Soft particles

Plastic deformation and mechanical dissolution of Cu precipitates in steel

T. Tsuchiyama[*1], S. Yamamoto[*2], S. Hata[*3], M. Murayama[*4] and S. Takaki[*1]

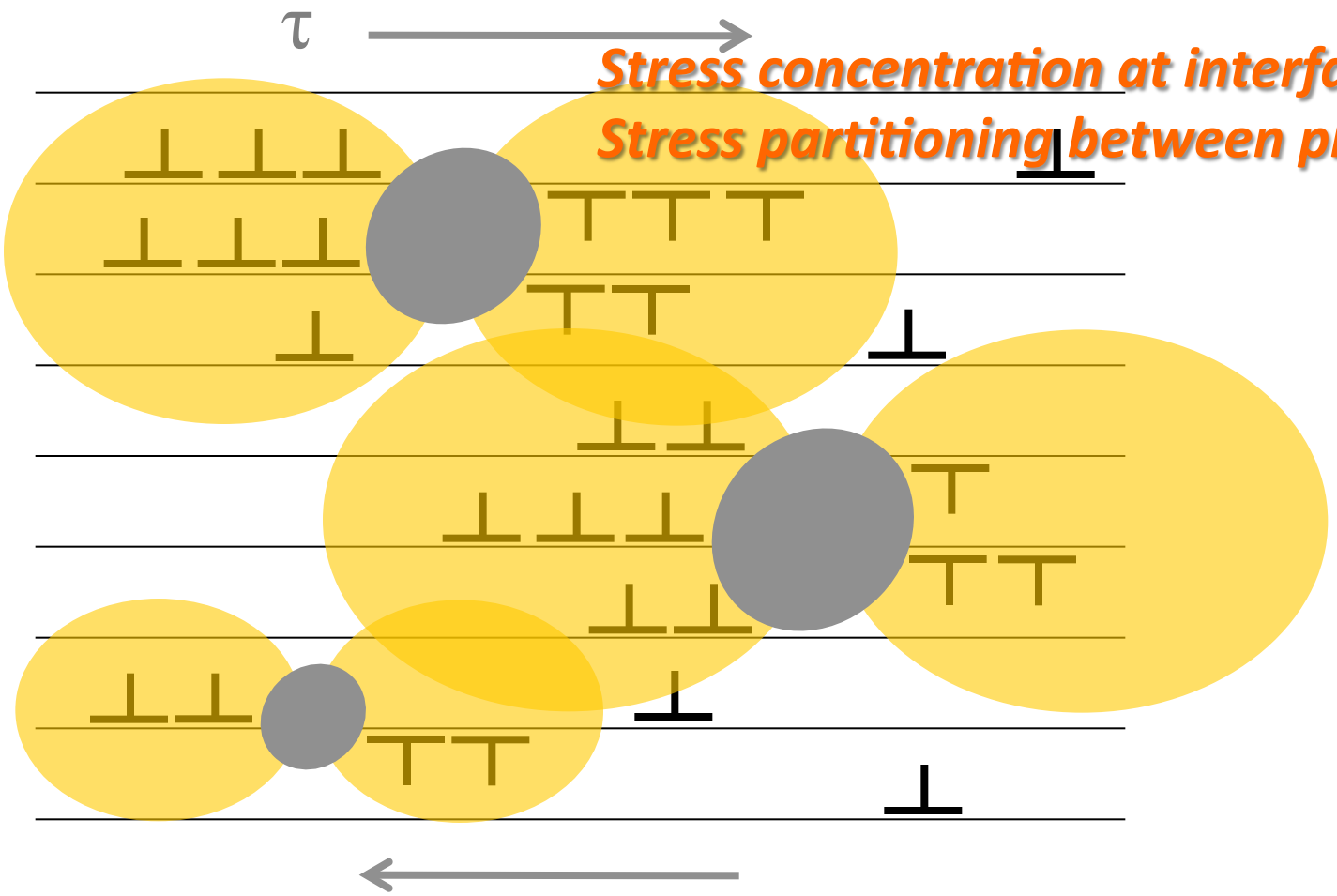
*1 Dept. Materials Science and Engineering, Kyushu University
*2 Graduate student of Kyushu University
*3 Dept. Electrical and Materials Science, Kyushu University
*4 Dept. Materials Science and Engineering, Virginia Tech

KYUSHU
UNIVERSITY

VirginiaTech
Invent the Future

Conventional Hetero structure

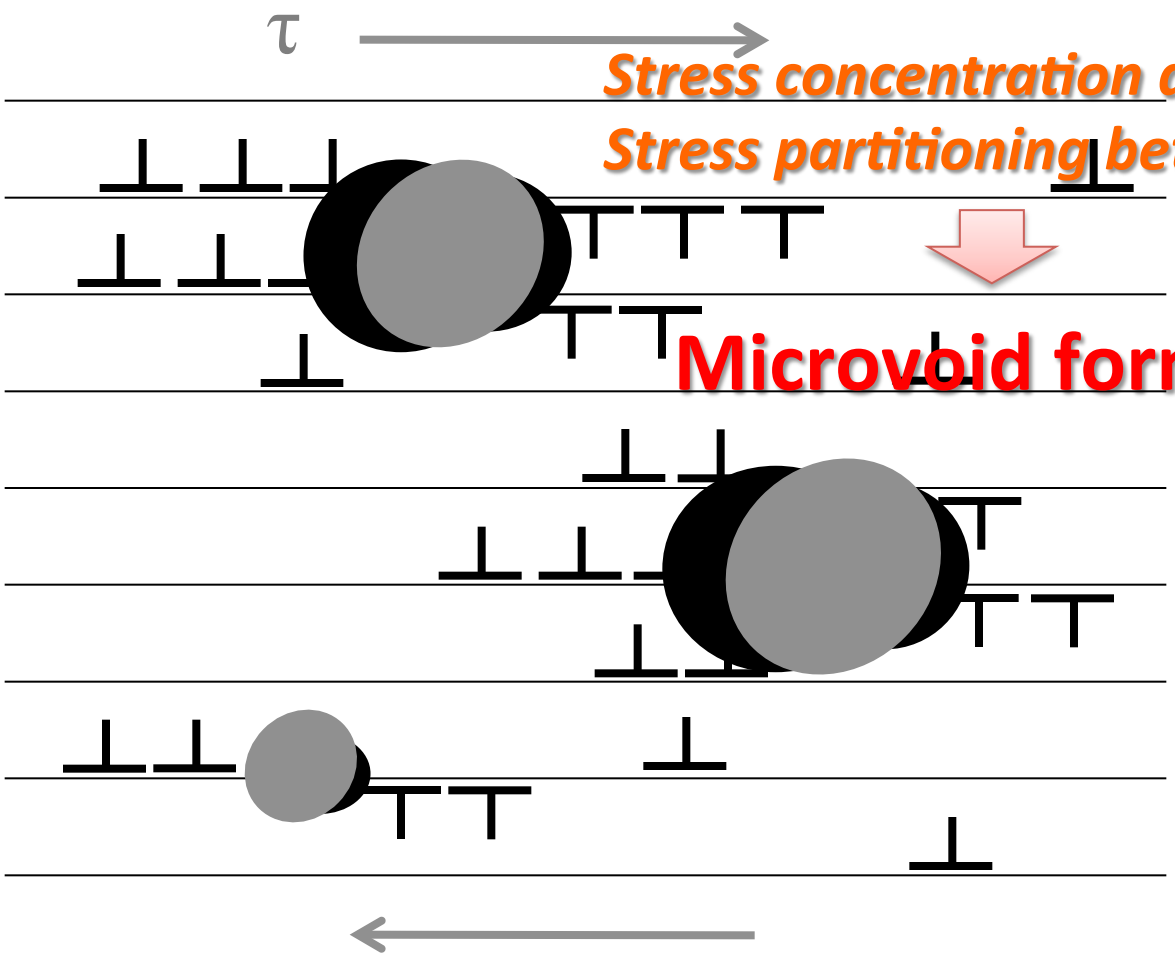
(microstructure containing hard second phase particles)



Work hardening rate is increased

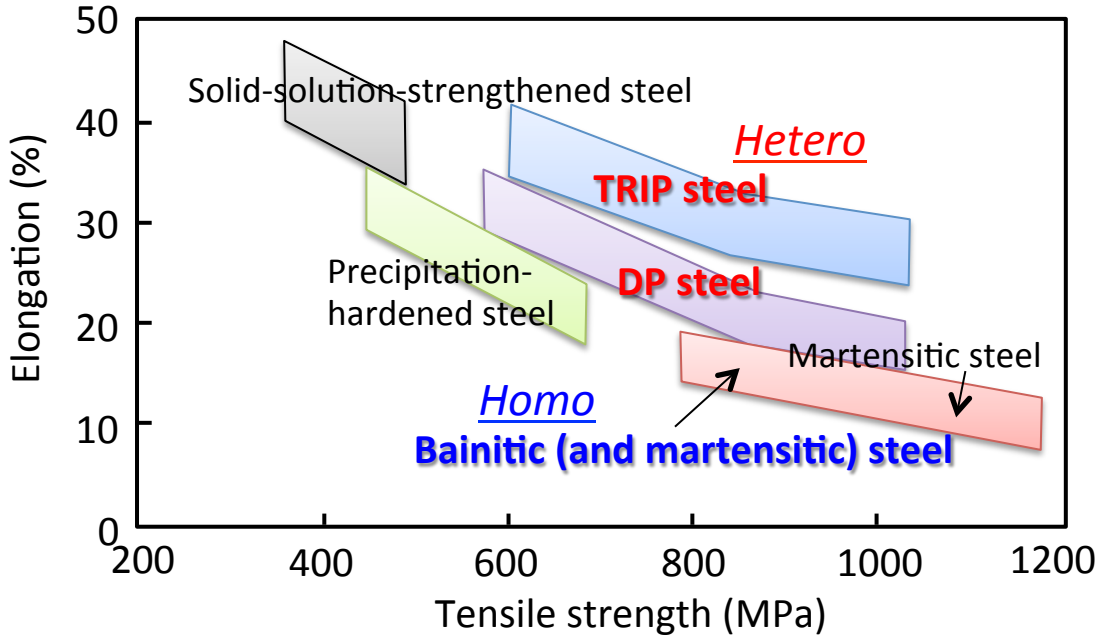
Conventional Hetero structure

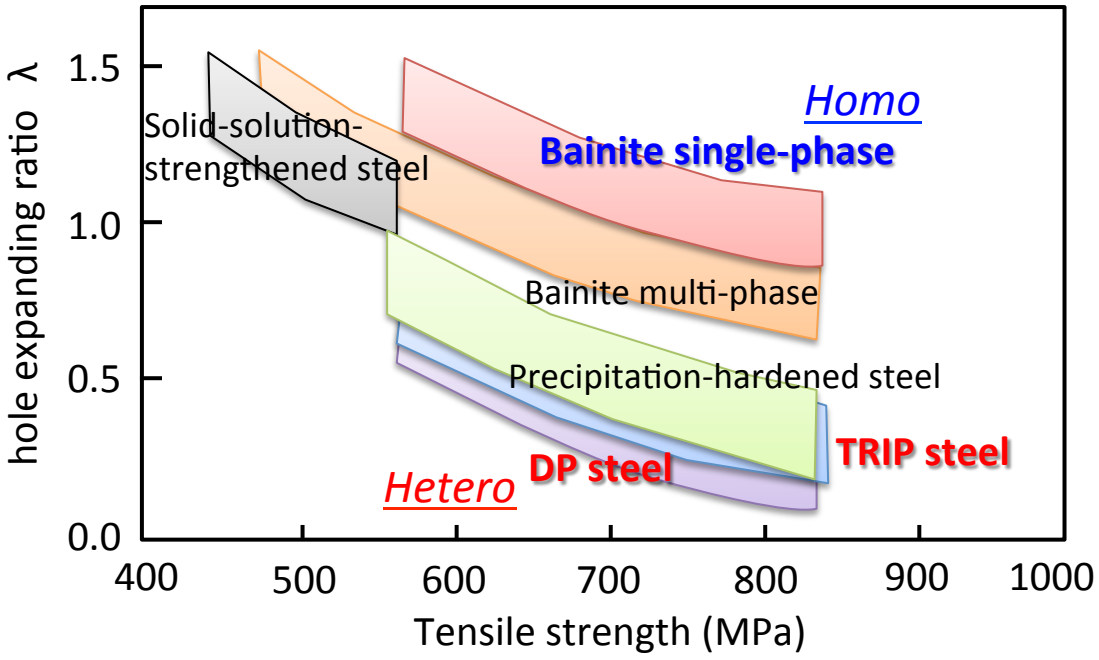
(microstructure containing hard second phase particles)



