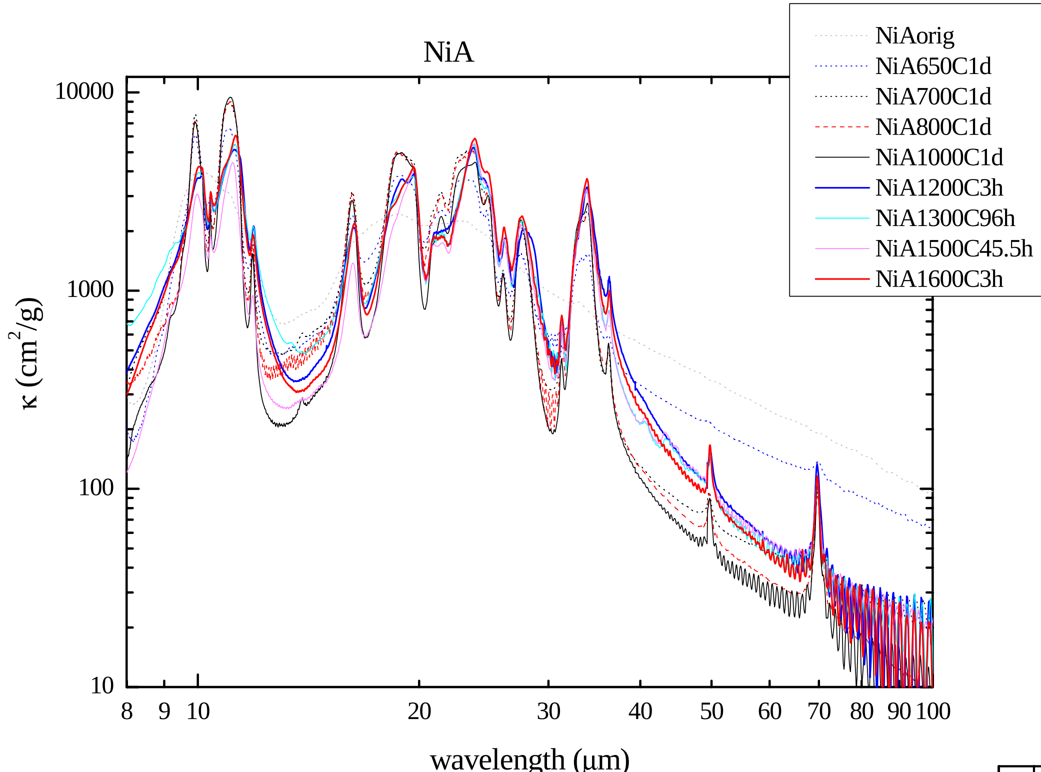
Single crystal



NiA_1200C3h

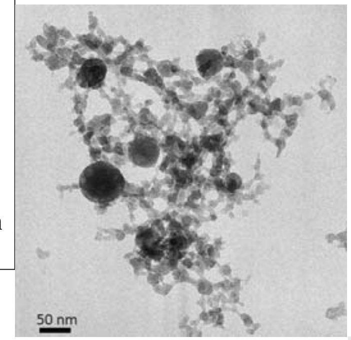
NiA_1600C3h



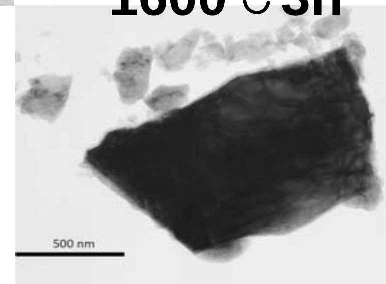


NiA

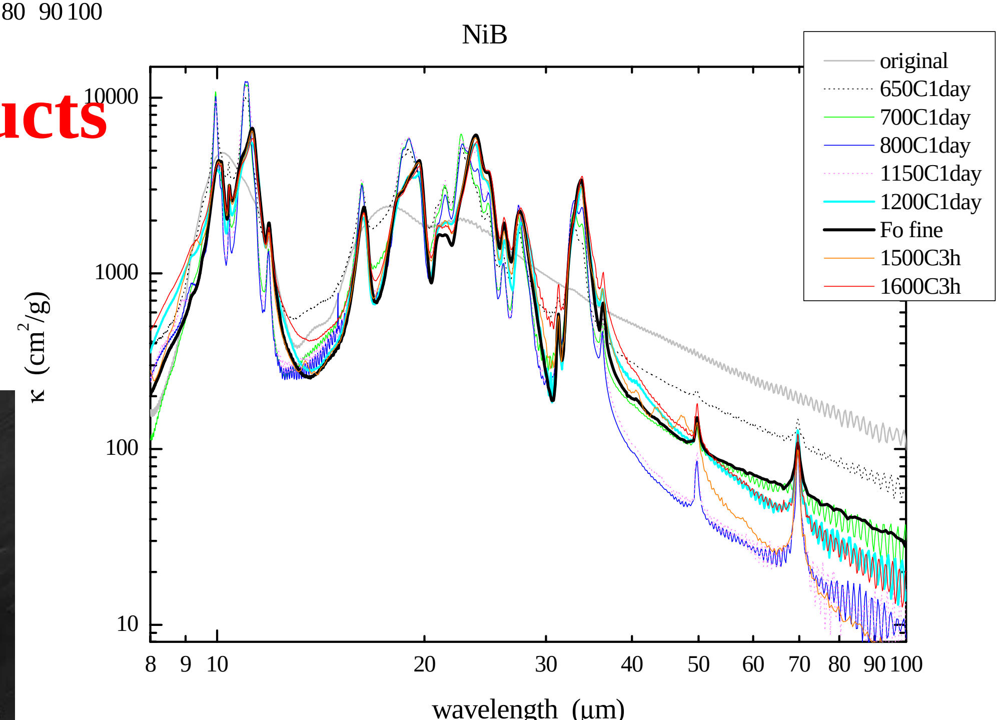
Original



1600℃3h

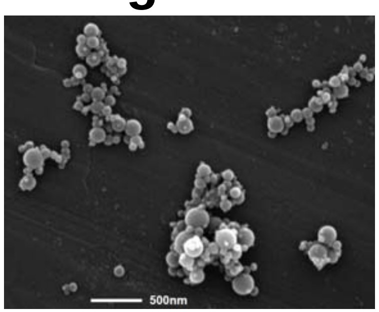


All spectra of two Ni products
For annealed samples

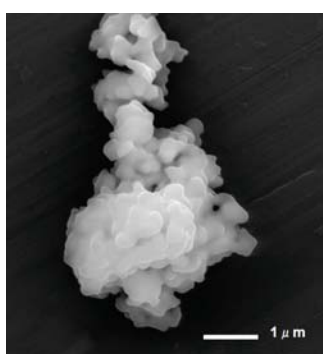


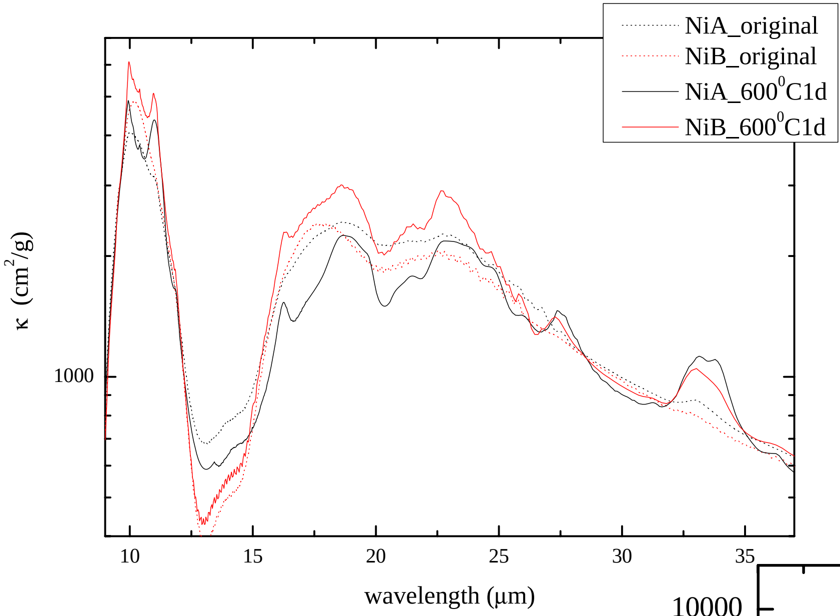
NiB

Original

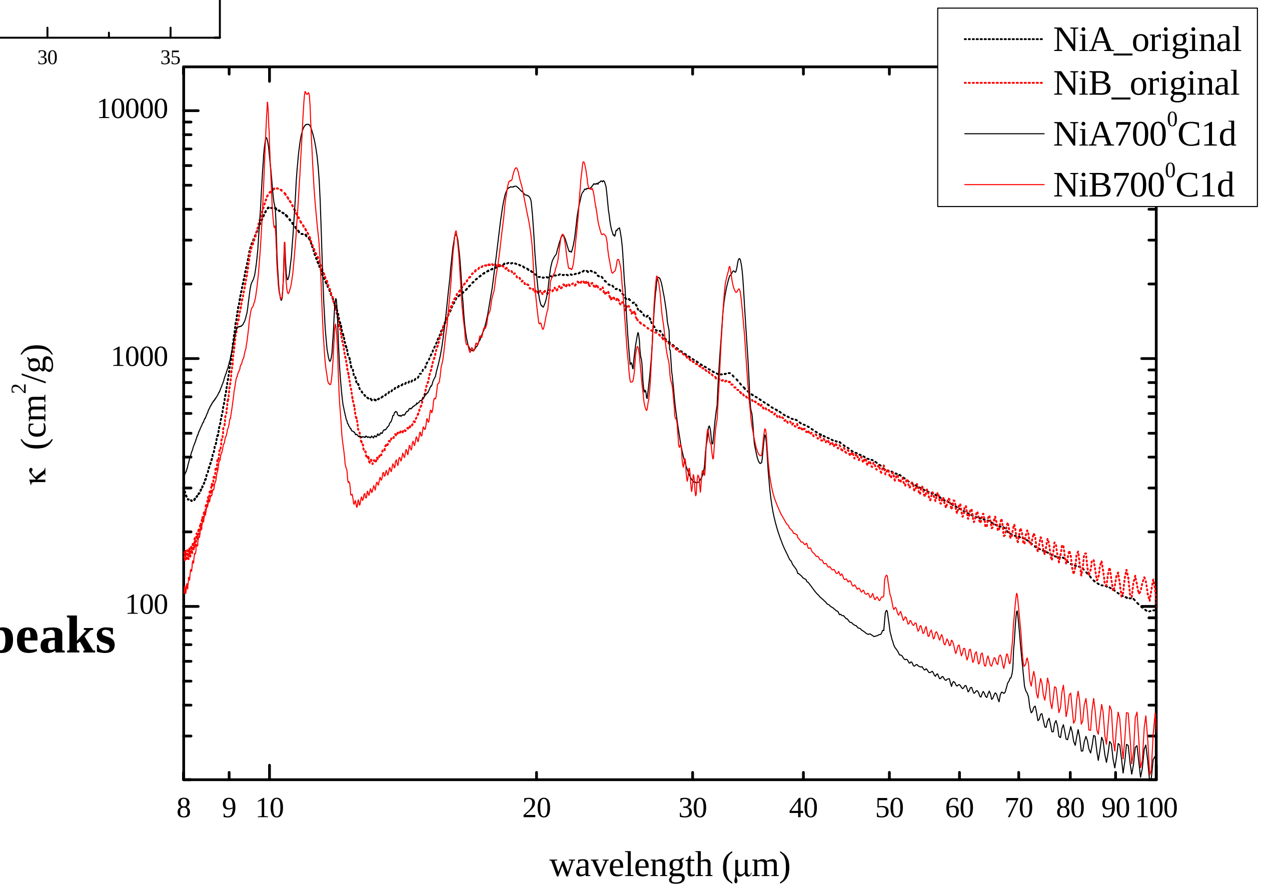


1200℃1d

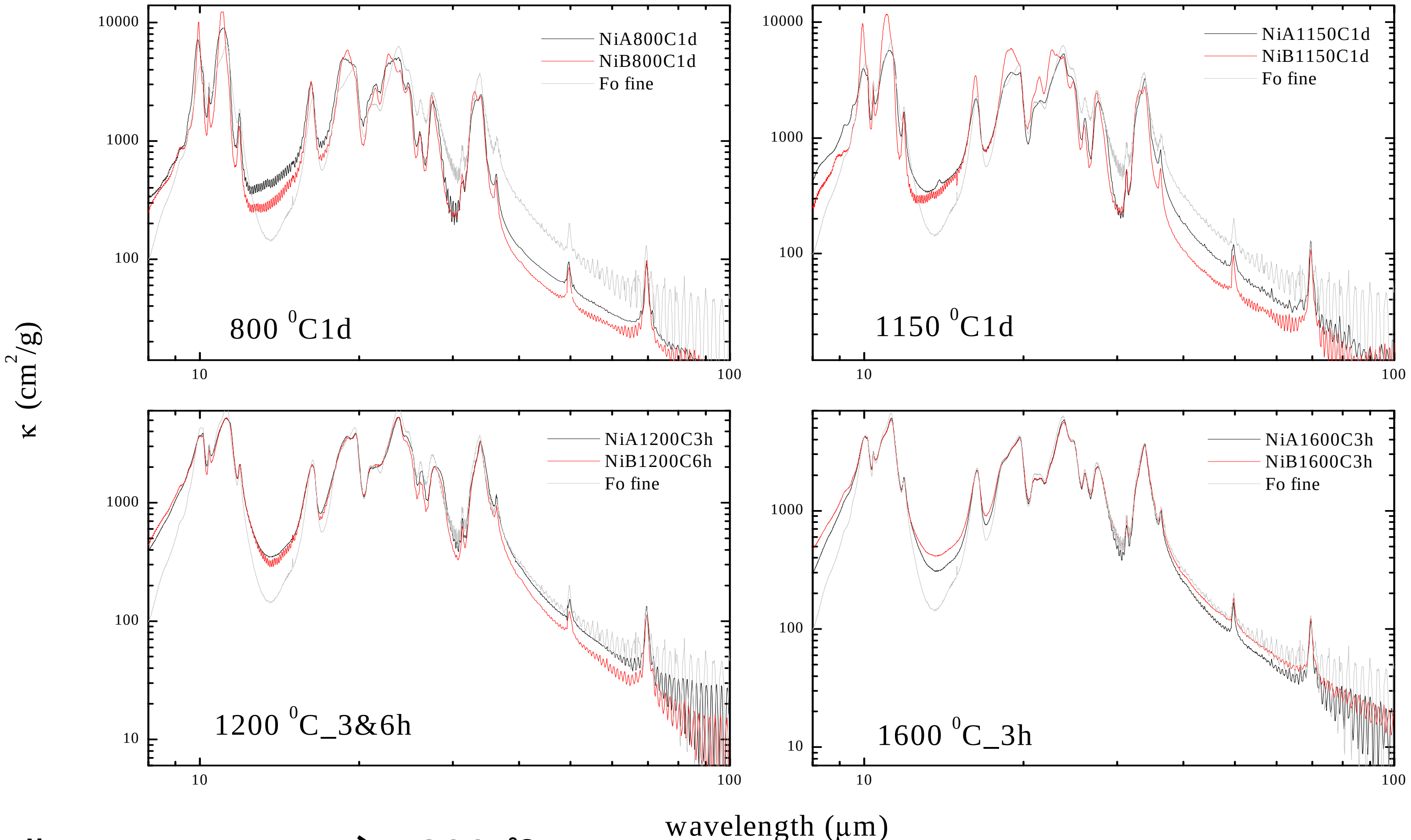




Annealing at 600 ℃
