Recrystallization in Ti5553 and Ti4733 detected by mechanical spectroscopy

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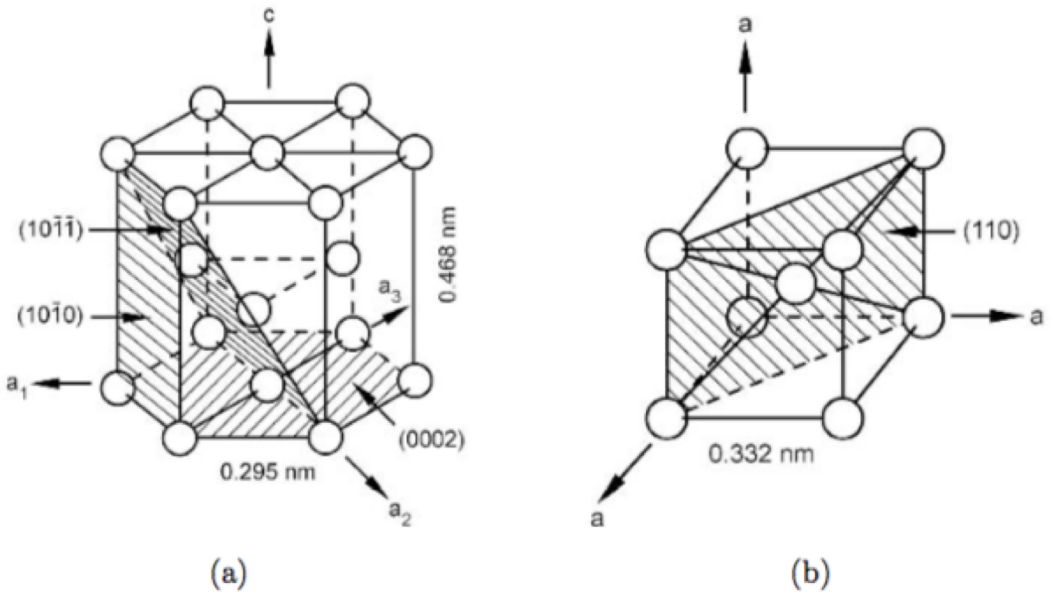
Summary about titanium and Ti alloys