Ductile fracture is enhanced

Strength-elongation and strength hole expanding ratio balances in steel

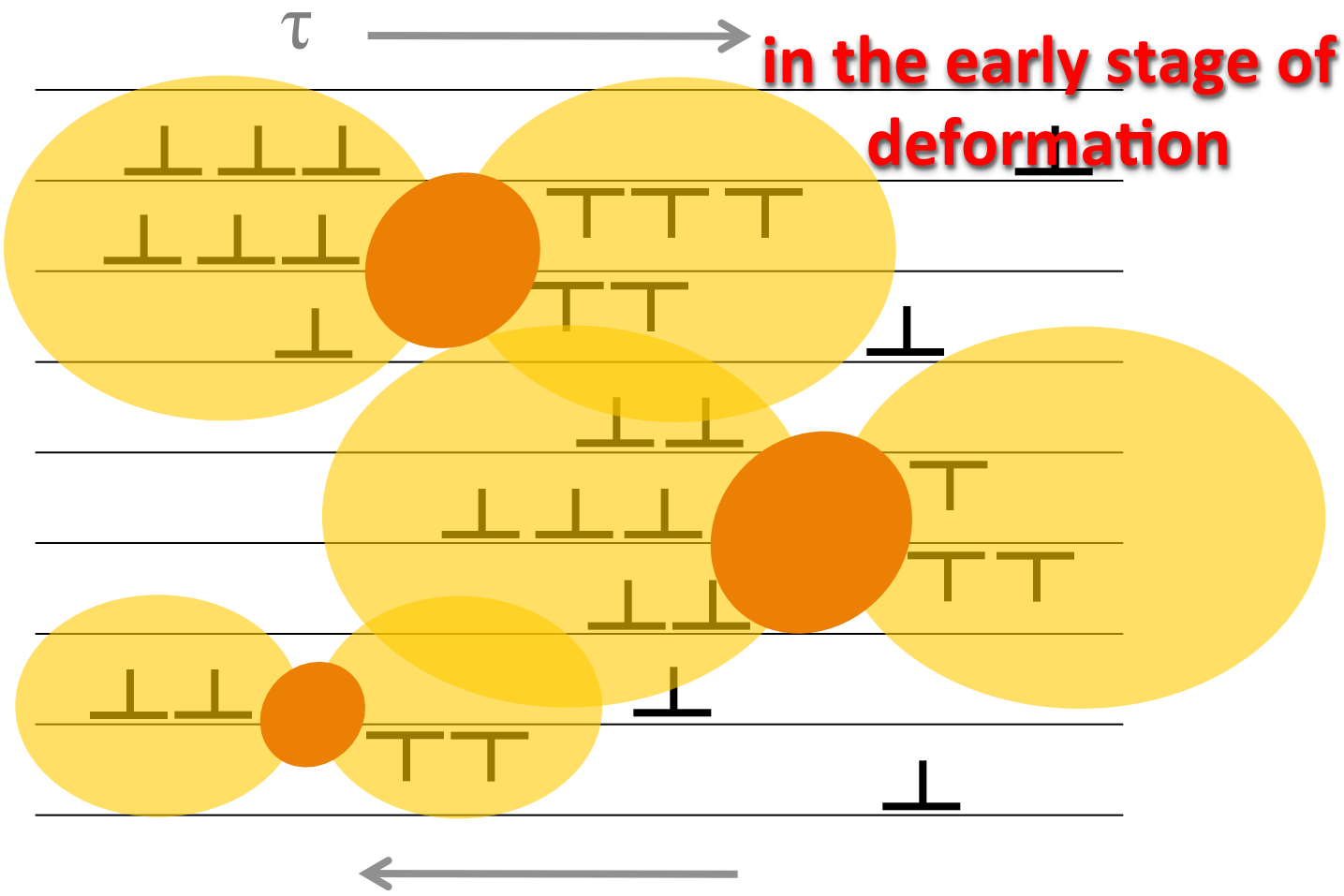




M. Takahashi: The 209 · 210th *Nishiyama Memorial Seminar*, (The Iron and Steel Institute of Japan, Tokyo, 2012) pp.97–125.

Proposed Hetero structure

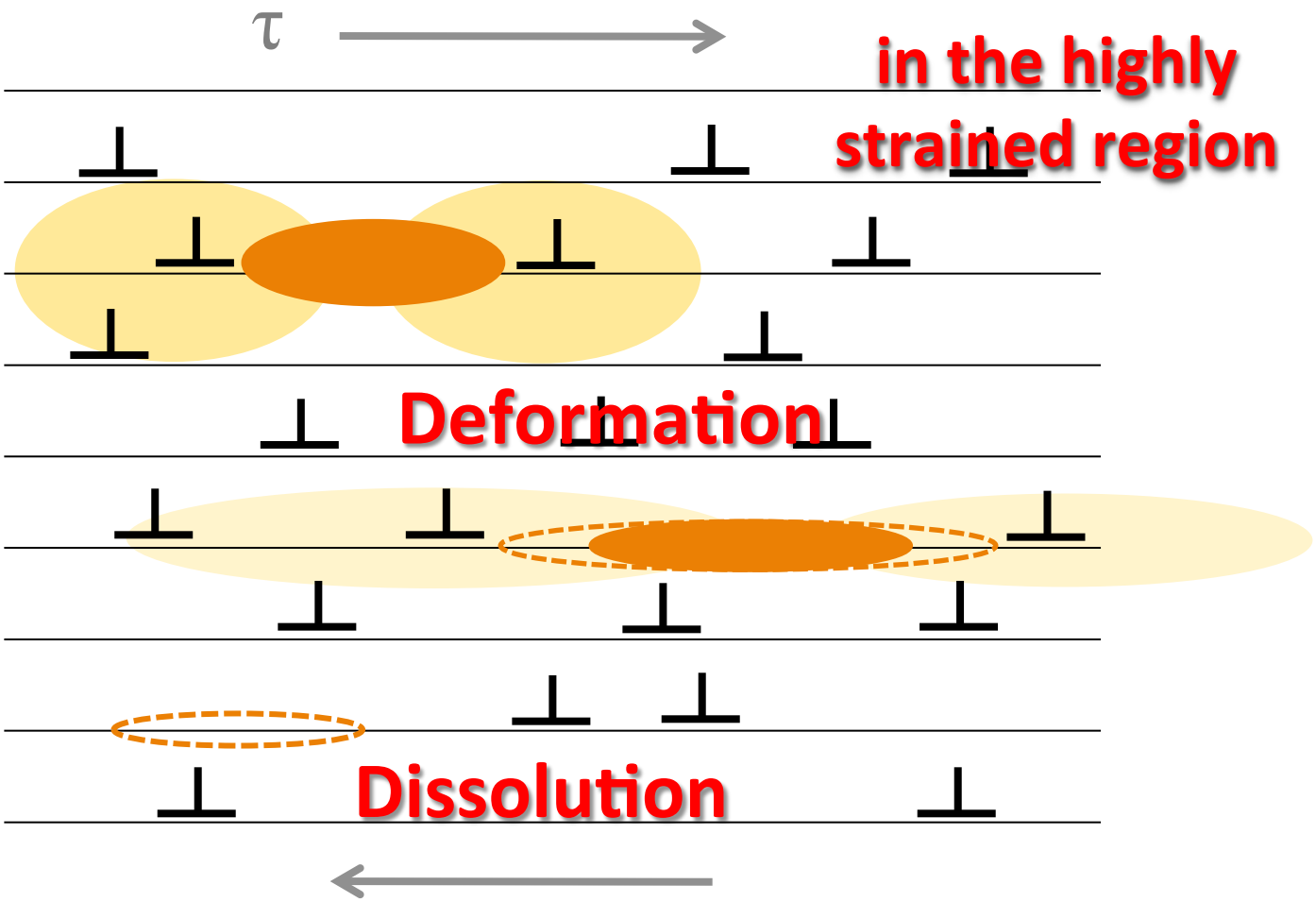
(microstructure containing soft particles)