Some broad peaks appear at each band and depend on original products



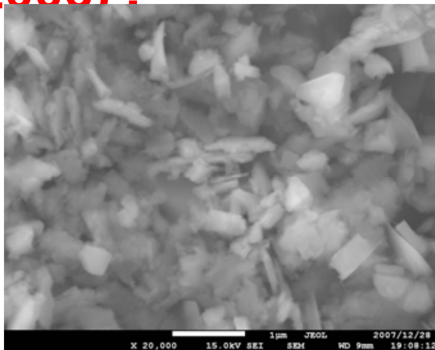
Annealing at 700 ℃
All spectra show sharp peaks
Spectra are depend on original products



Annealing temperature ≥ 1200 ℃

All spectra became similar to that of Fo fine (Koike et al.2006) .

Fo fine

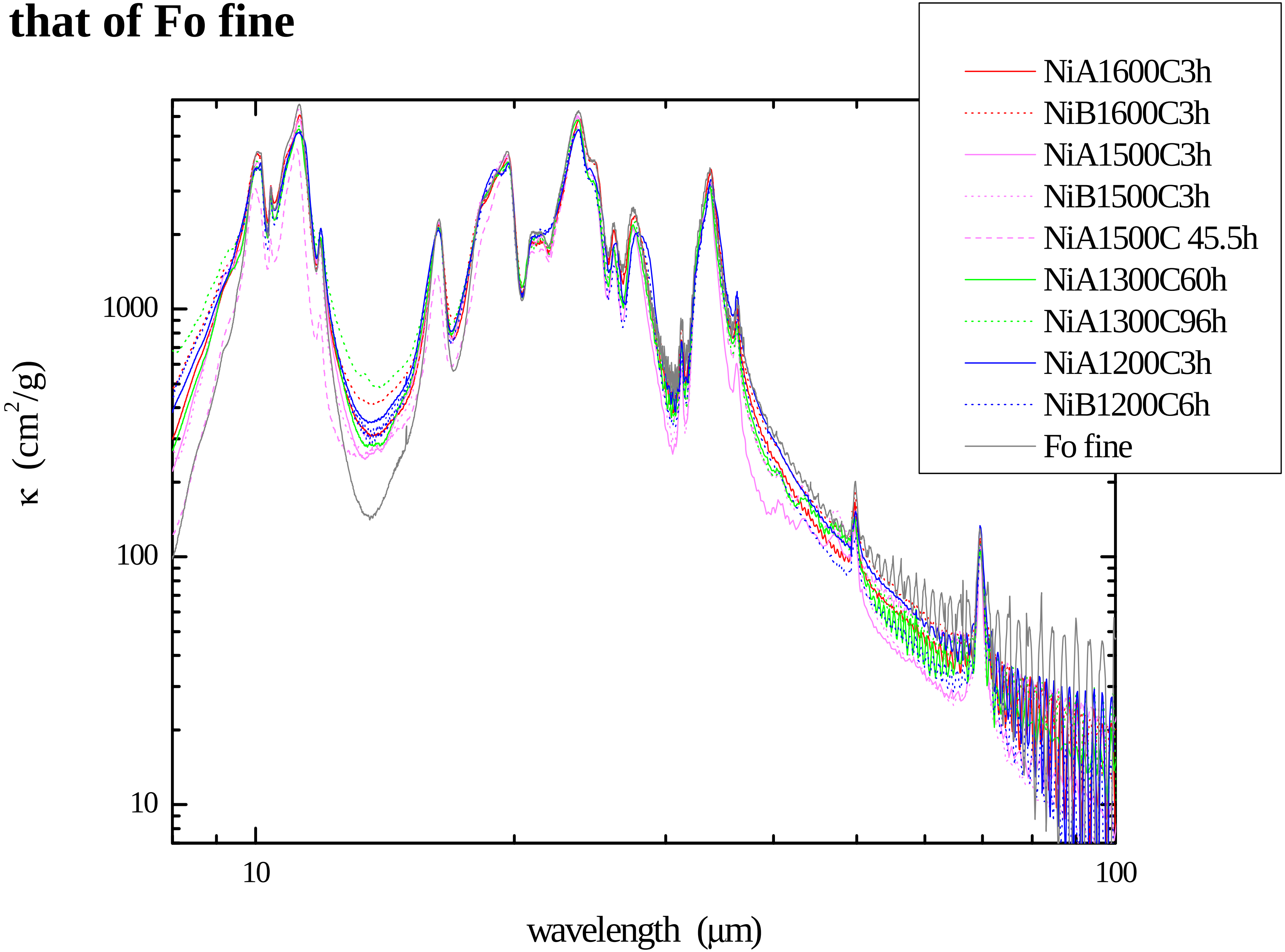


Fo fine

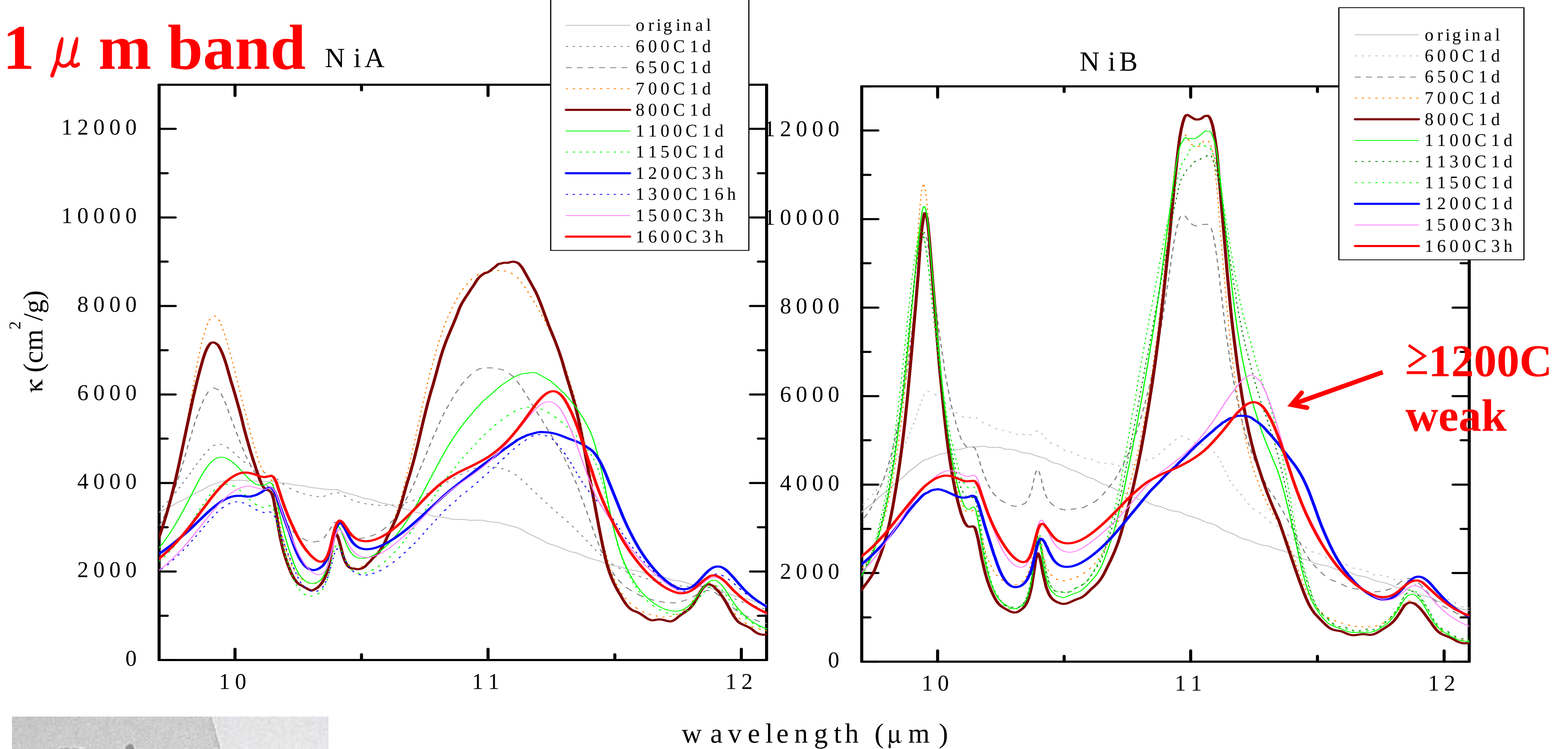
(ground from bulk Fo synthesized by Czochralski method)

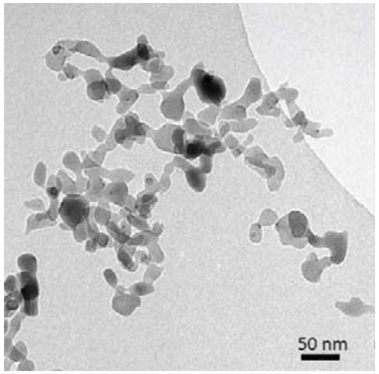
(irregular shape)

Both of products have similar spectra for annealing at above 1200 ℃ as that of Fo fine