α $\quad T_\beta(882°C) \quad \beta$

- Hexagonal structure
- Low temperature
- Harder
- More brittle



https://upload.wikimedia.org/wikipedia/commons/2/21/Maille_Titane.jpg

- Cubic centered structure
- High temperature
- Softer
- More ductile

Effect of the alloying elements

Alpha stabilizers

Al, O, N, C, B

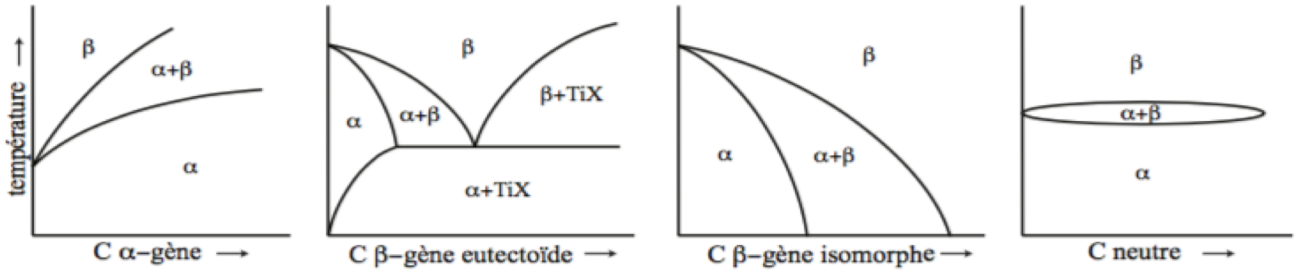
Betastabilizers

Mn, Fe, Cr, Co, W, Ni, Cu, Au, Ag, Si

Mo, V, Nb, Ta

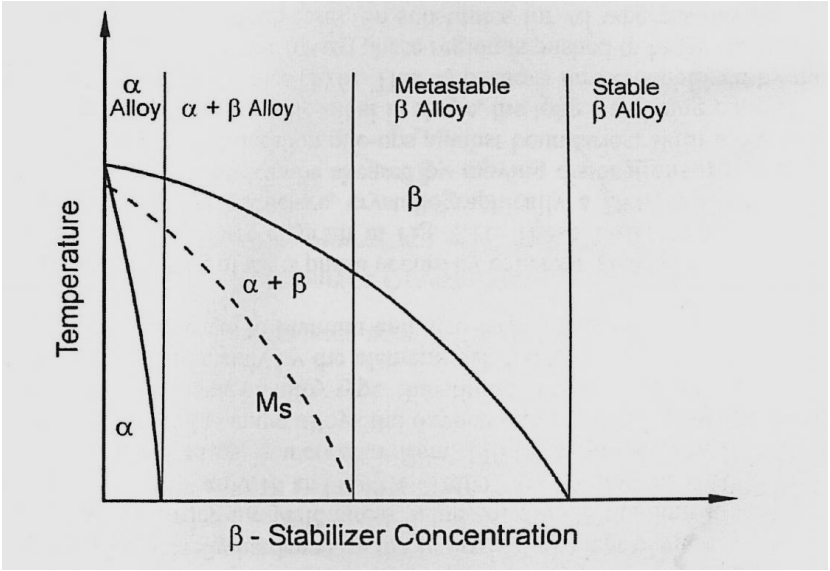
Neutral element

Zr, Hf



$$Mo_{eq}(\%mass) = Mo + 0.67V + 0.44W + 0.28Nb + 0.22Ta + 1.6Cr + 1.25\,Ni + 1.7\,Co + 2.9\,Fe - 1\,Al$$

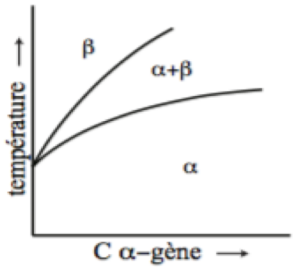
- Adding alloying element create region in the phase diagram where both α and β are stable
- Alloying elements are classified with the phase they stabilize
- Adding both α and β stabiliser help forming dual microstructure