Similar to conventional Hetero structure

Proposed Hetero structure

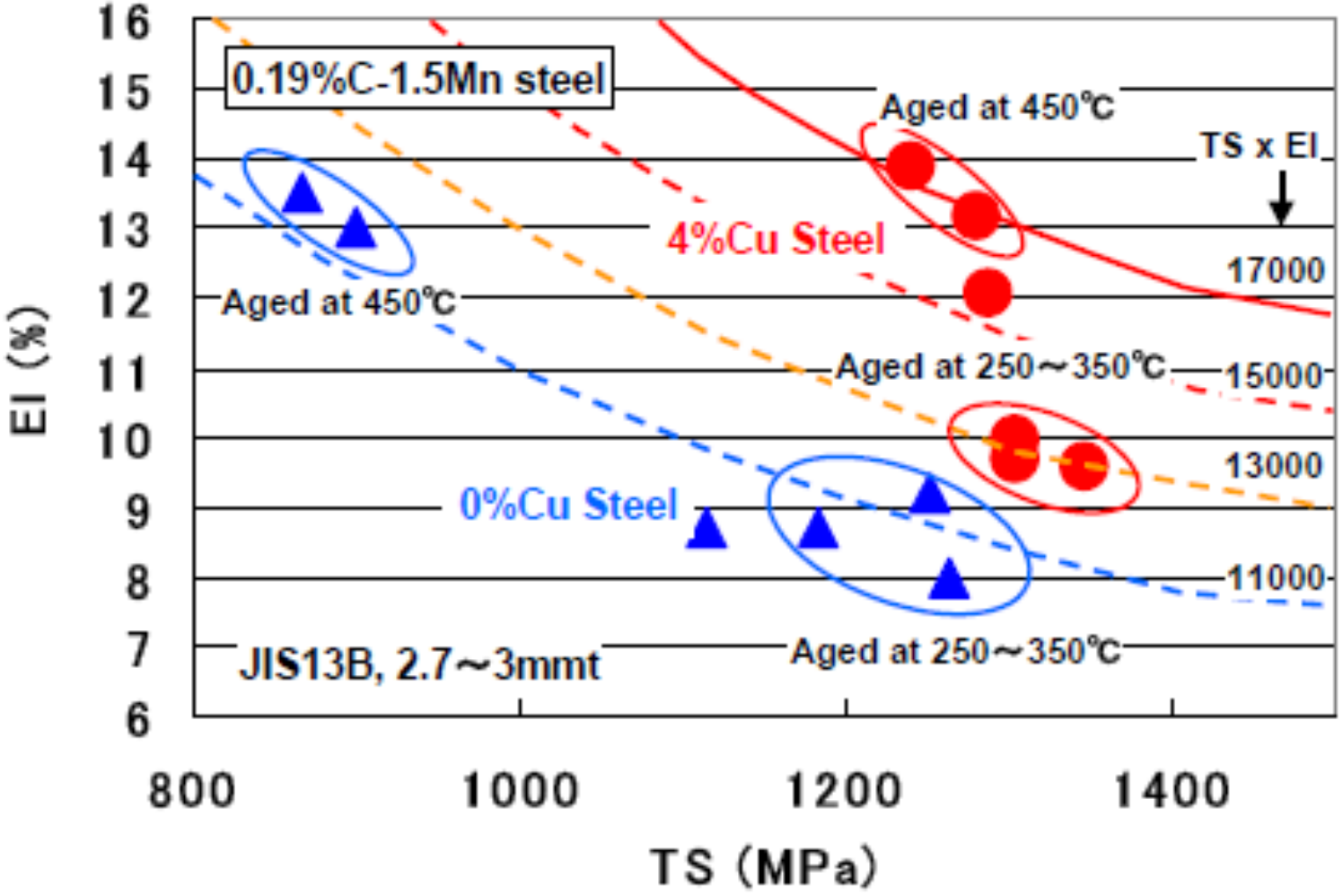
(microstructure containing soft particles)



*Transition to **Homo structure***

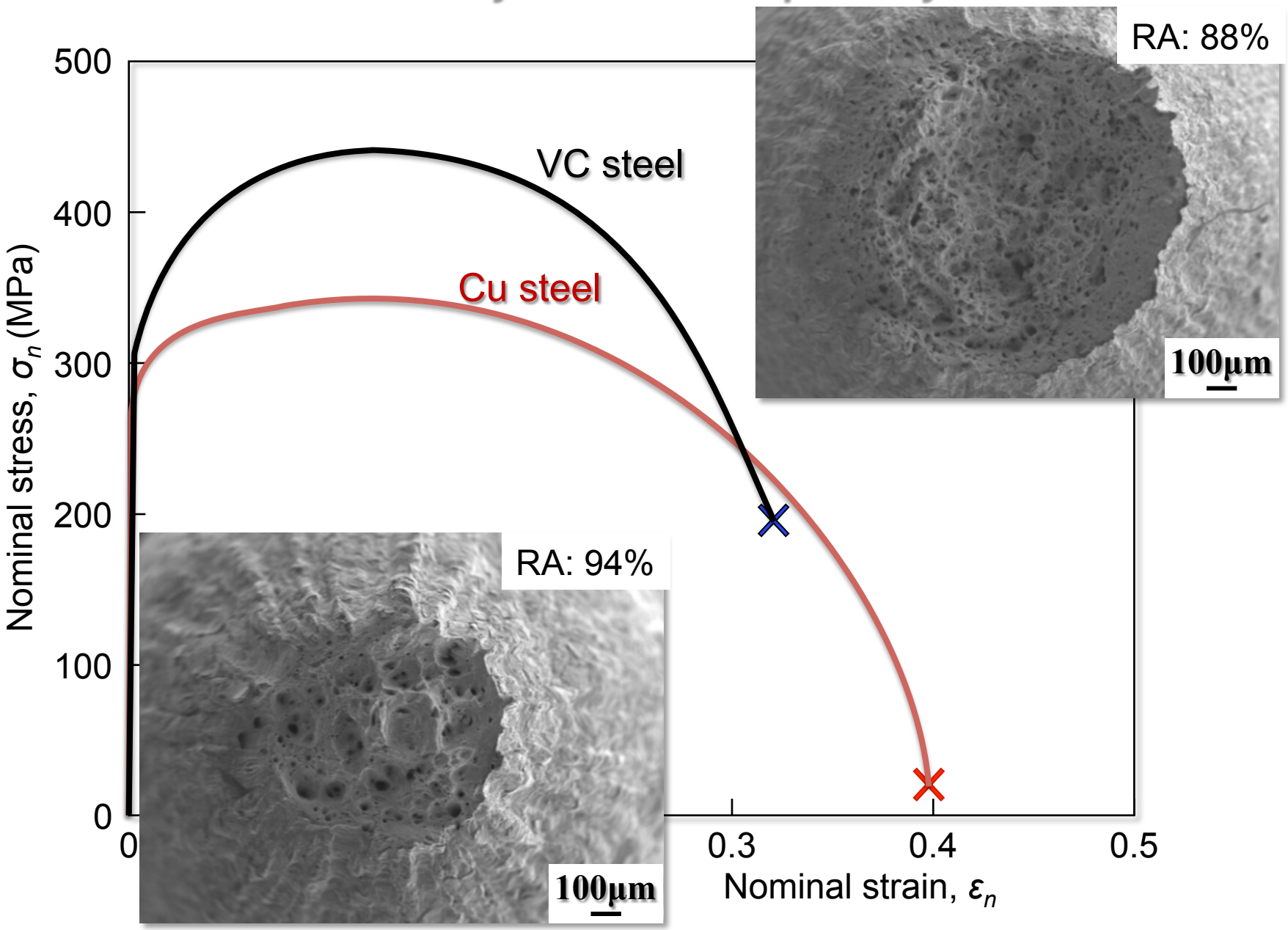
Strength-elongation balance in Cu bearing low-carbon steel

(Fe-0.19%C-1.5%Mn-4.0%Cu alloy)



Nagataki et al.: Report of NANOMETAL technology project (NEDO, 2003), pp. 38-49.

Stress-strain curves of Cu and VC dispersed ferritic steels



Targets of this research

Current topic

1st. Obtain direct (experimental) evidence of mechanical dissolution of Cu particles during plastic deformation

2nd. Understand the mechanism and condition of the mechanical dissolution of Cu particles

3rd. Develop an effective use of soft particles to improve strength-deformability balance of high strength steel sheet

4th. Establish a design principle of soft particle dispersion steel

Specimens

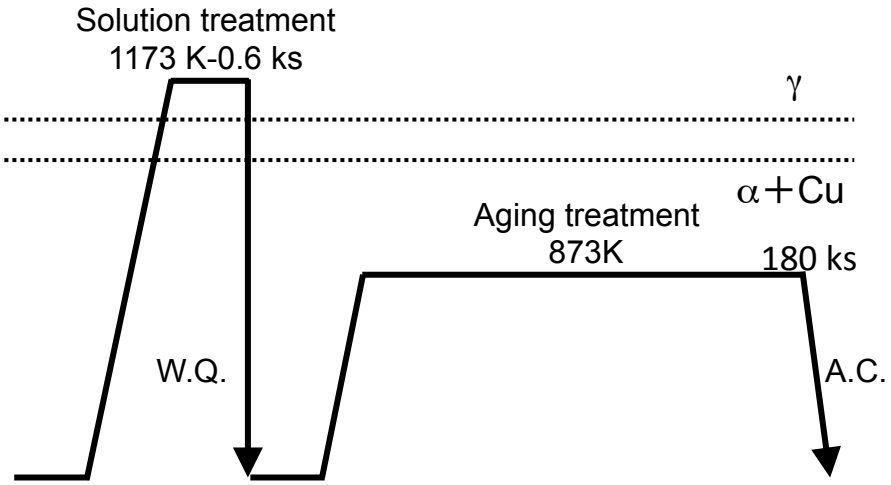
Chemical composition (mass%)

	C	Si	Mn	P	S	V	Cu	N
Cu steel	0.0069	0.01	0.07	<0.004	0.001	<0.001	2.03	0.0029
VC steel	0.194	0.08	0.09	<0.004	0.001	0.94	0.01	0.005