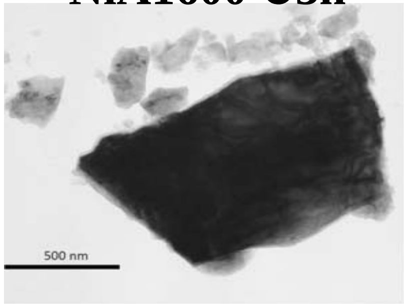
11 μm band

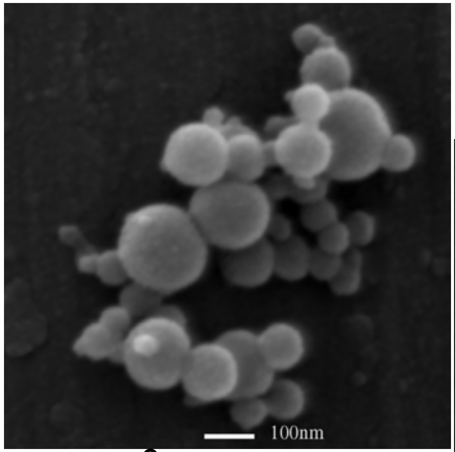




NiA800℃1d

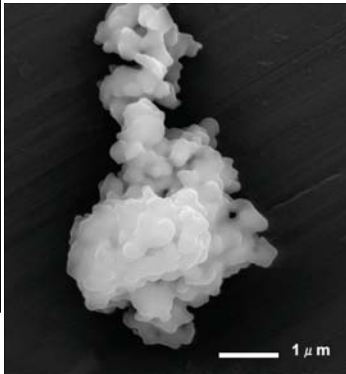
NiA1600℃3h



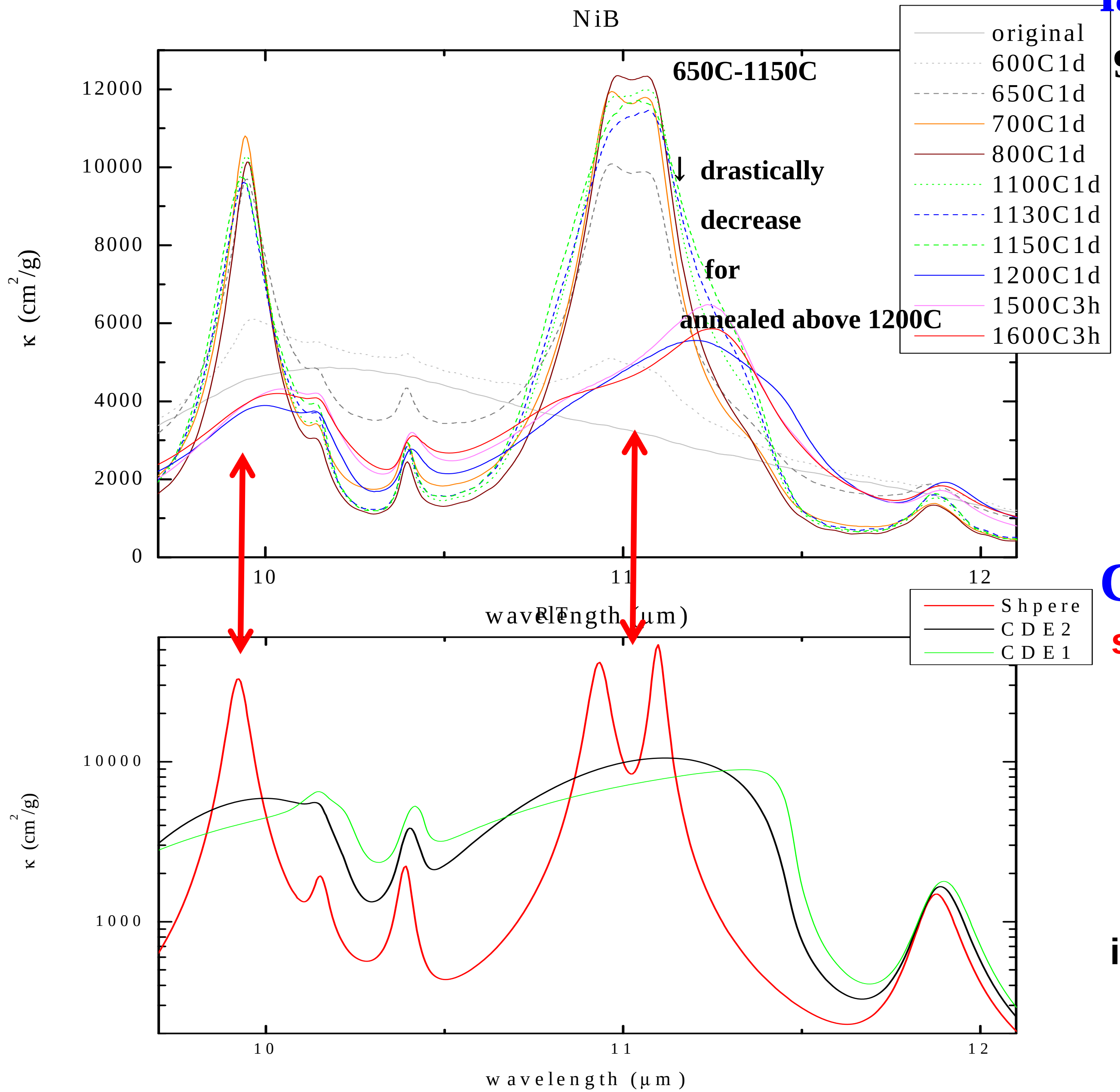


NiB800℃1d

NiB1200℃1d



labo data



9.95 μ m and 11 μ m peak intensity

strong → weak

spherical & coagulate

↓

irregular (≥1200 C)

Calculation (in KBr)

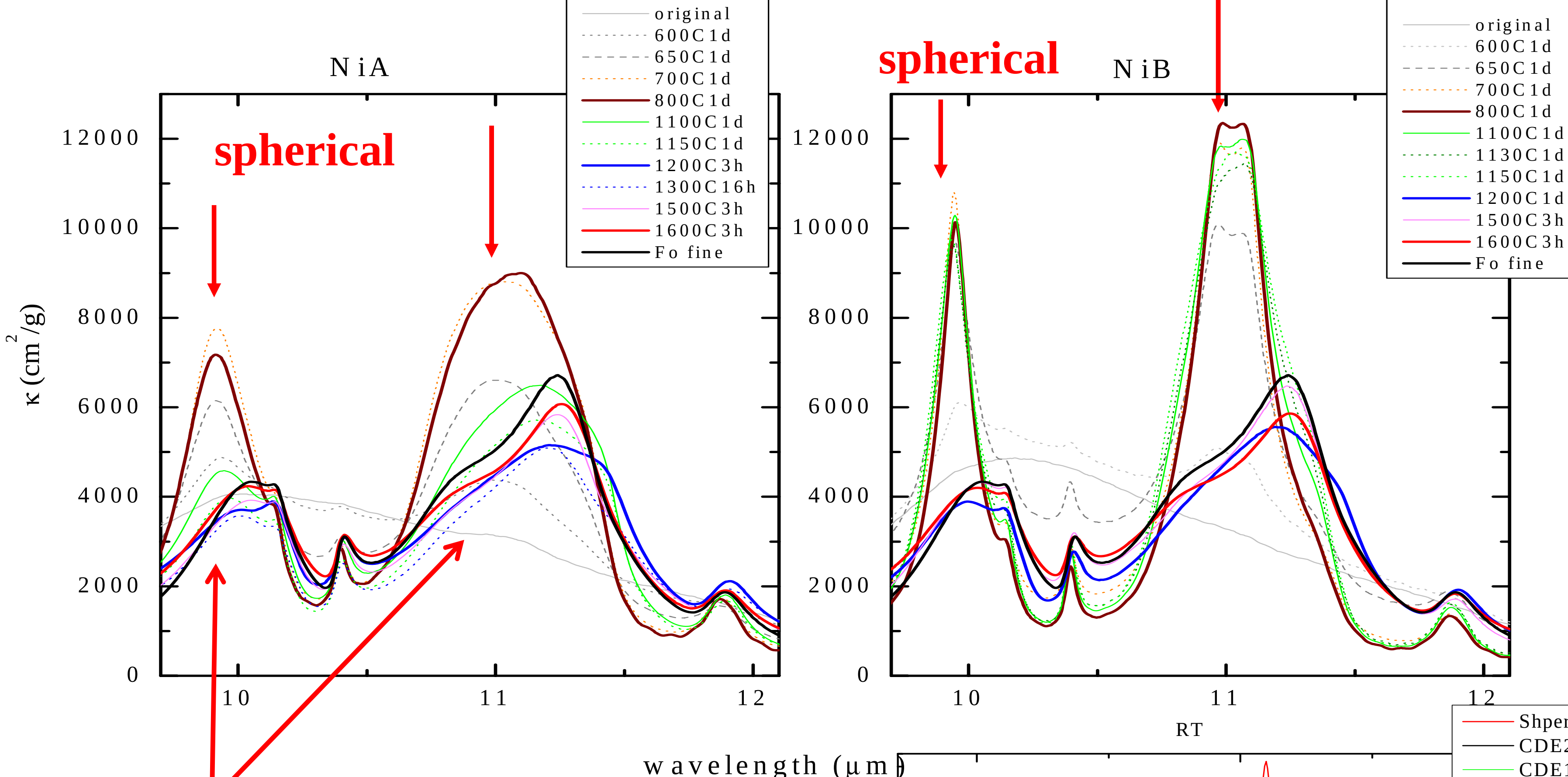
spherical

9.95 μ m sharp peak

11 μ m peak double peak

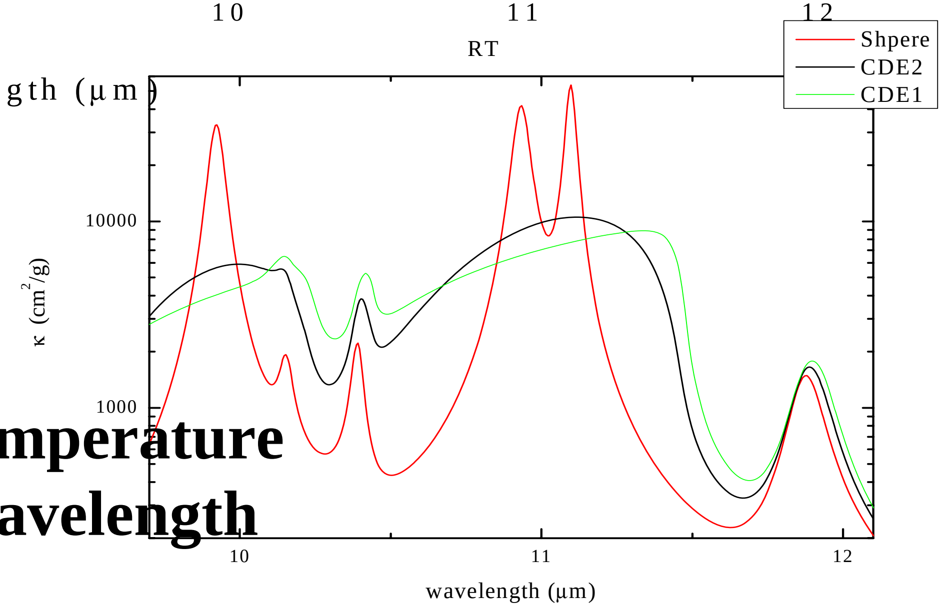
irregular broad, peak position shift

CDE1: Continuous Distributions of Ellipsoids (CDE2: near-spherical particle shapes)