Effect of the alloying elements

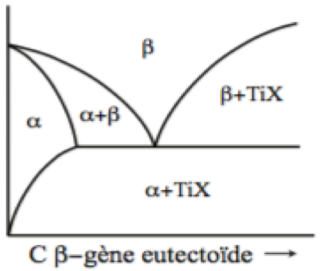
Alpha stabilizers

Al, O, N, C, B

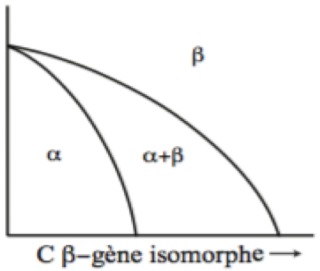


Betastabilizers

Mn, Fe, Cr, Co, W, Ni, Cu, Au, Ag, Si

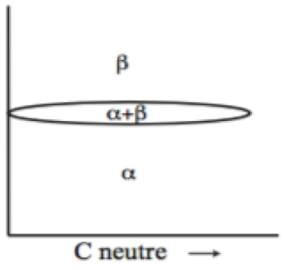


Mo, V, Nb, Ta



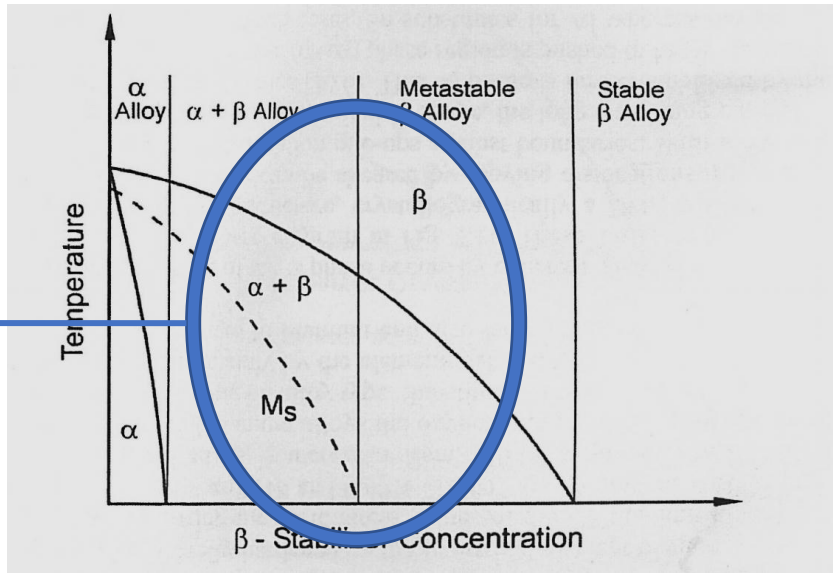
Neutral element

Zr, Hf

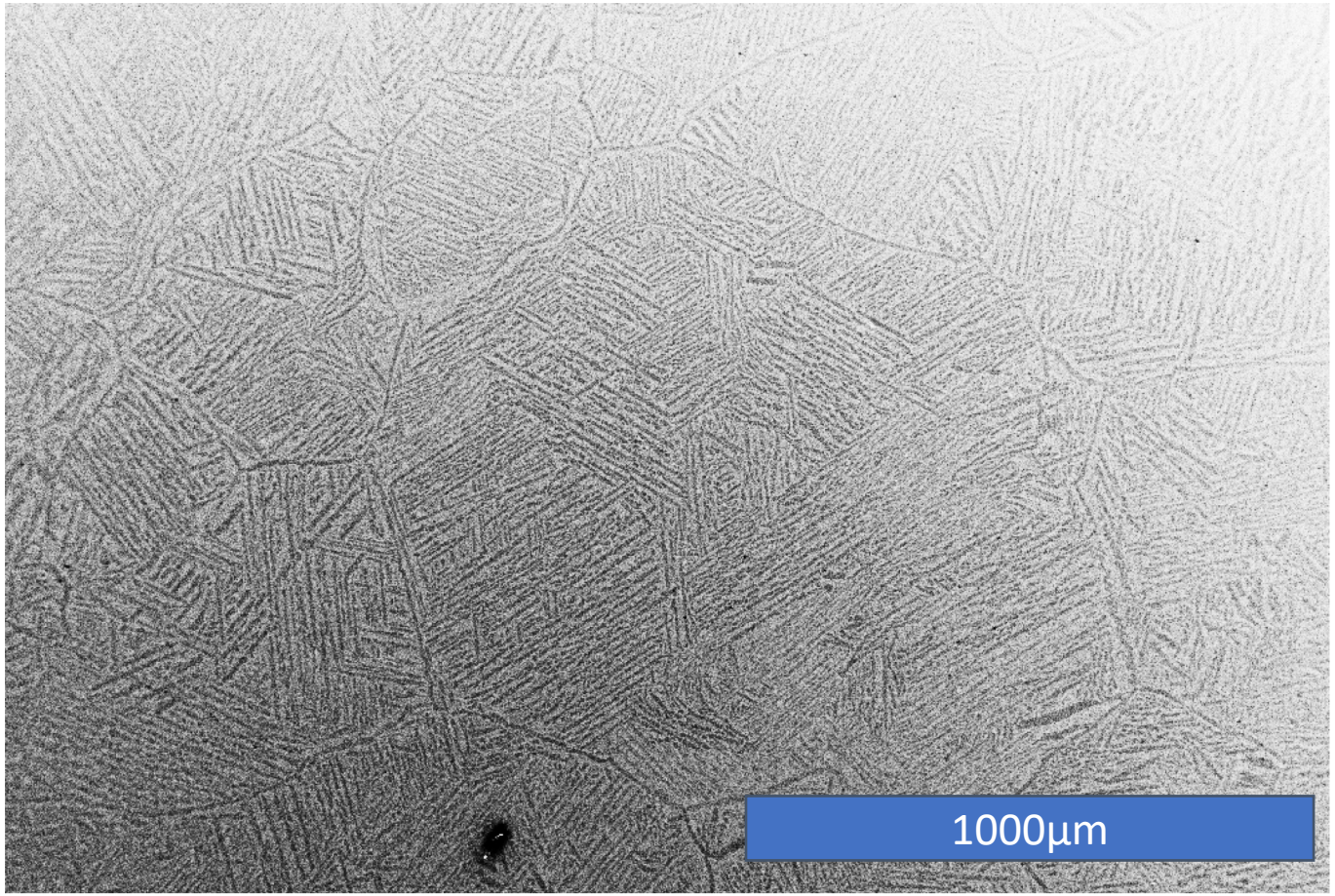


$$Mo_{eq}(\%mass) = Mo + 0.67V + 0.44W + 0.28Nb + 0.22Ta + 1.6Cr + 1.25\,Ni + 1.7\,Co + 2.9\,Fe - 1\,Al$$