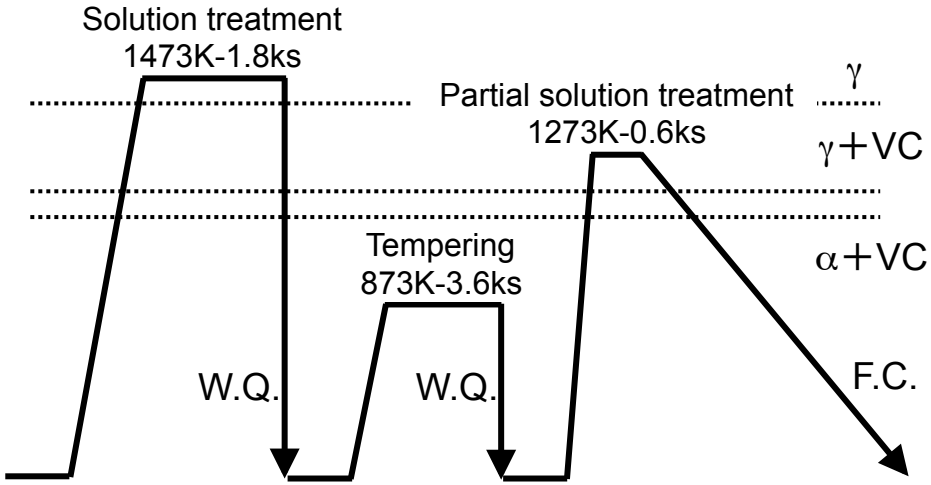
Heat treatment

Volume fraction : **ε-Cu, VC** --- 1.4 vol%

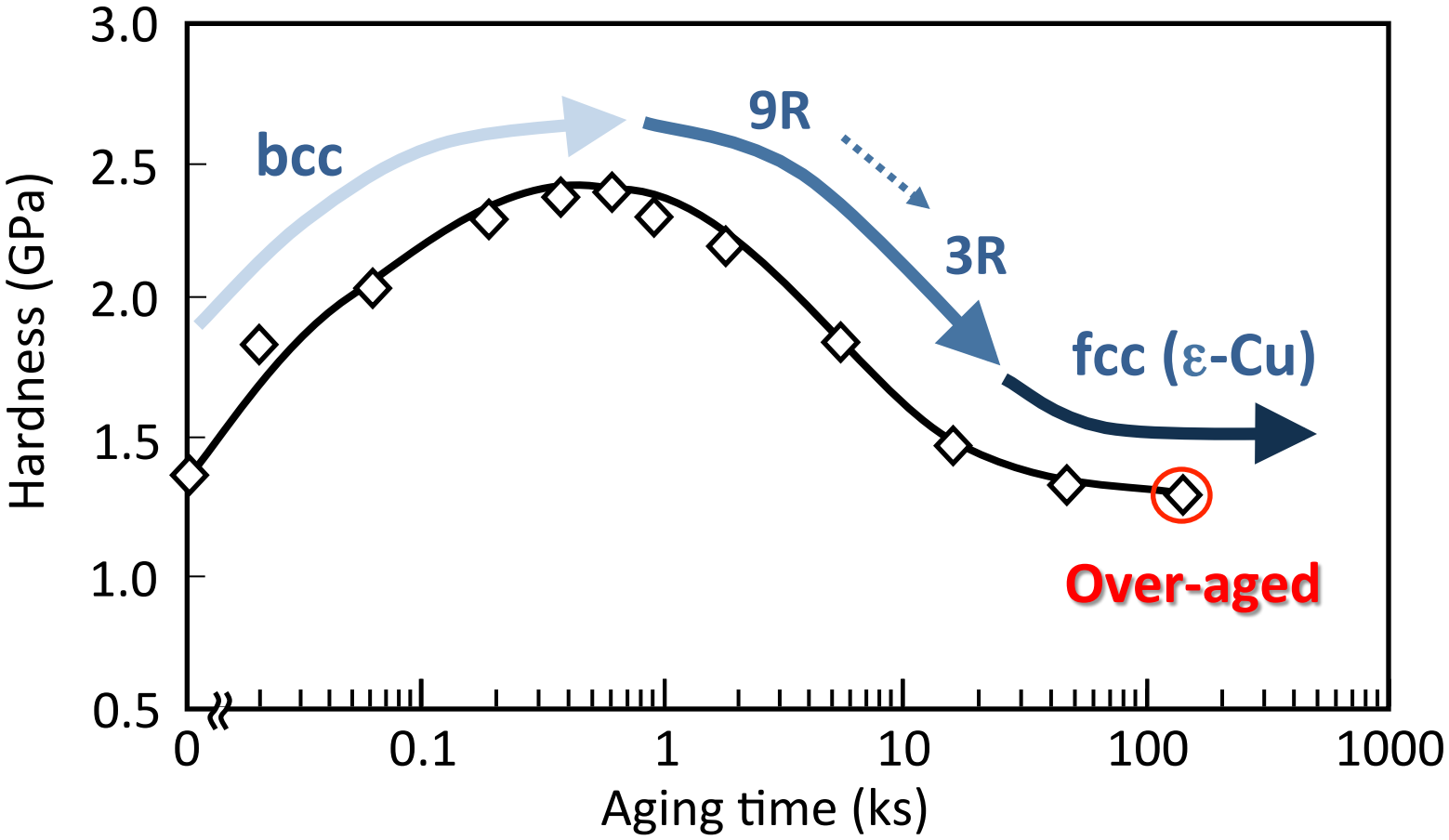
Cu steel



VC steel



Structural transition of Cu precipitates during aging treatment at 873K in Fe-2Cu alloy

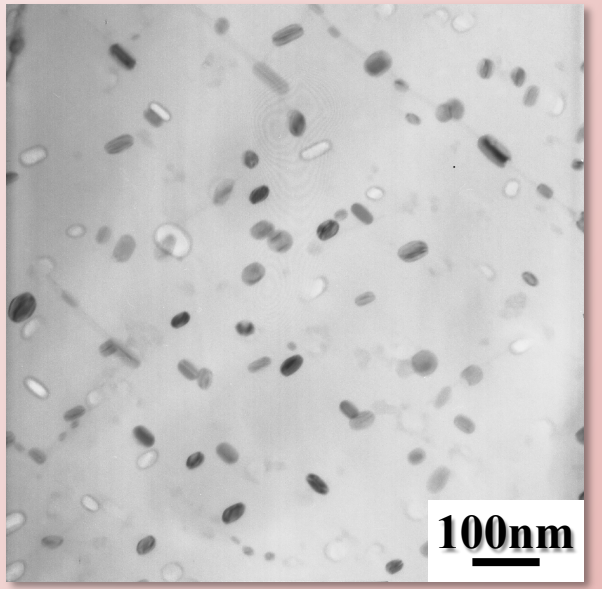


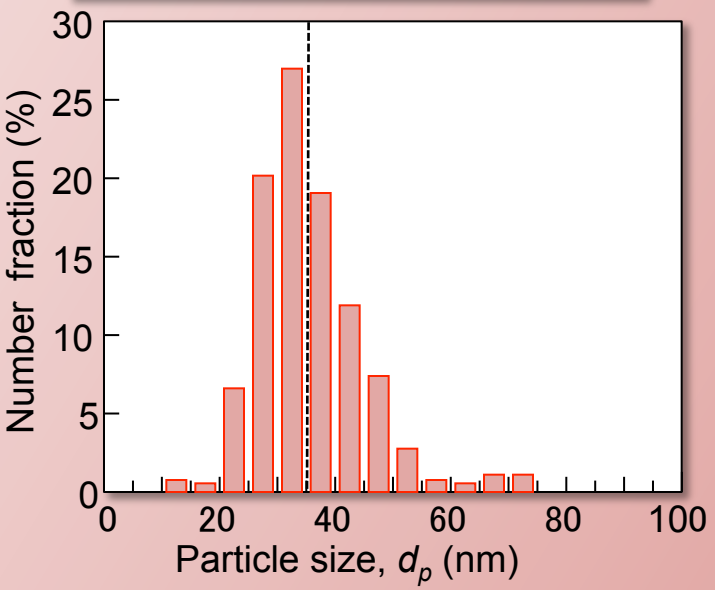
Microstructure of VC and Cu steels

TEM

Size distribution

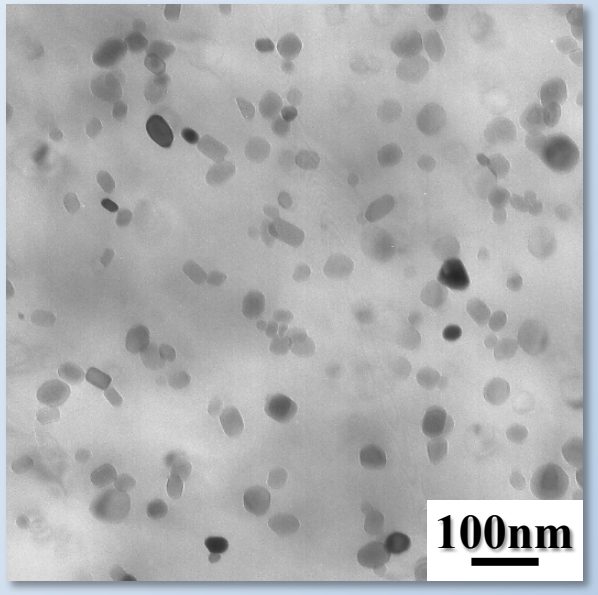
Cu steel (over-aged)