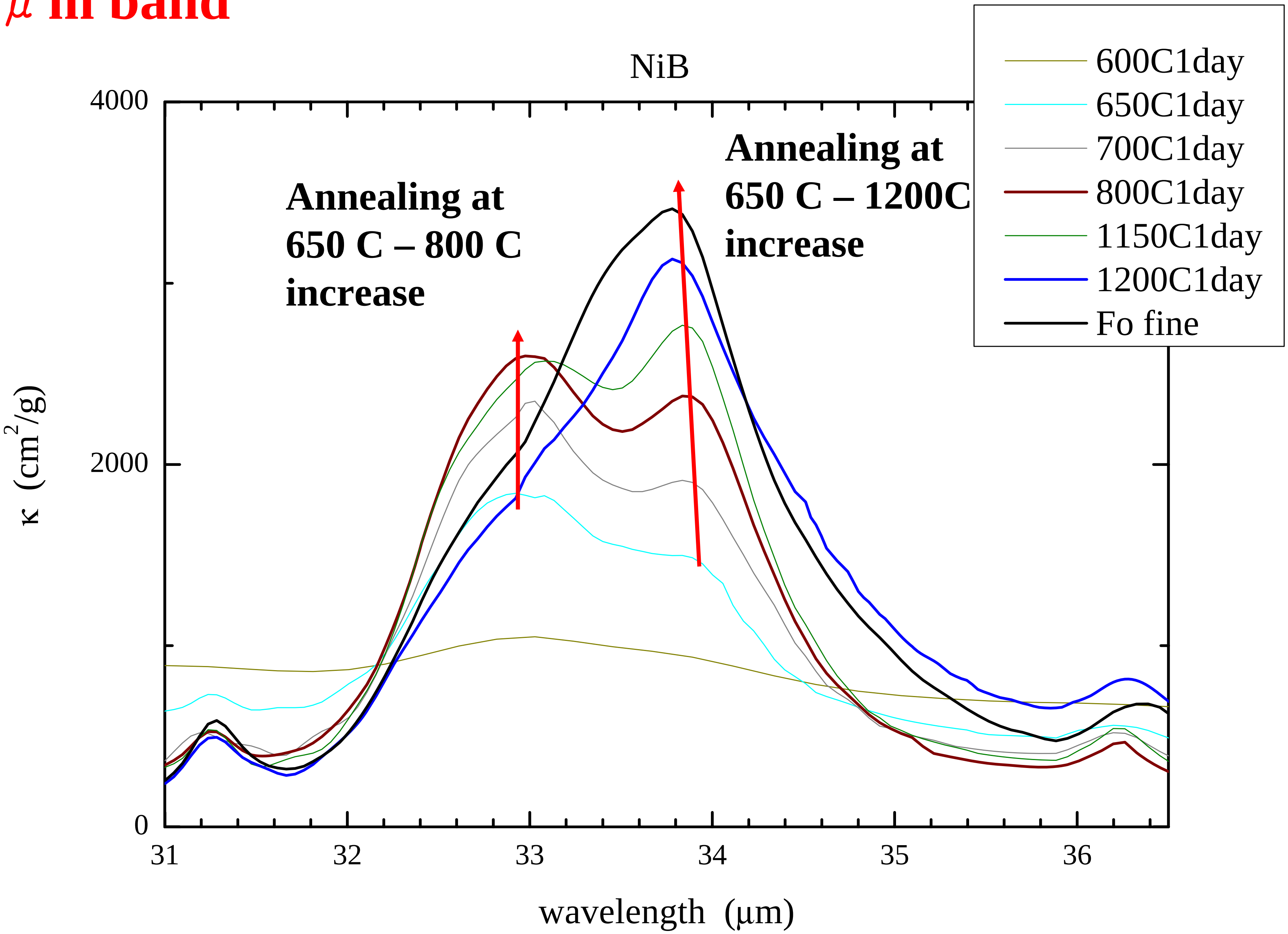
NiA compare to NiB

9.95 μm & 11 μm
broad due to coagulation

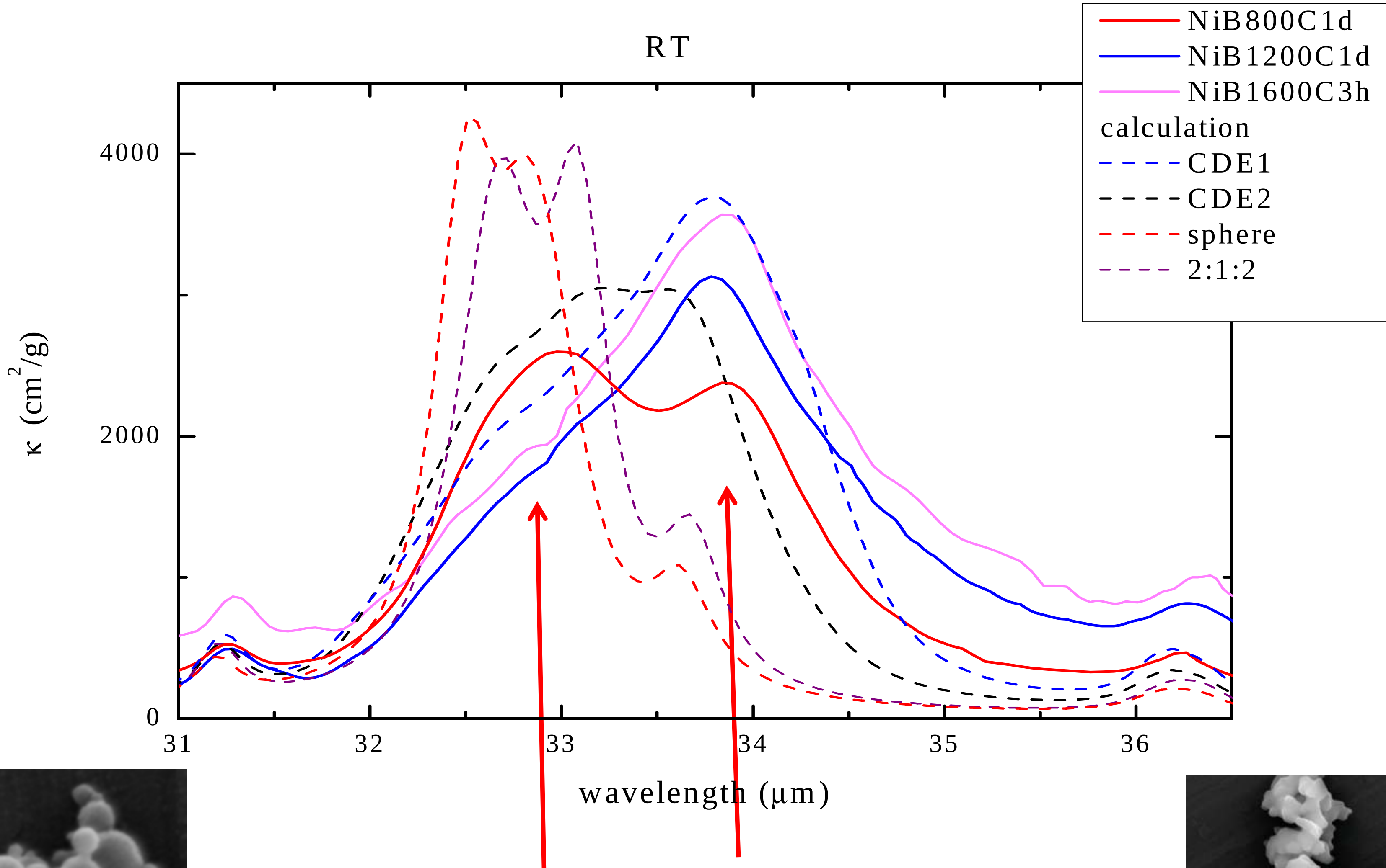


NiA & NiB for high annealing temperature
peak position shifts to long wavelength
due to irregular shape

33 μ m band

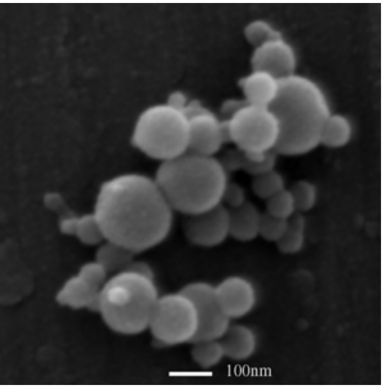


NiB
Annealing at
650 C – 800 C
increase
Annealing at
650 C – 1200C
increase
600C1day
650C1day
700C1day
800C1day
1150C1day
1200C1day
Fo fine
4000
2000
0
κ (cm²/g)
31
32
33
34
35
36
wavelength (μm)

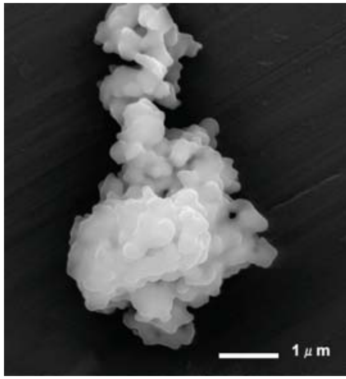


spherical
& coagulation

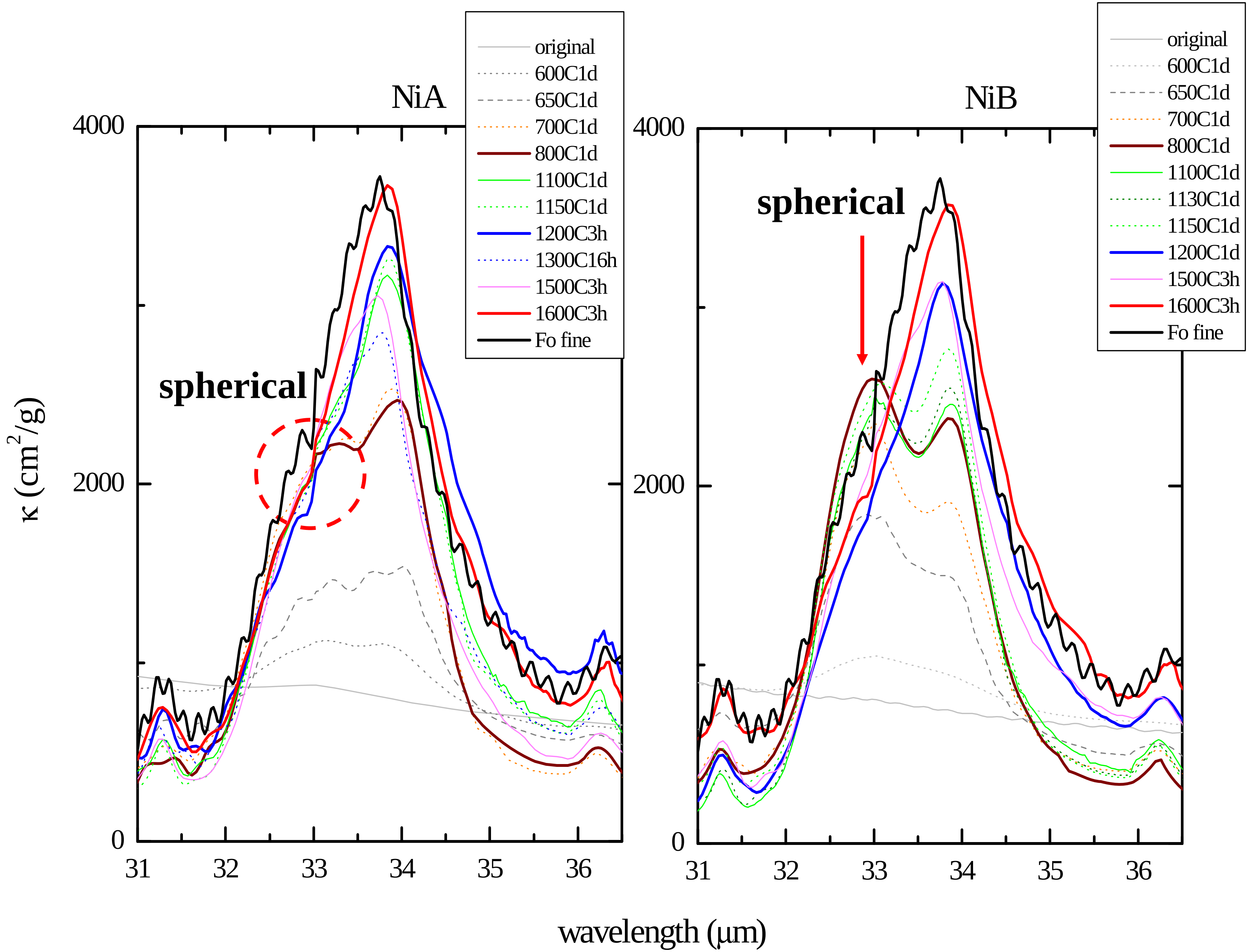
CDE (irregular shape)