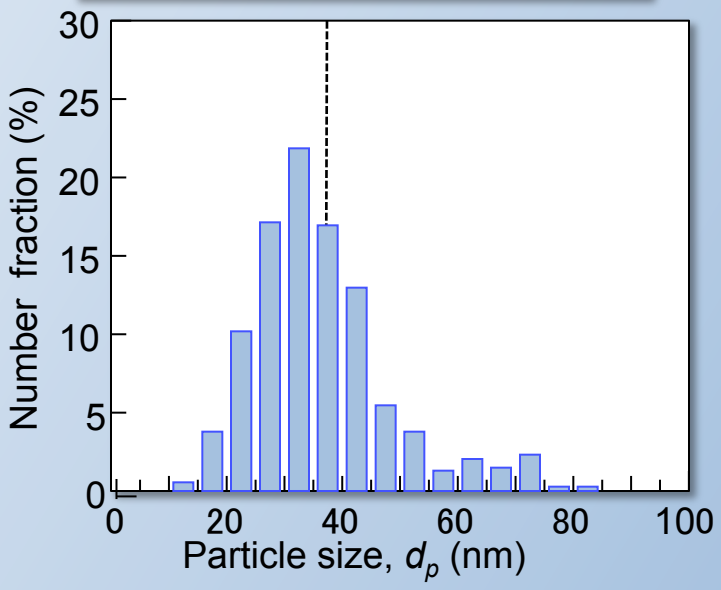




Mean particle size = 35nm

VC steel





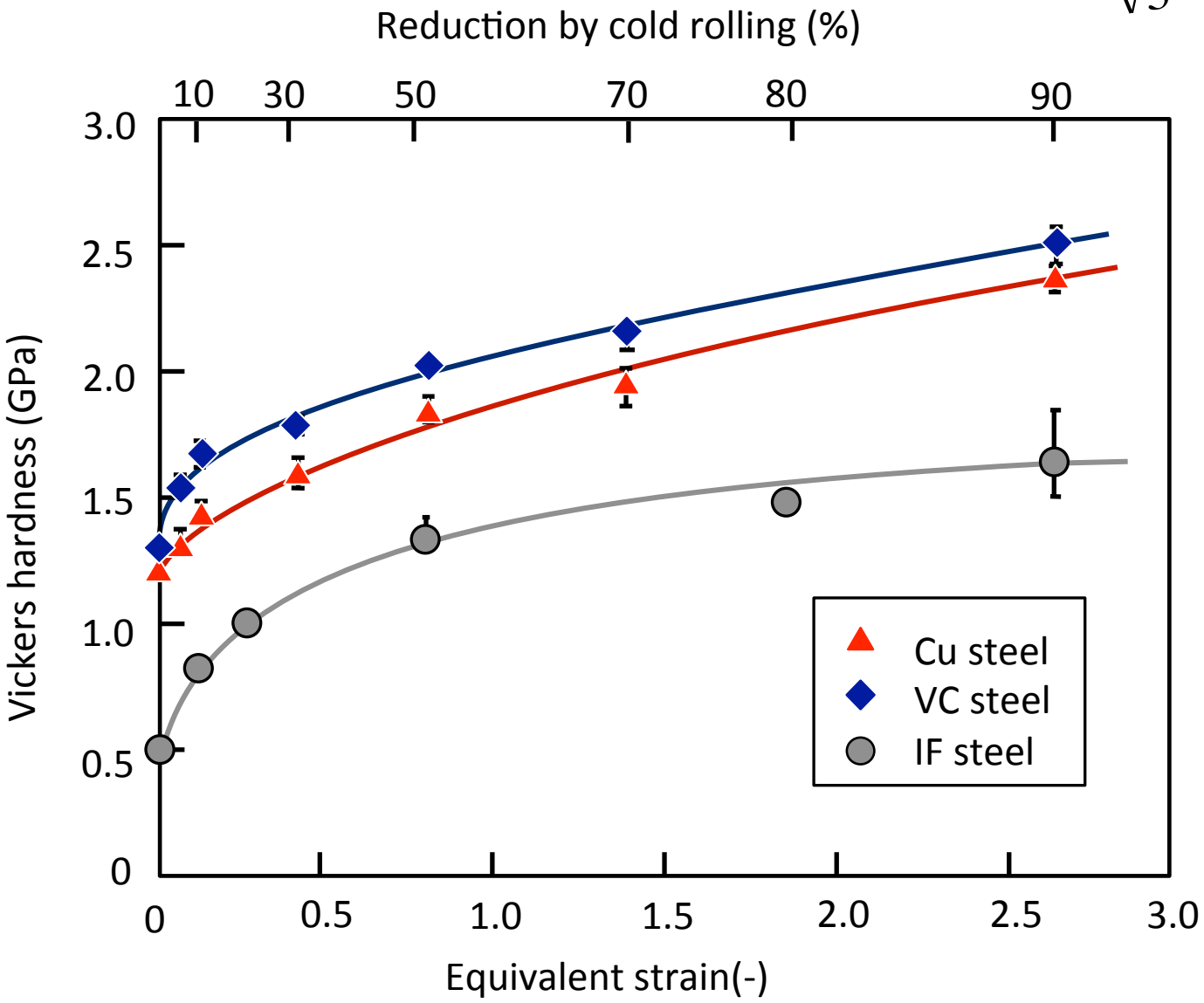
Mean particle size = 37nm

Change in hardness with cold rolling

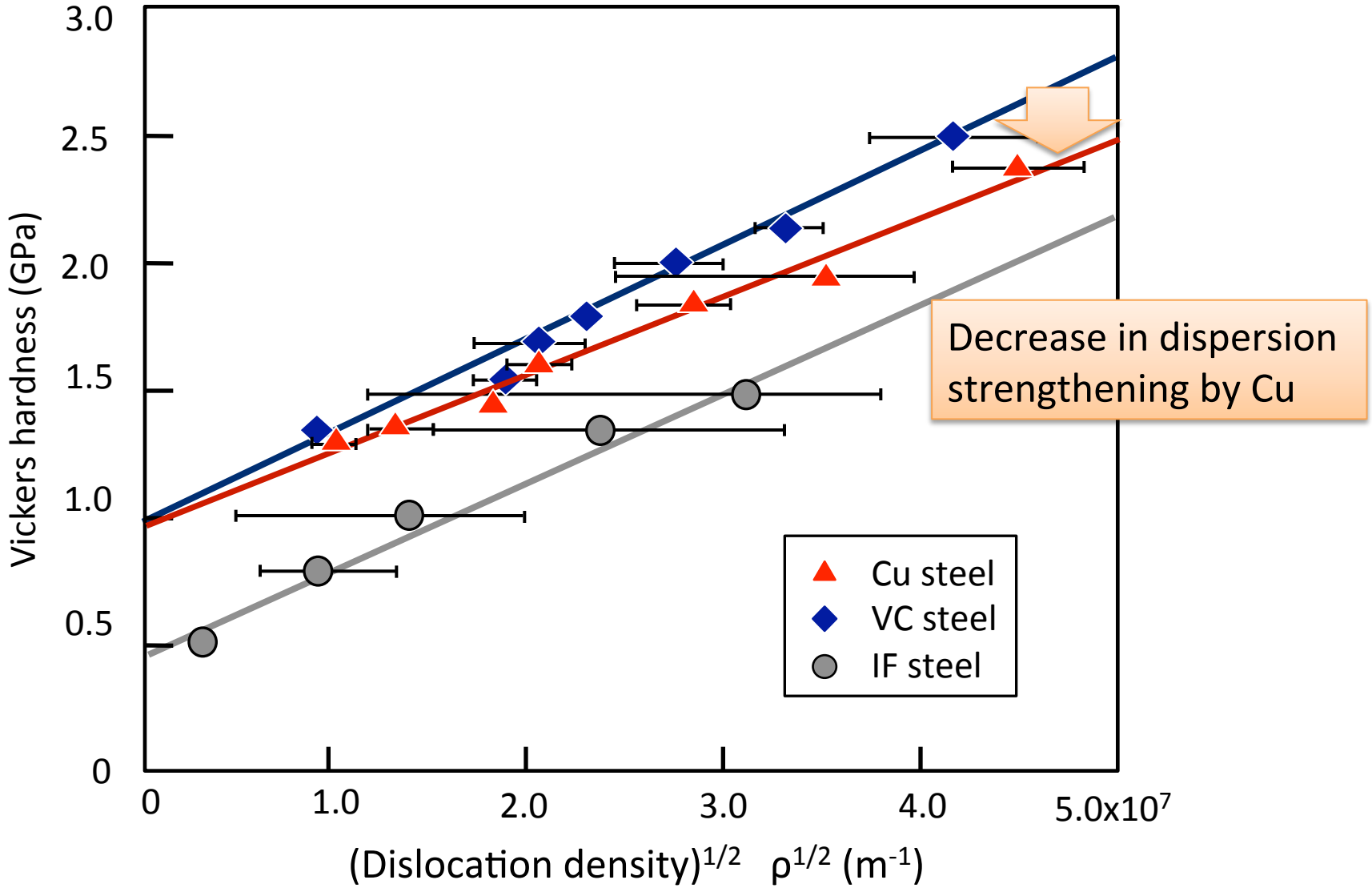
Equivalent strain

$$-\frac{2}{\sqrt{3}}\ln\left(\frac{100-\alpha}{100}\right)$$

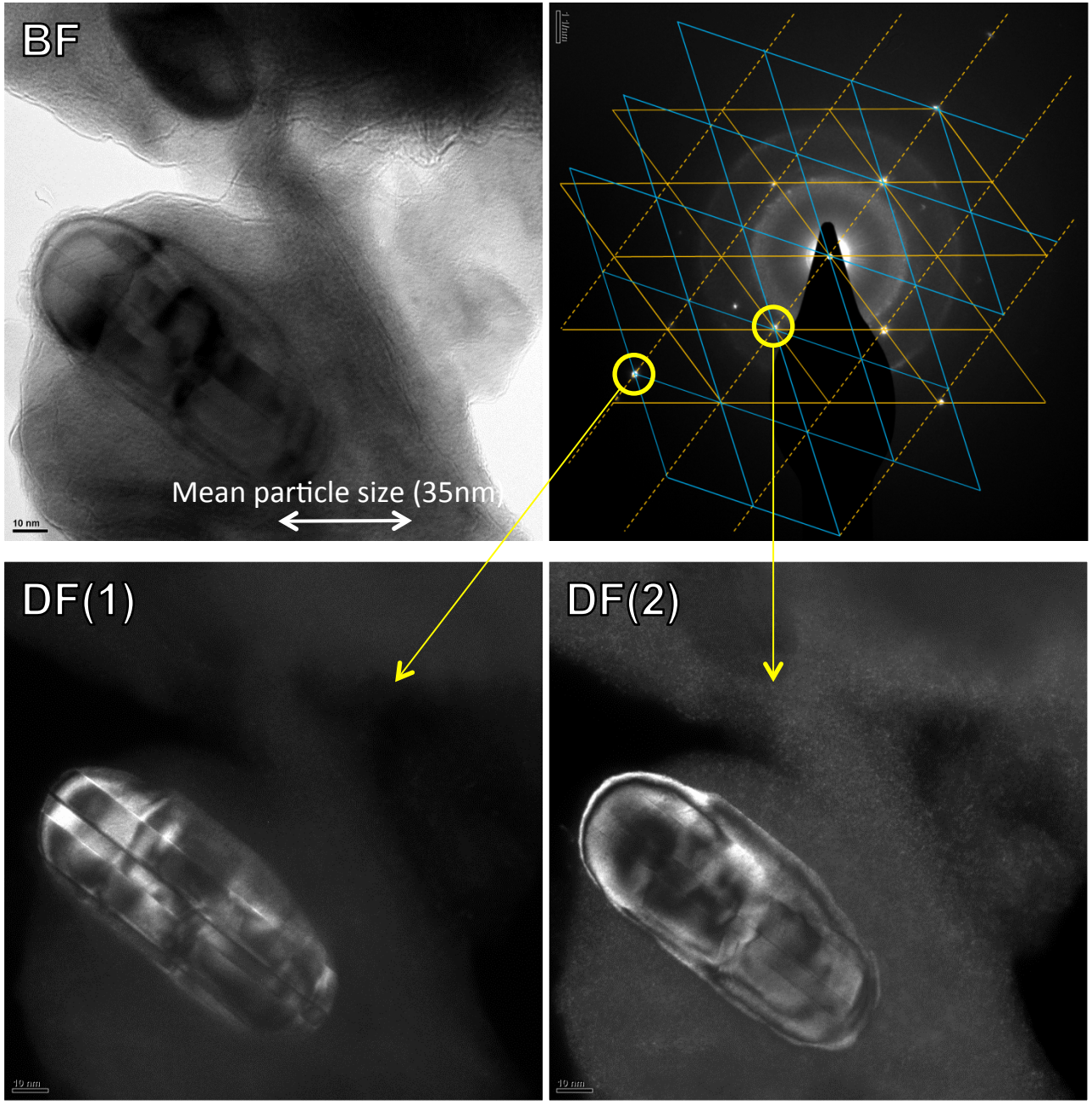
α : reduction of area

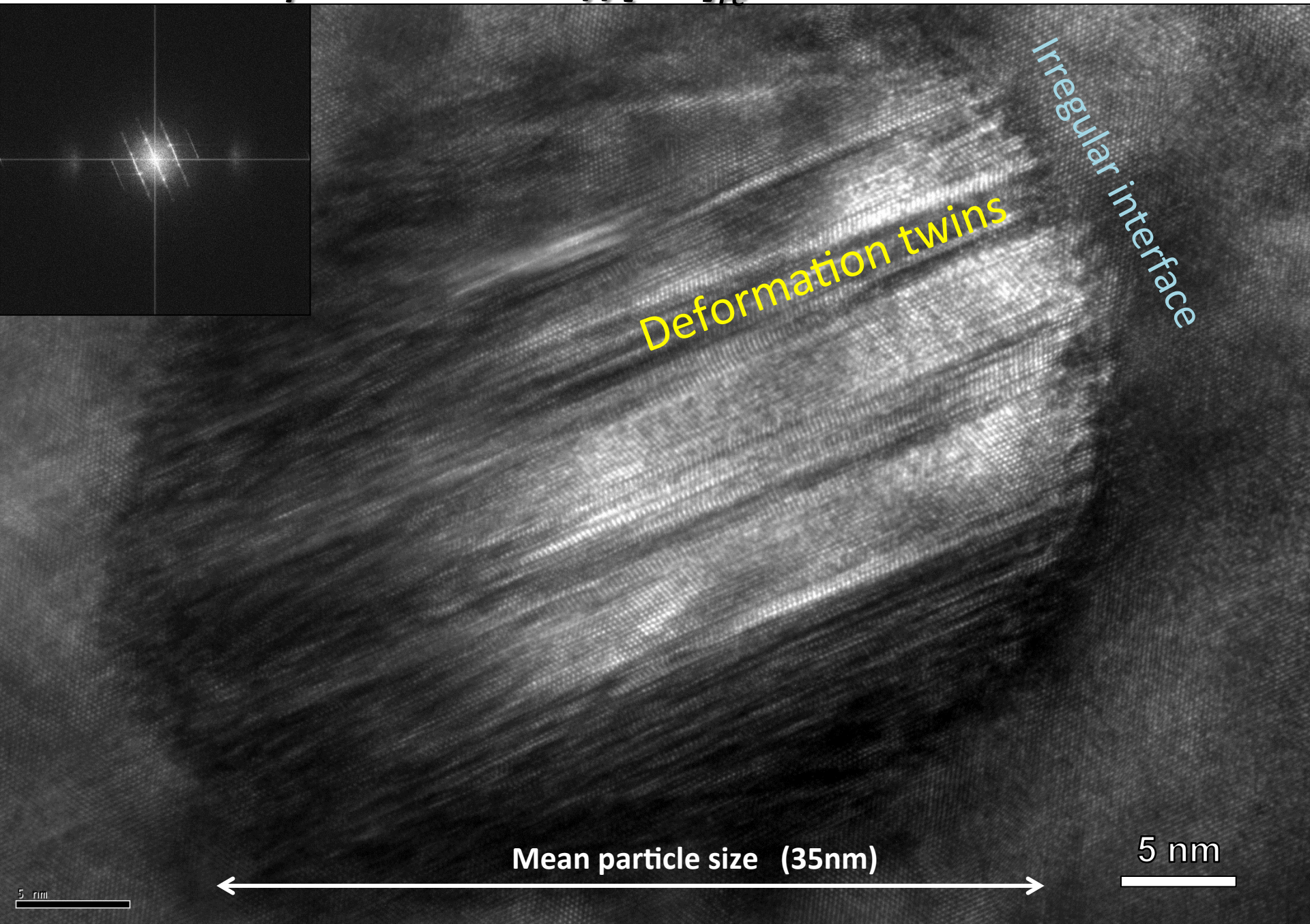


Relation between hardness and dislocation density in cold-rolled Cu and VC dispersion steel



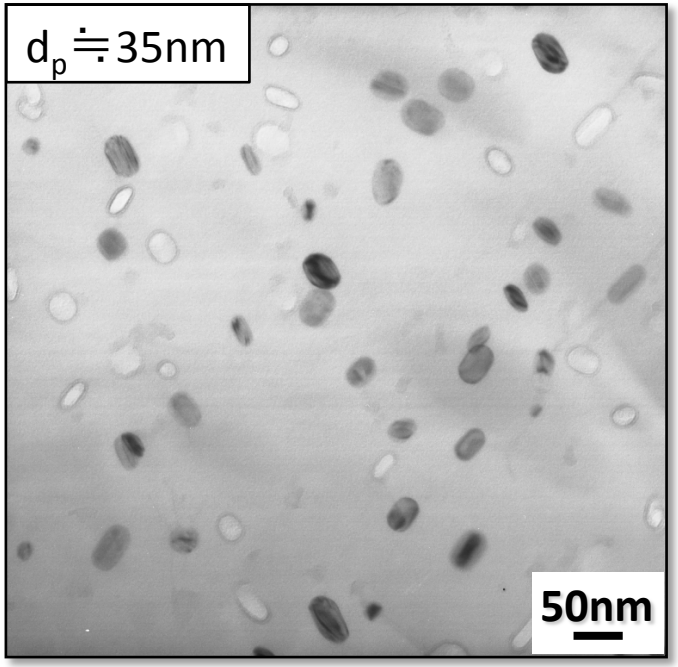
TEM images of ε-Cu particle in over-aged specimen



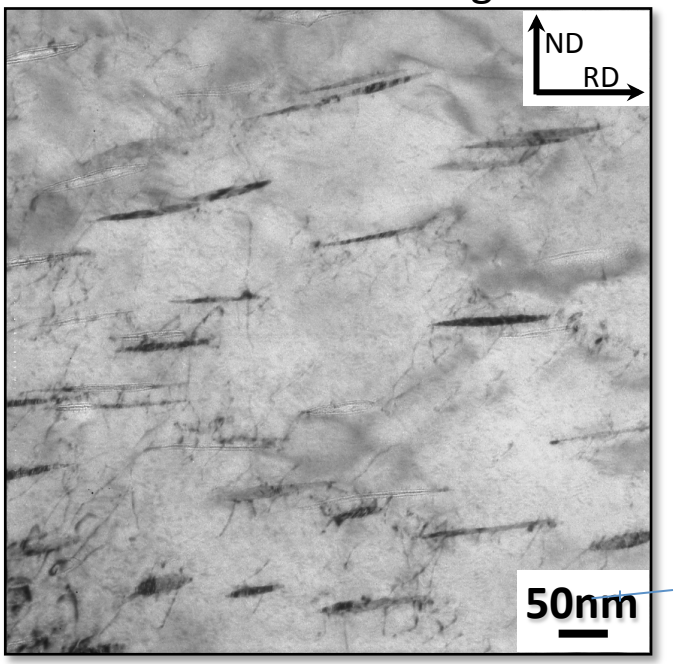

5%cold-rolled specimen beam//[111]Fe
Deformation twins
Irregular interface
Mean particle size (35nm)
5 nm

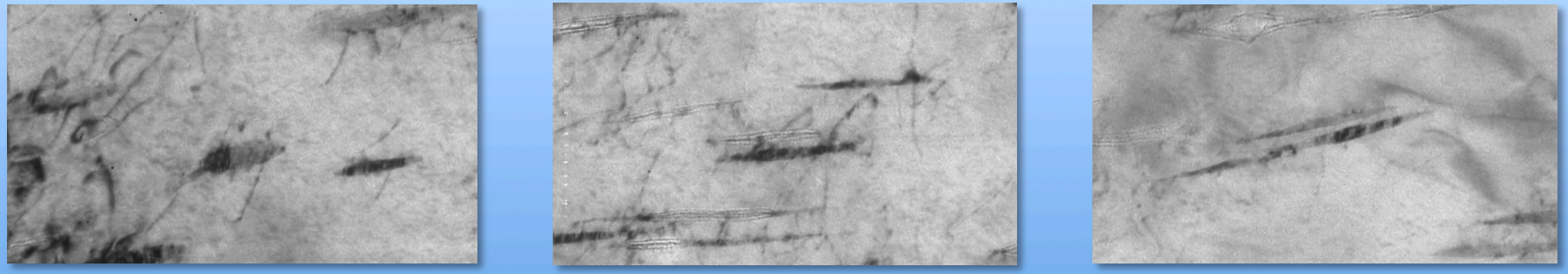
Change in morphology of Cu particles by 70% cold rolling