NiB800℃1d

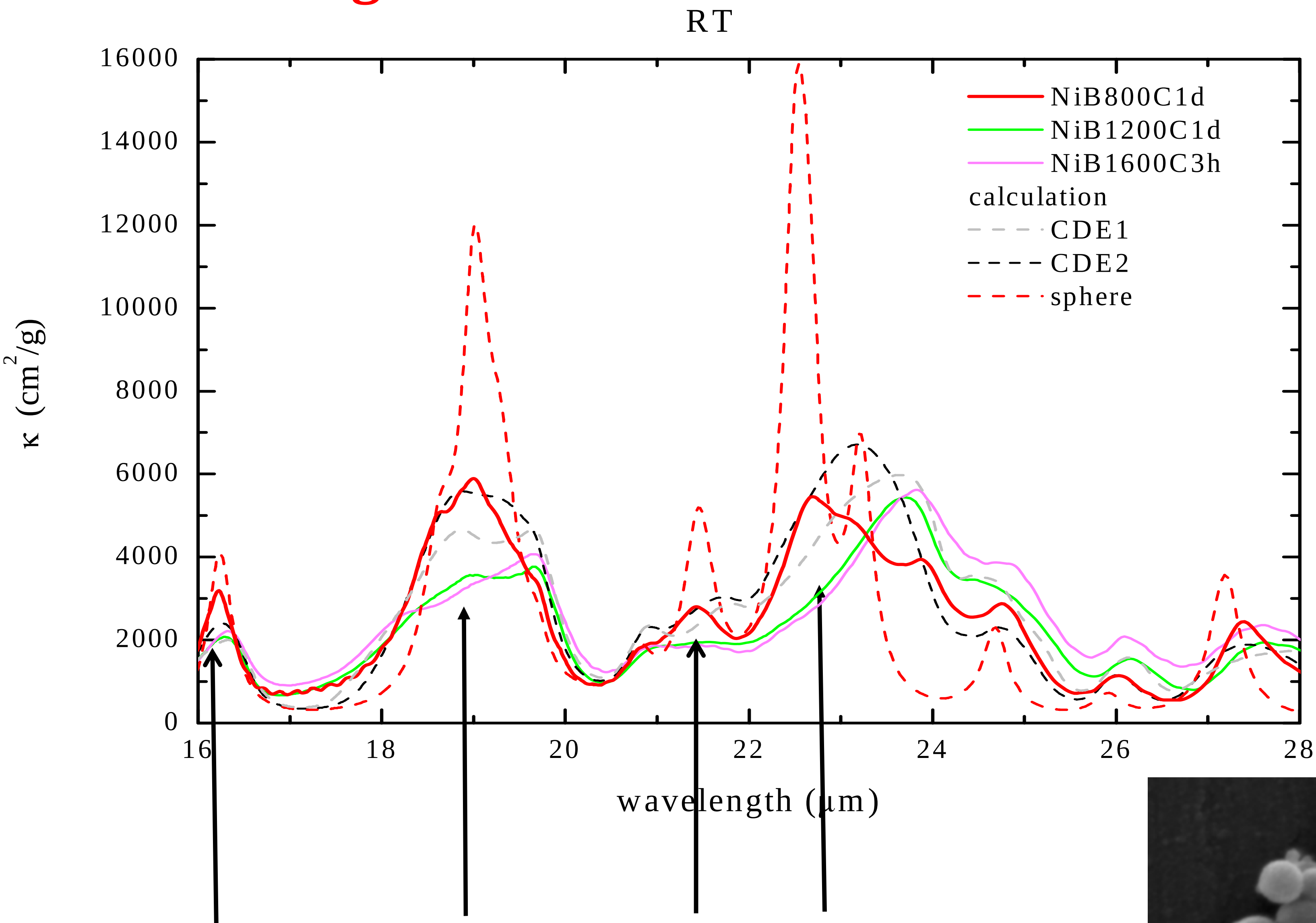


NiB1200℃1d



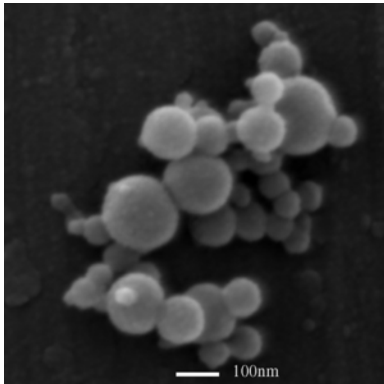
NiA
NiB
spherical
spherical
original
600C1d
650C1d
700C1d
800C1d
1100C1d
1130C1d
1150C1d
1200C3h
1200C1d
1300C16h
1500C3h
1600C3h
Fo fine
κ (cm²/g)
wavelength (μm)
4000
2000
0
31
32
33
34
35
36