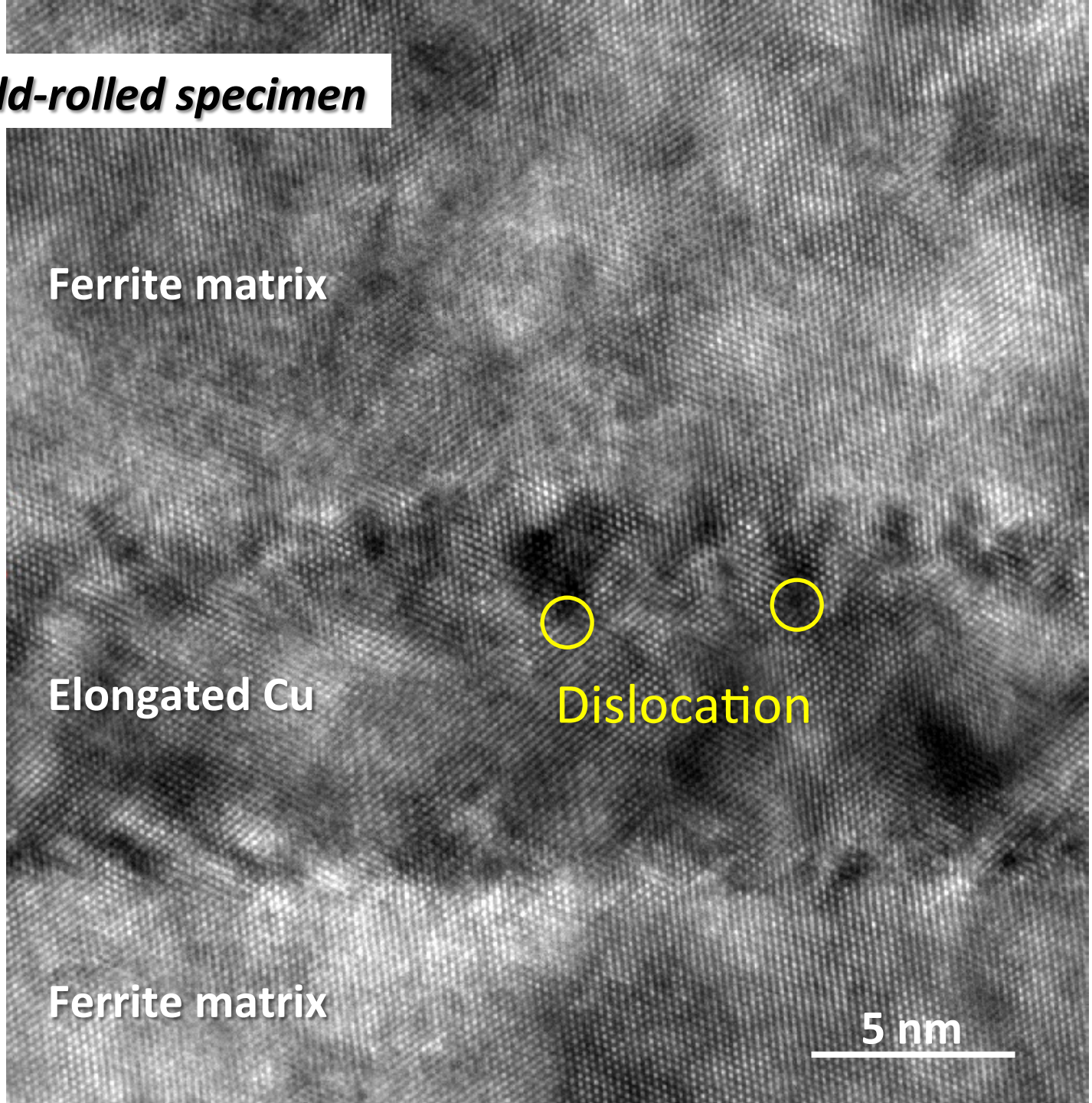
Before rolling



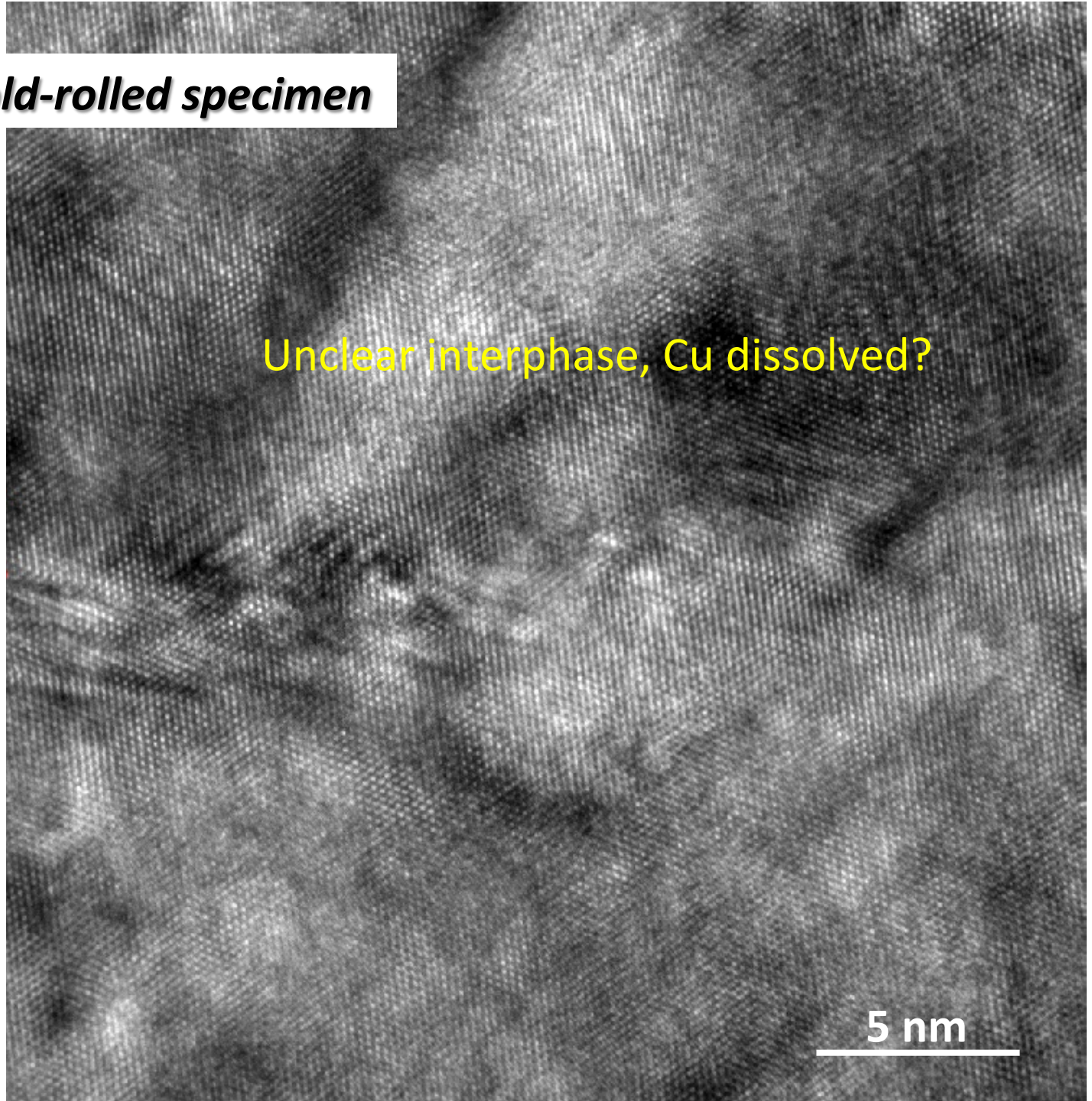
After 70% rolling



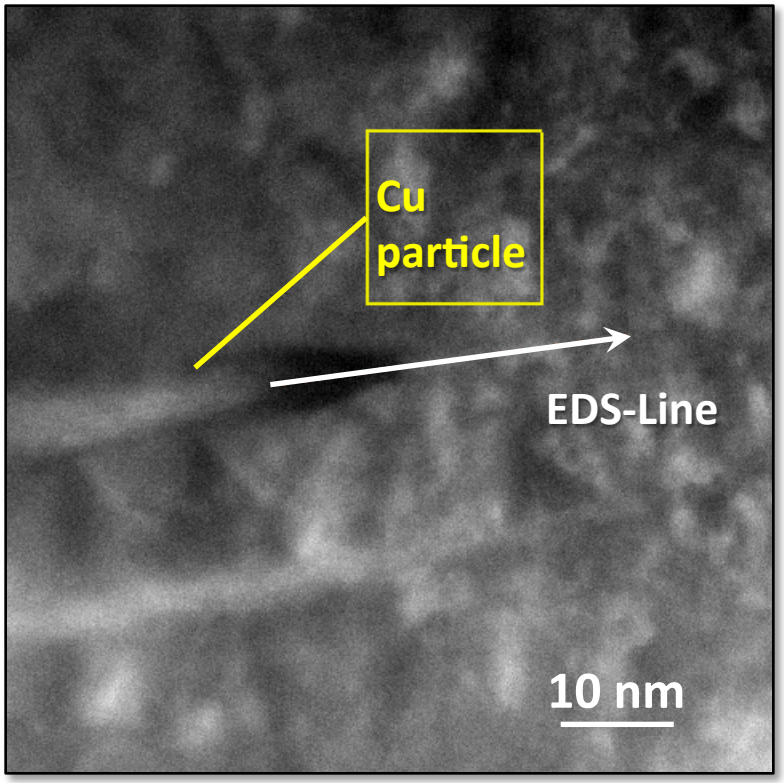


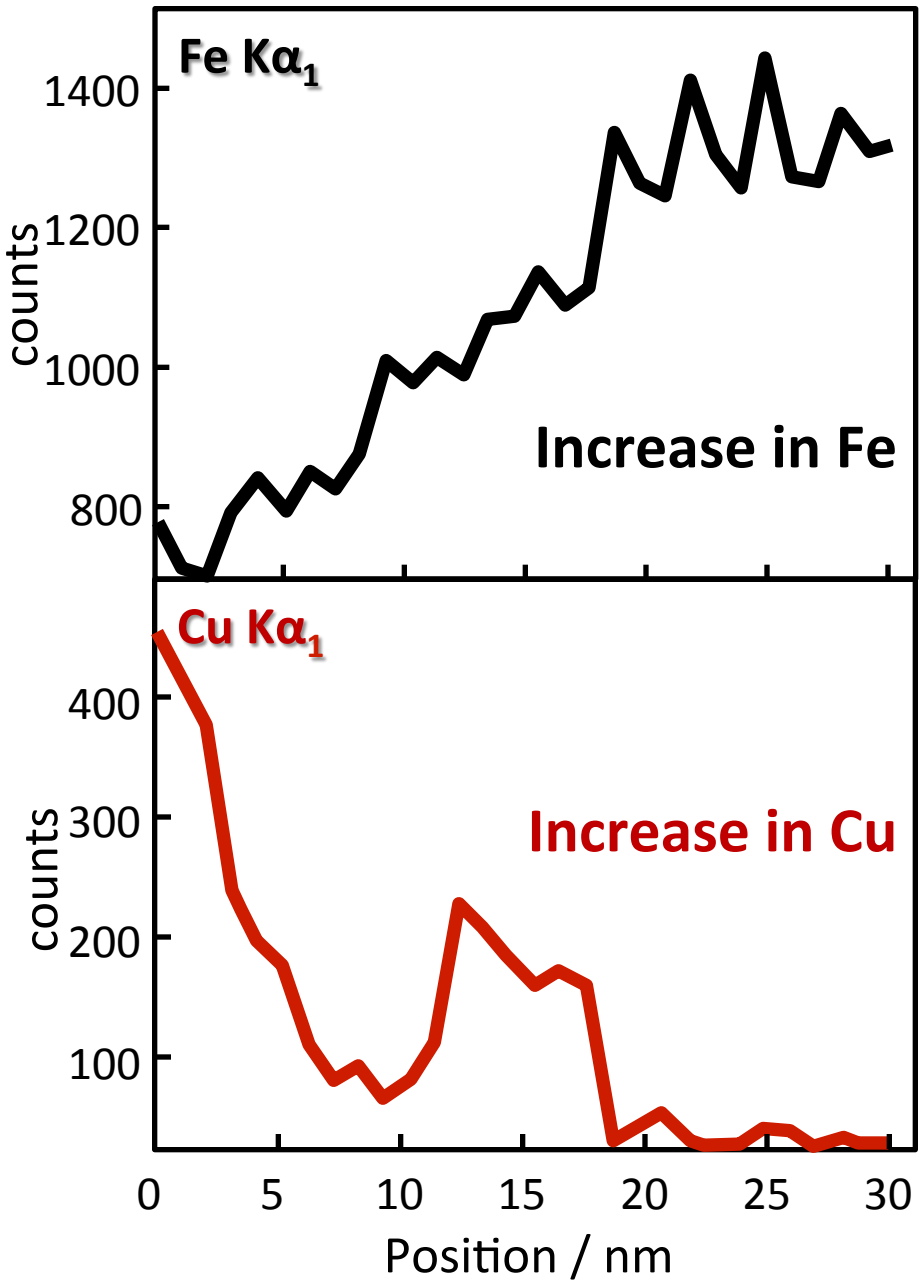

80% cold-rolled specimen
Ferrite matrix
Elongated Cu
Dislocation
Ferrite matrix
5 nm

80% cold-rolled specimen

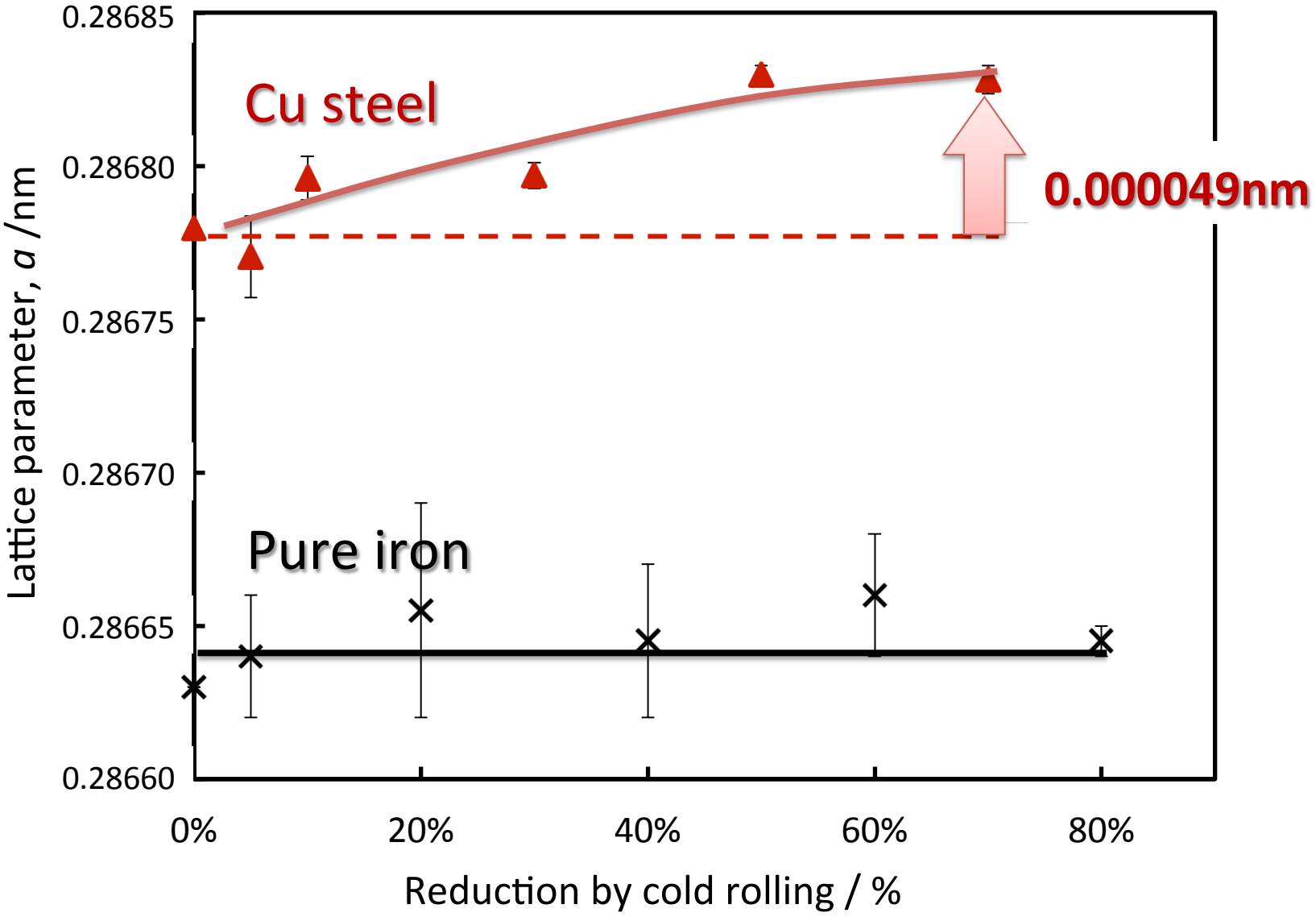


STEM-HAADF (EDS)