16 – 28 μ m region

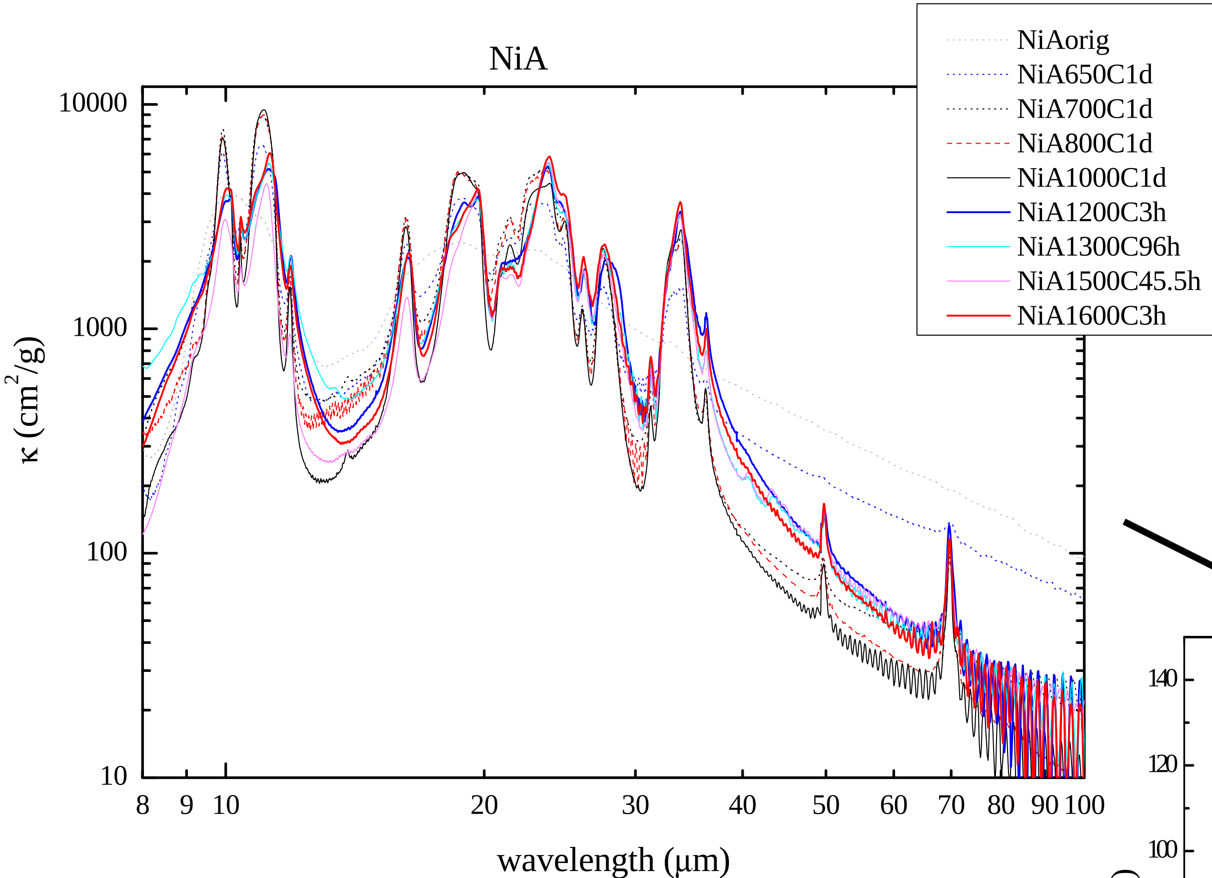


Spherical & coagulation

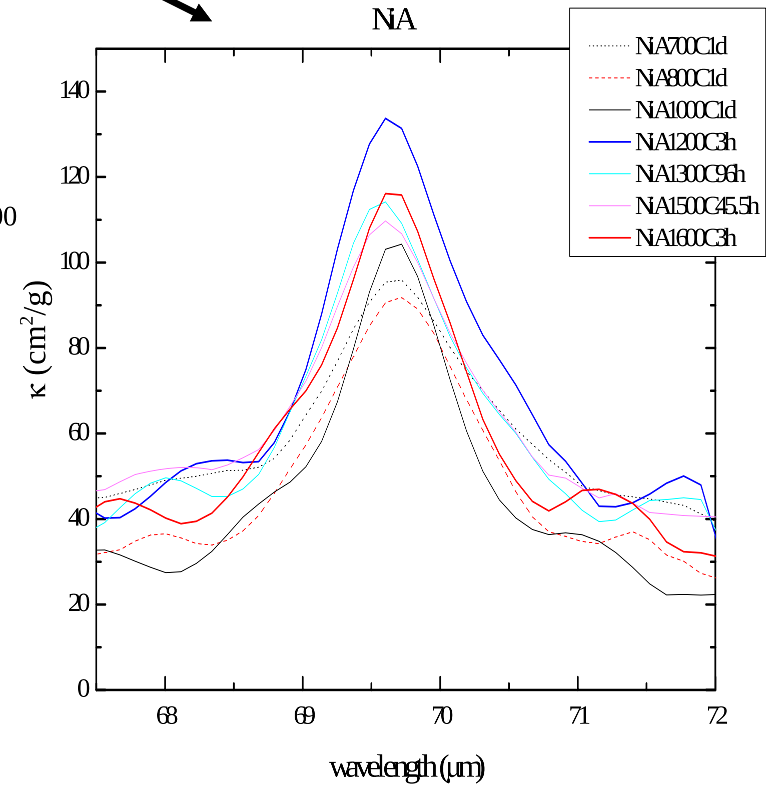
NiB800℃1d



69um band

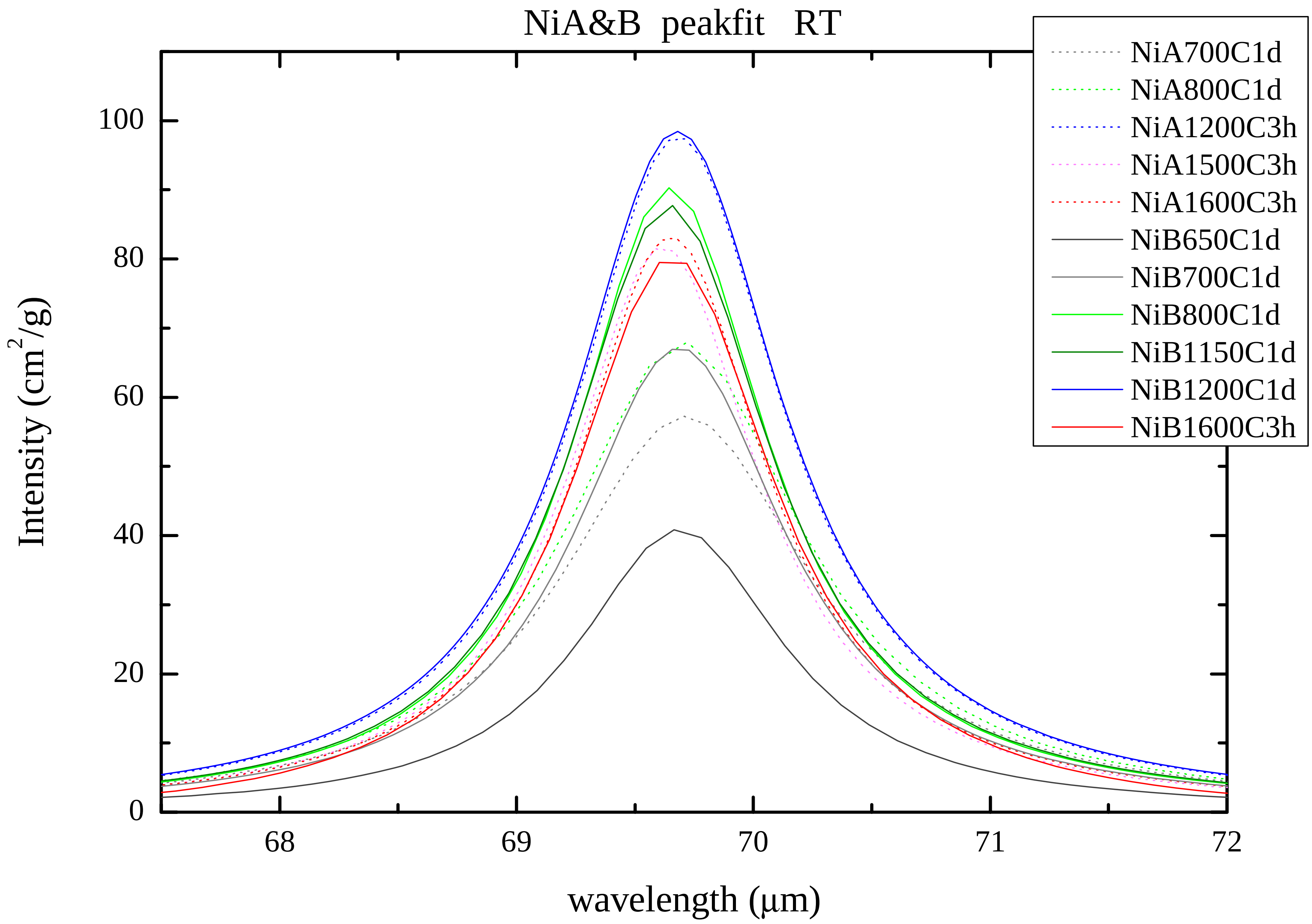


69 μm band

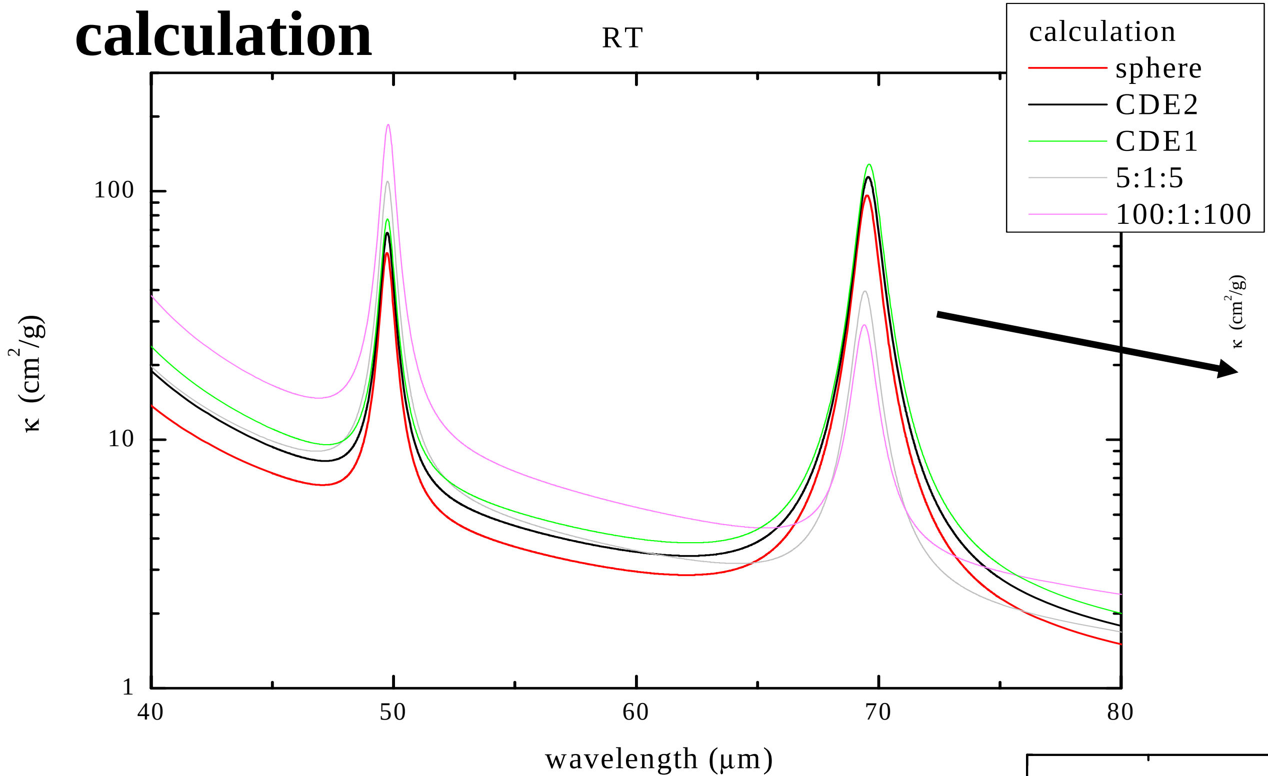


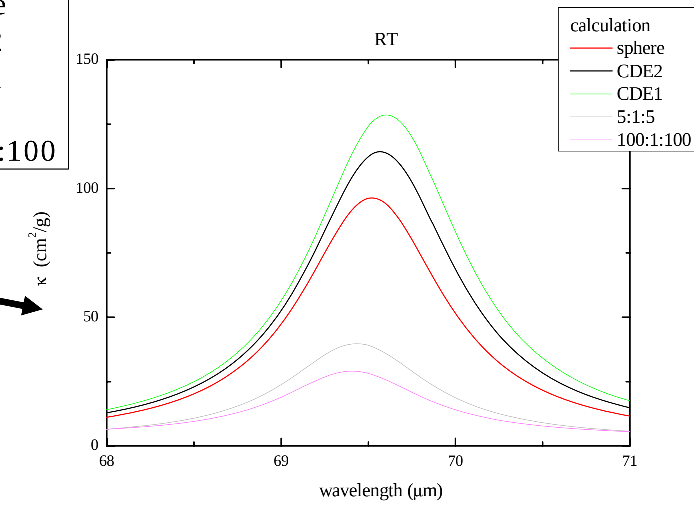
How to change intensity, peak position, and FWHM of 69 um band

These may be depend on shape of particles ?

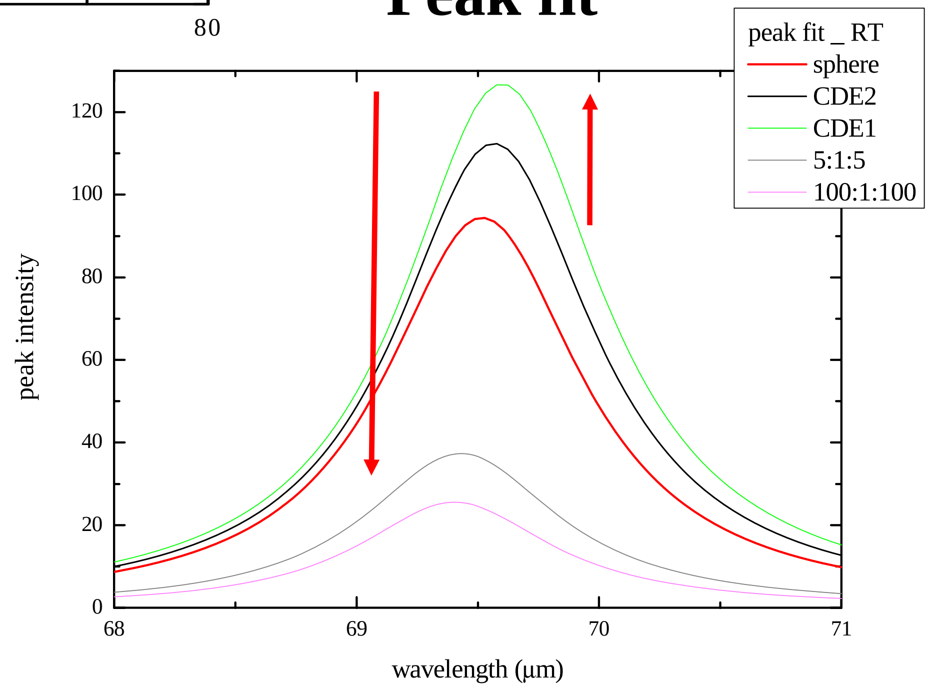

NiA&B peakfit RT
NiA700C1d
NiA800C1d
NiA1200C3h
NiA1500C3h
NiA1600C3h
NiB650C1d
NiB700C1d
NiB800C1d
NiB1150C1d
NiB1200C1d
NiB1600C3h
Intensity (cm²/g)
0
20
40
60
80
100
68
69
70
71
72
wavelength (μm)

calculation



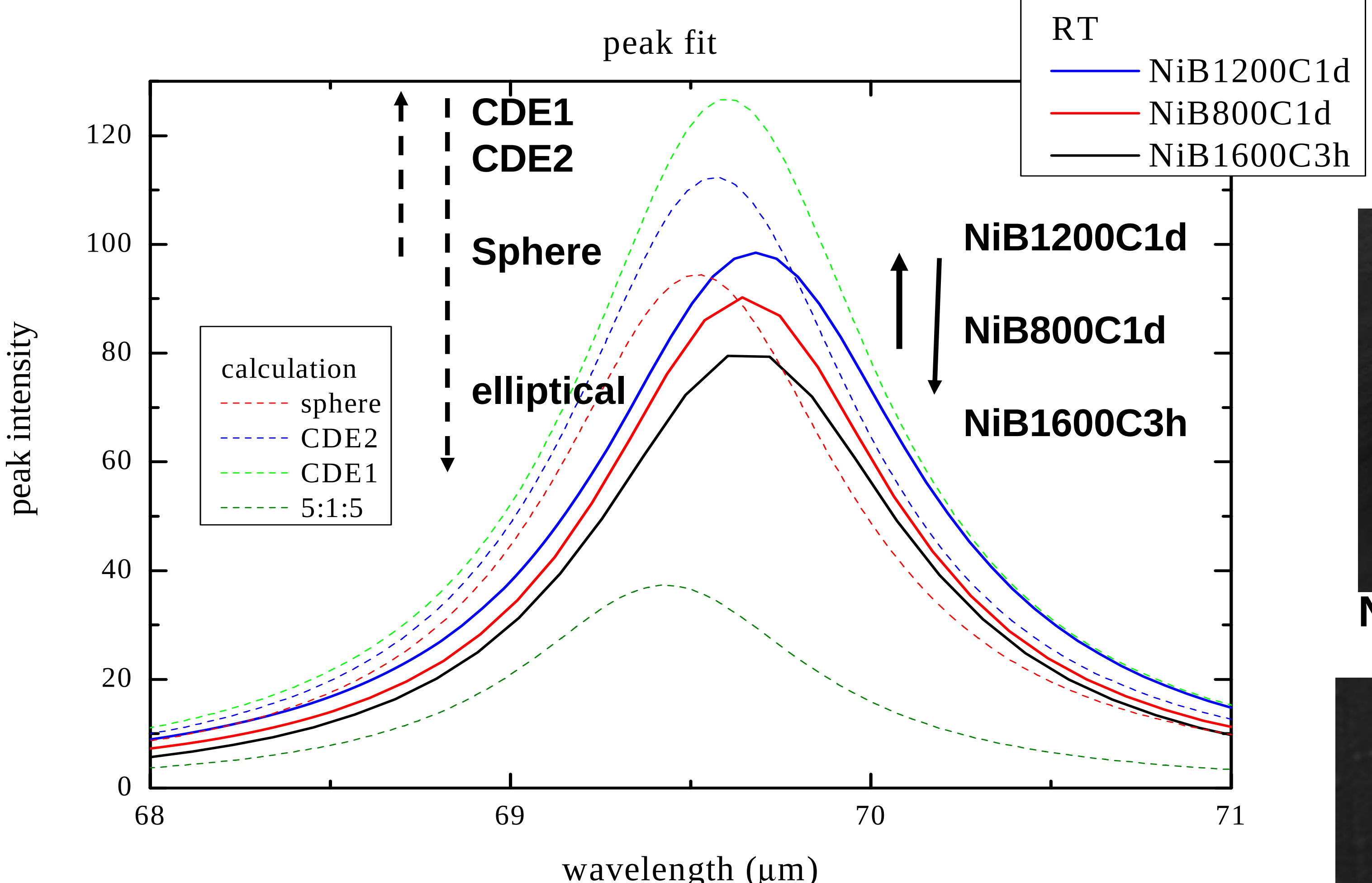


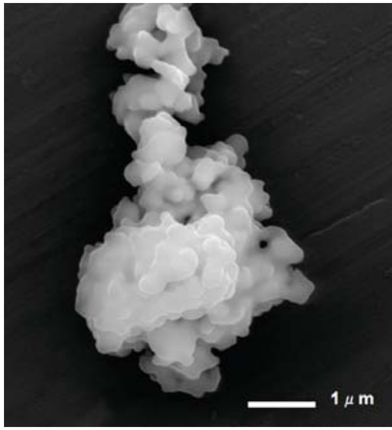
Peak fit



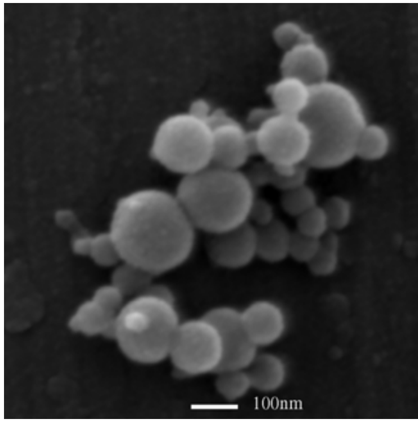
Calculation (in PE)
Peak intensity
sphere
↓ **strong**
CDE1, CDE2
↓ **weak**
elliptical