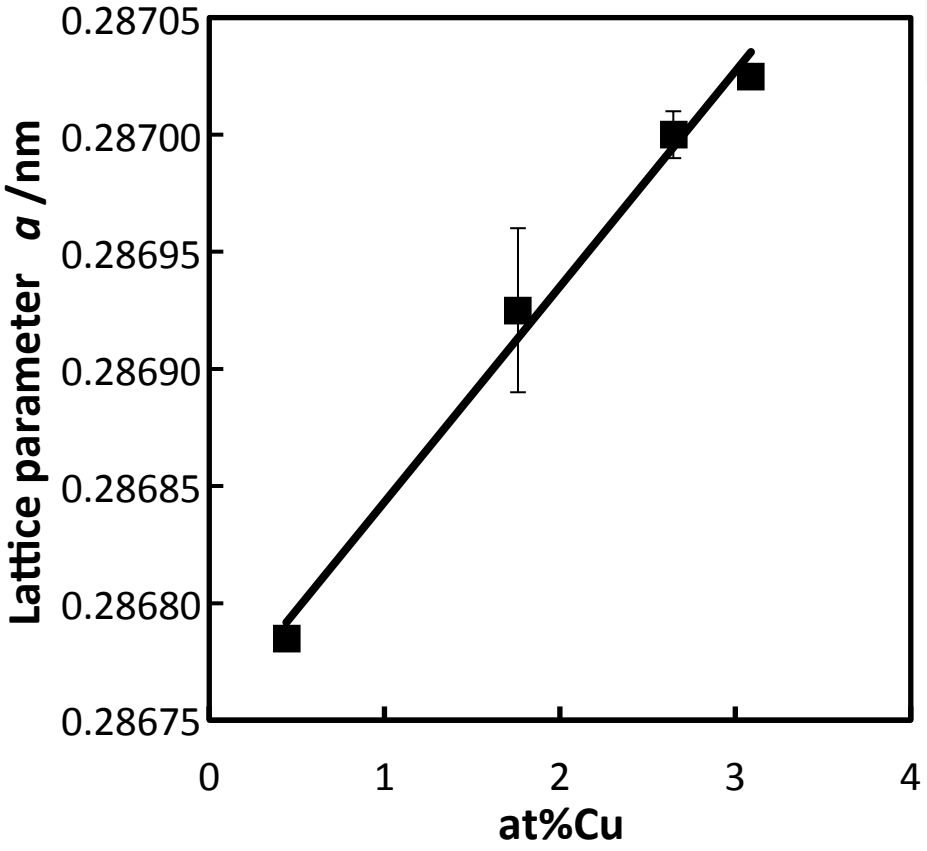




Change in lattice parameter of ferrite by cold rolling



Relation between lattice parameter and solute Cu content



$a = 0.286751 + 9.2\times10^{-5}$ [at%Cu]

Increment of *a*

$\Delta a = 4.9\times10^{-5}$ nm

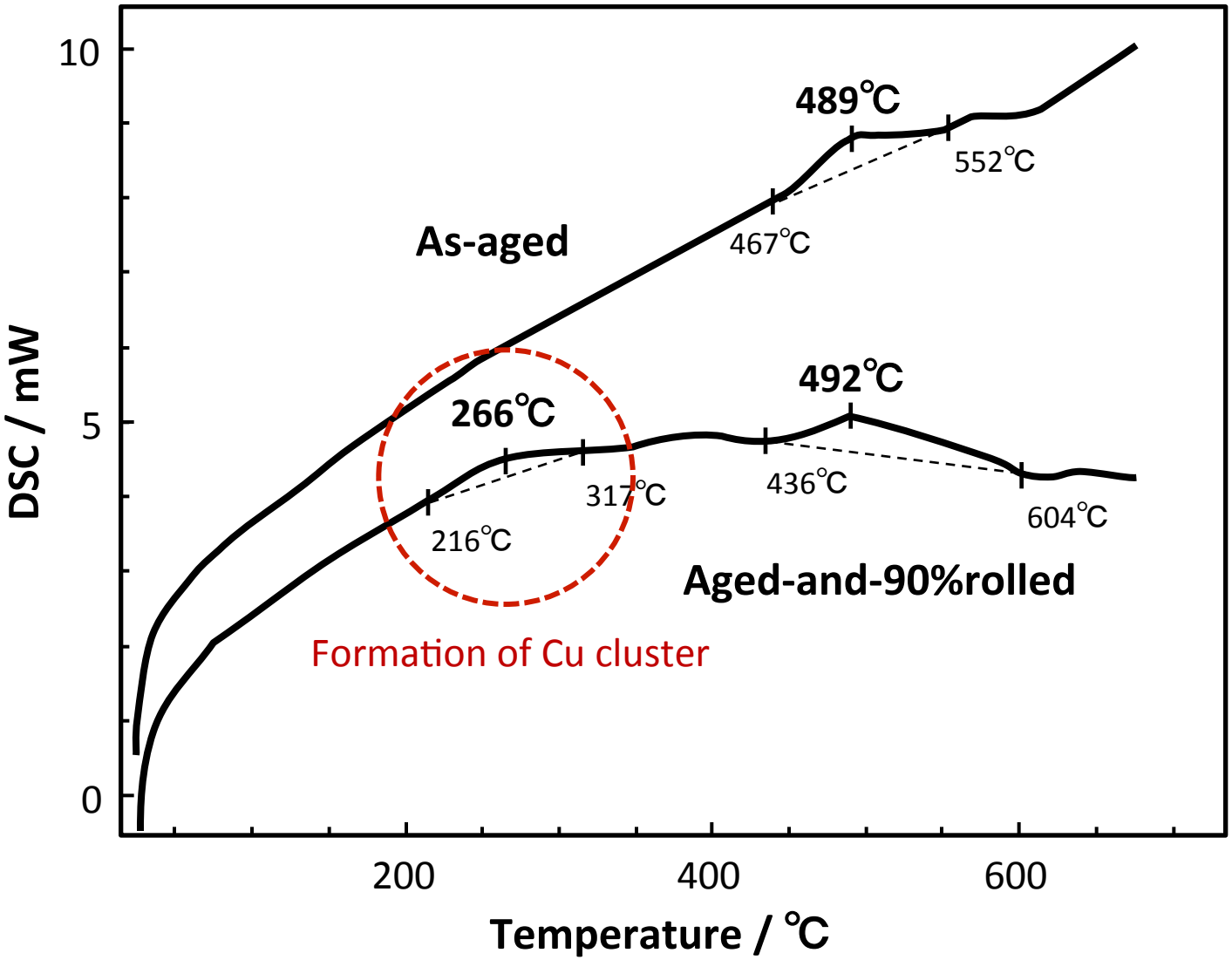
Change in solute Cu

0.600mass% (0.528at%)

1/3 of precipitate dissolved?

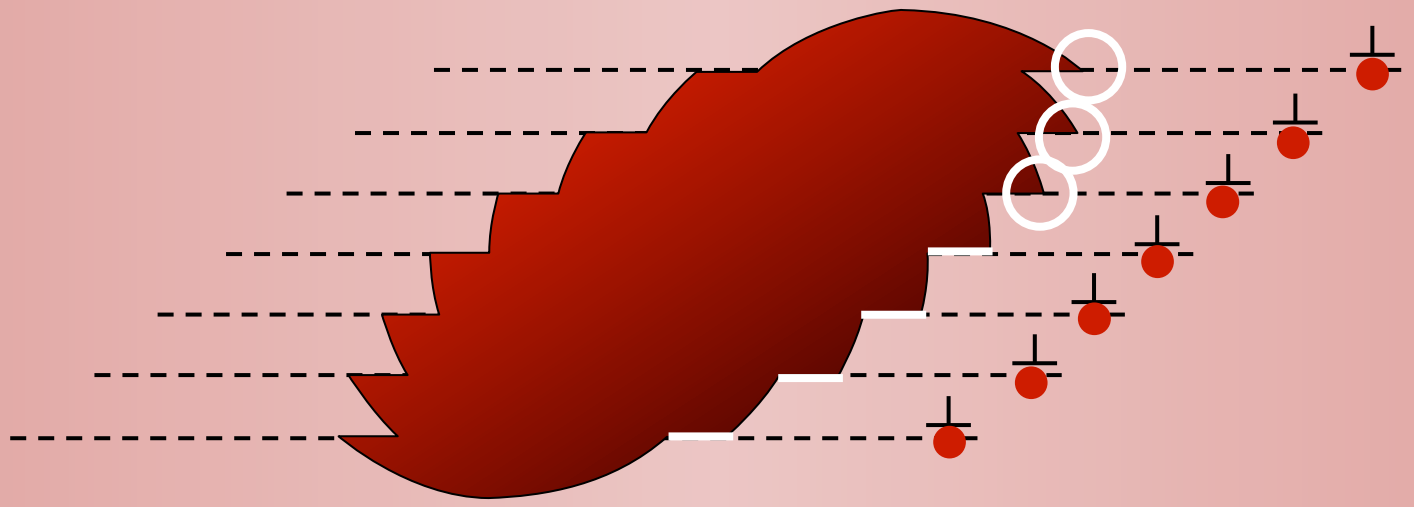
(initial: 1.6mass%)

Change in DSC curve by cold rolling



*Possible mechanism of **mechanical** dissolution of Cu particle*

Assumption: dislocations go through the Cu particle by cutting



Formation of atomic-scale **edge** and **new interface**

Sweeping of Cu atoms by dislocations (**Dynamic diffusion**)

Gibbs-Thomson equation

$$N_\alpha(r) = N_\alpha(\infty)\exp\left(\frac{2\sigma V_m}{RTr}\cdot\frac{1}{N_\varepsilon}\right)$$

Concentration in α phase equilibrated with precipitates of radius r.

Distribution of Cu atoms?

↓

3DAP (Now considering)

Conclusions

- ε−Cu particles are plastically deformed and partially dissolved into ferrite by cold rolling (mechanical dissolution).
- Dispersion (precipitation) strengthening by ε−Cu in ferritic steel tends to be weaken by cold working, which is related with the mechanical dissolution.
- The mechanism of mechanical dissolution needs to be further investigated by both experiments and calculations.