Annealing
sphere
↓
irregular
↓
Plate-like including





NiB1200C1d



NiB800C1d

Difference of Peak intensity
due to shape effects & coagulation
(irregular & only small part of plate-like)

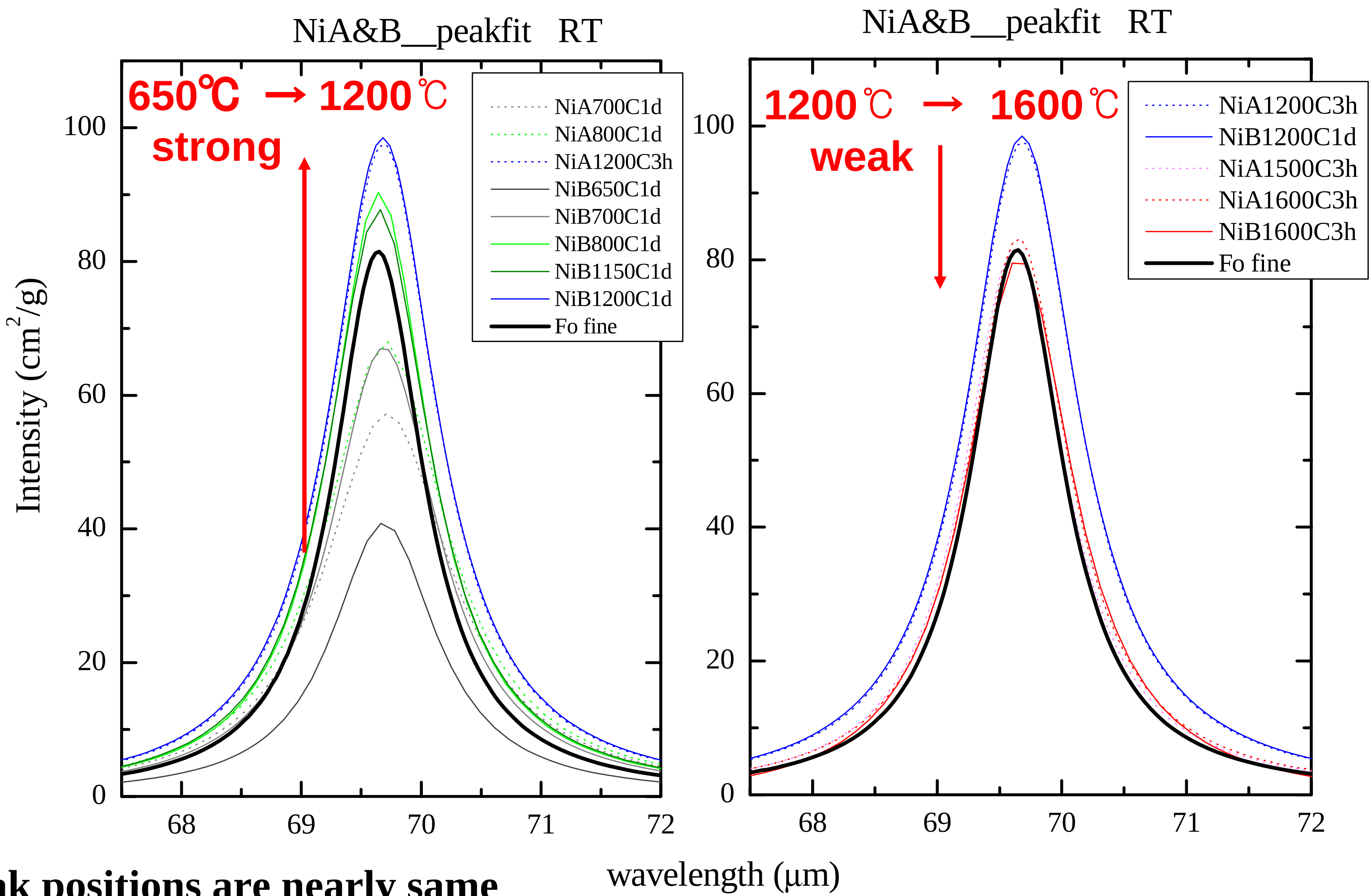
Difference of peak position among labo data and calculation
may be due to refractive index of PE ?
LDPE n = 1.46 (here assume1.50) , HDPE n = ?

Peak intensity of 69 um band

peak intensity strong weak

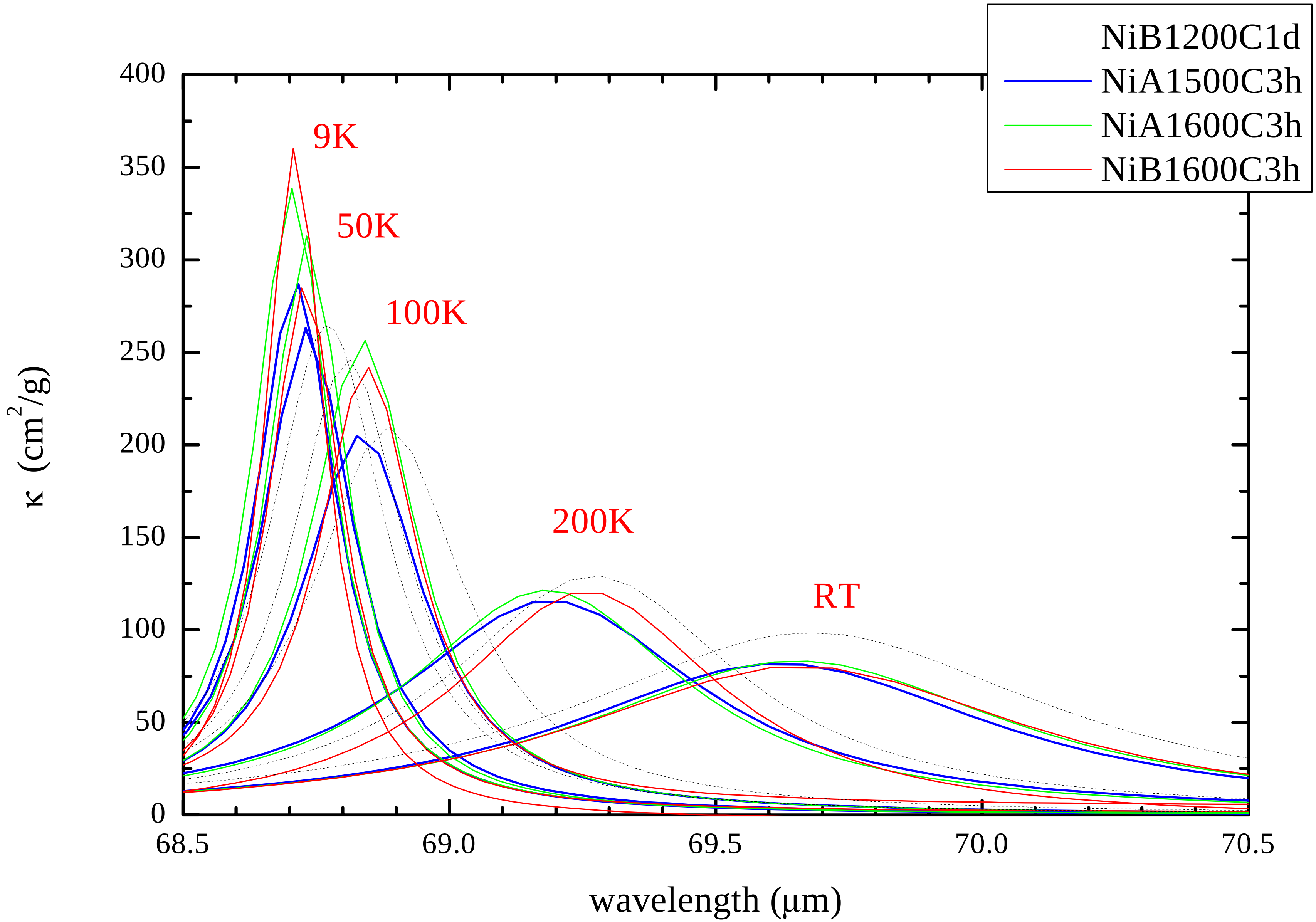
annealing temperature 650 ℃ → 1200 ℃ → 1600 ℃

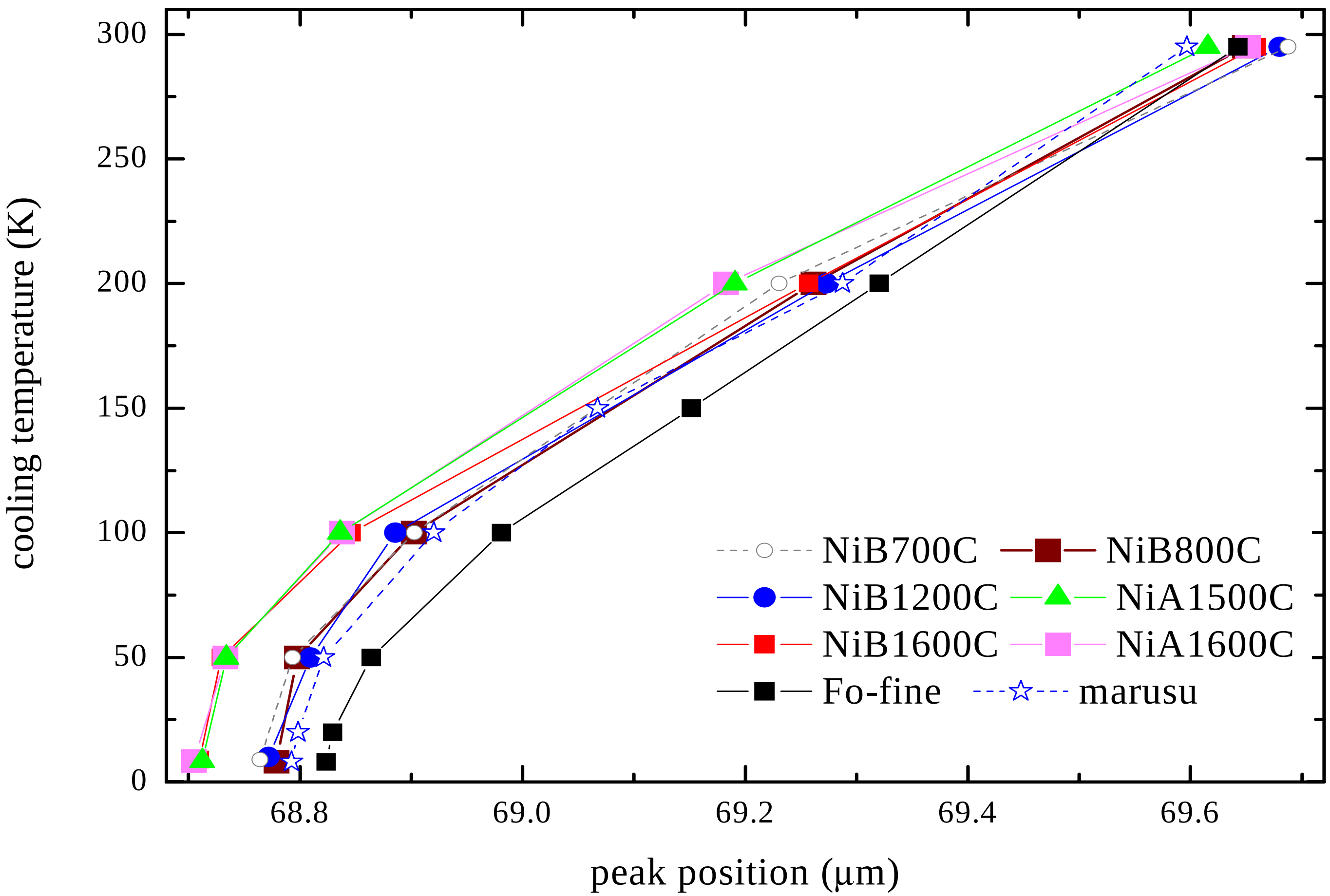
crystal growth & shape effects shape effects

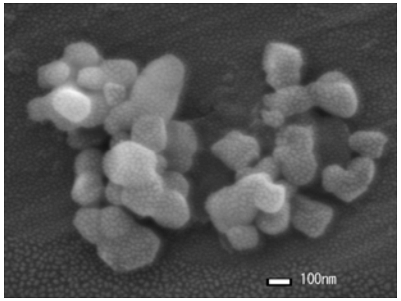


Peak positions are nearly same

69 μ m band at each cooling temperature





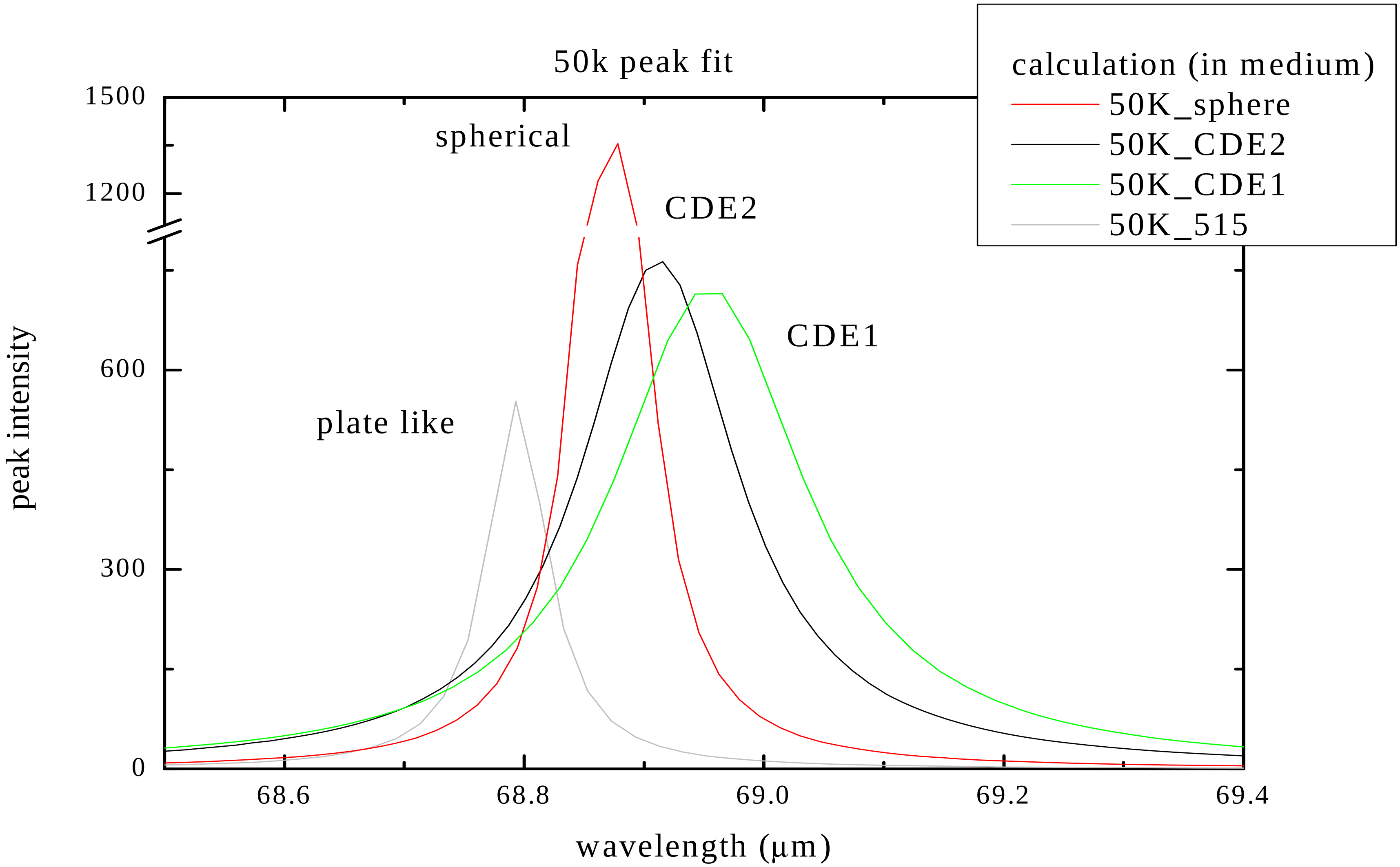


Marusu Fo (commercial) (about 0.2 μm) (elliptical)

All peak positions shift shorter than that of Fo fine lower 200 K

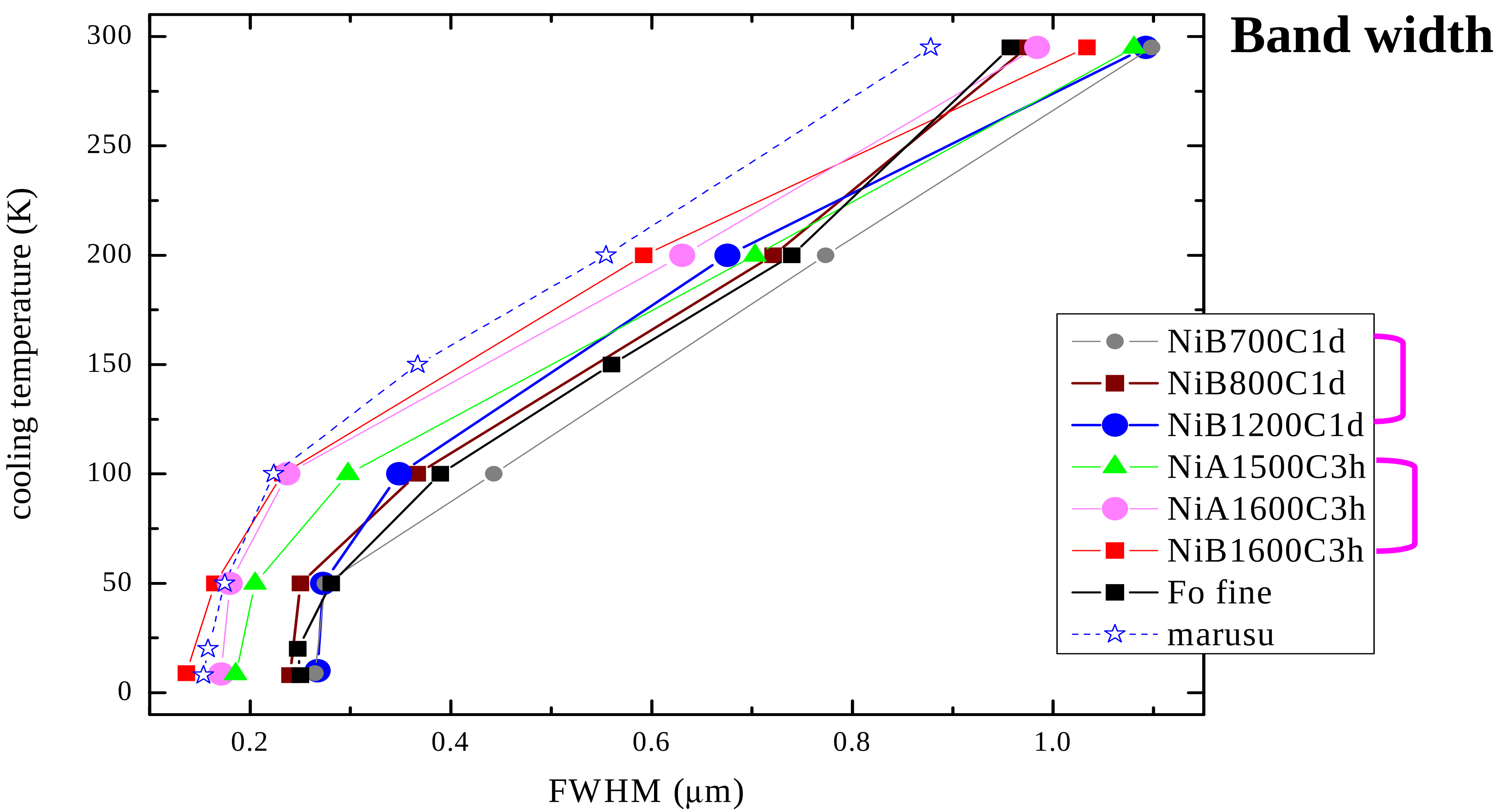
Samples of annealing at 1500C and 1600C

Peak positions shift to a little shorter wavelength than spherical this may be due to increase plate-like shape? It is not clear.



Peak position

plate like : shift to shorter wavelength than spherical



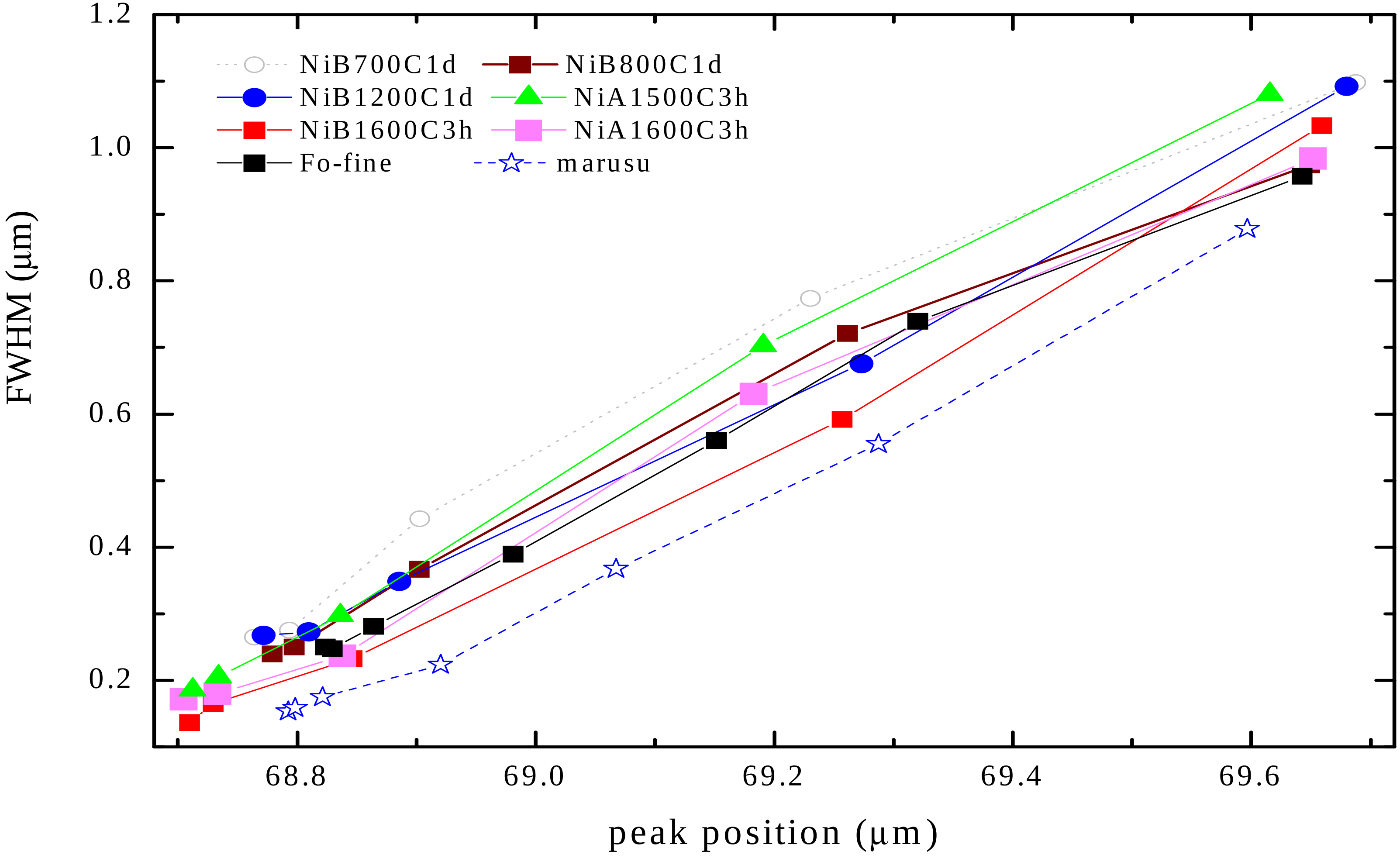
Cooling temperature ↓ : FWHM (Full Width of Half Maximum) ↓

At low temperature : high annealing temperature samples

FWHM became a little sharp

: may be due to similar size ?

Marusu Fo: band is very sharp due to similar size ?



Cooling temperature became low

Peak position & FWHM : correlation

The tendency is same as for annealed sample and Fo fine except for marusu

Summary

Annealing temperature

Below 1200 ℃ for both products

spectra depend on shape (spherical & coagulation)

11 μm, 19 μm, 23 μm, 33 μ, 69 μm band

for spherical ---- each peak became sharp and strong

above 1200 ℃ for both products (irregular)

all spectra became similar to that of Fo fine

69 μm band for cooling

peak strength

depend on shape (annealing temperature) & coagulation