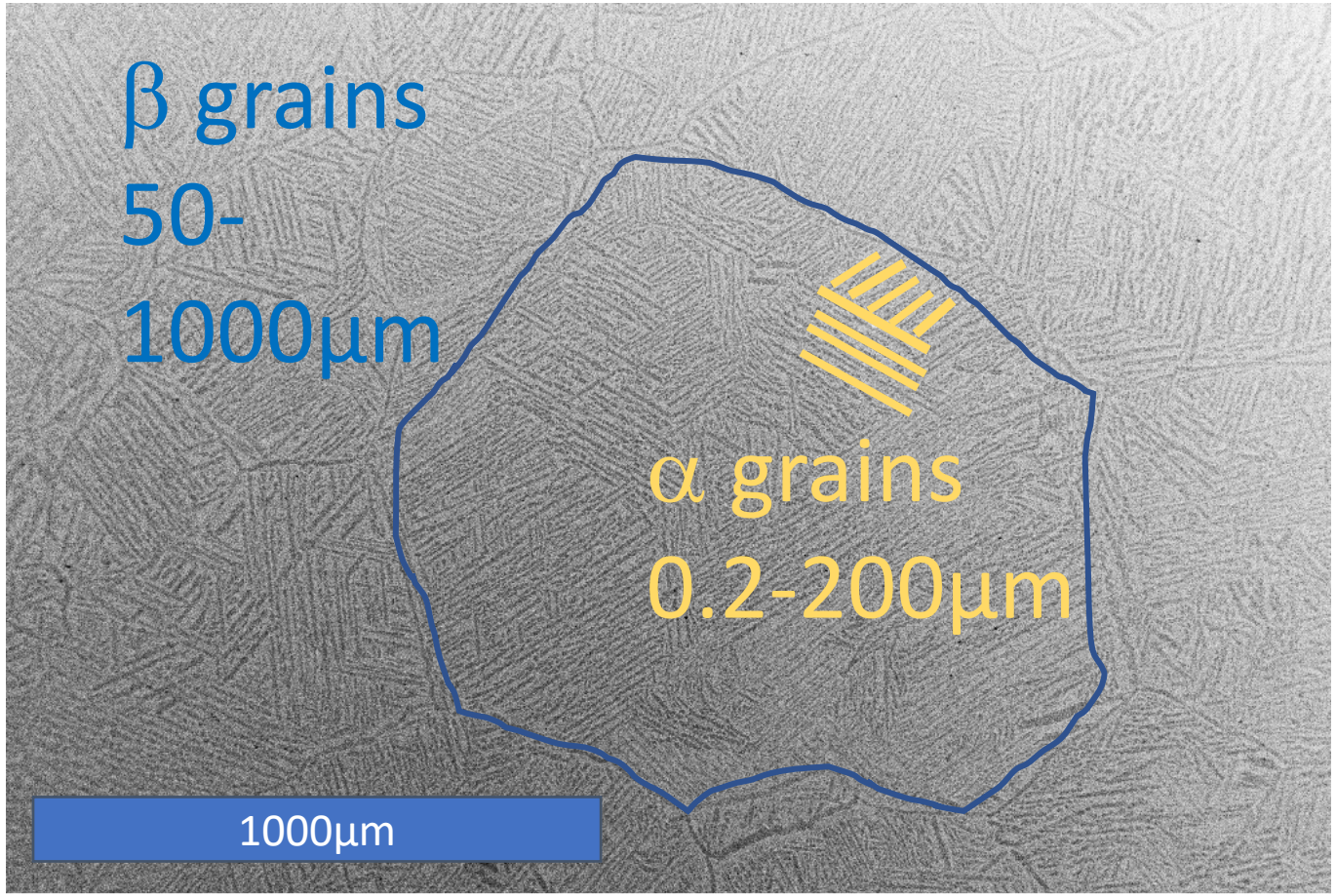
Region of interest



A microstructure on two scales



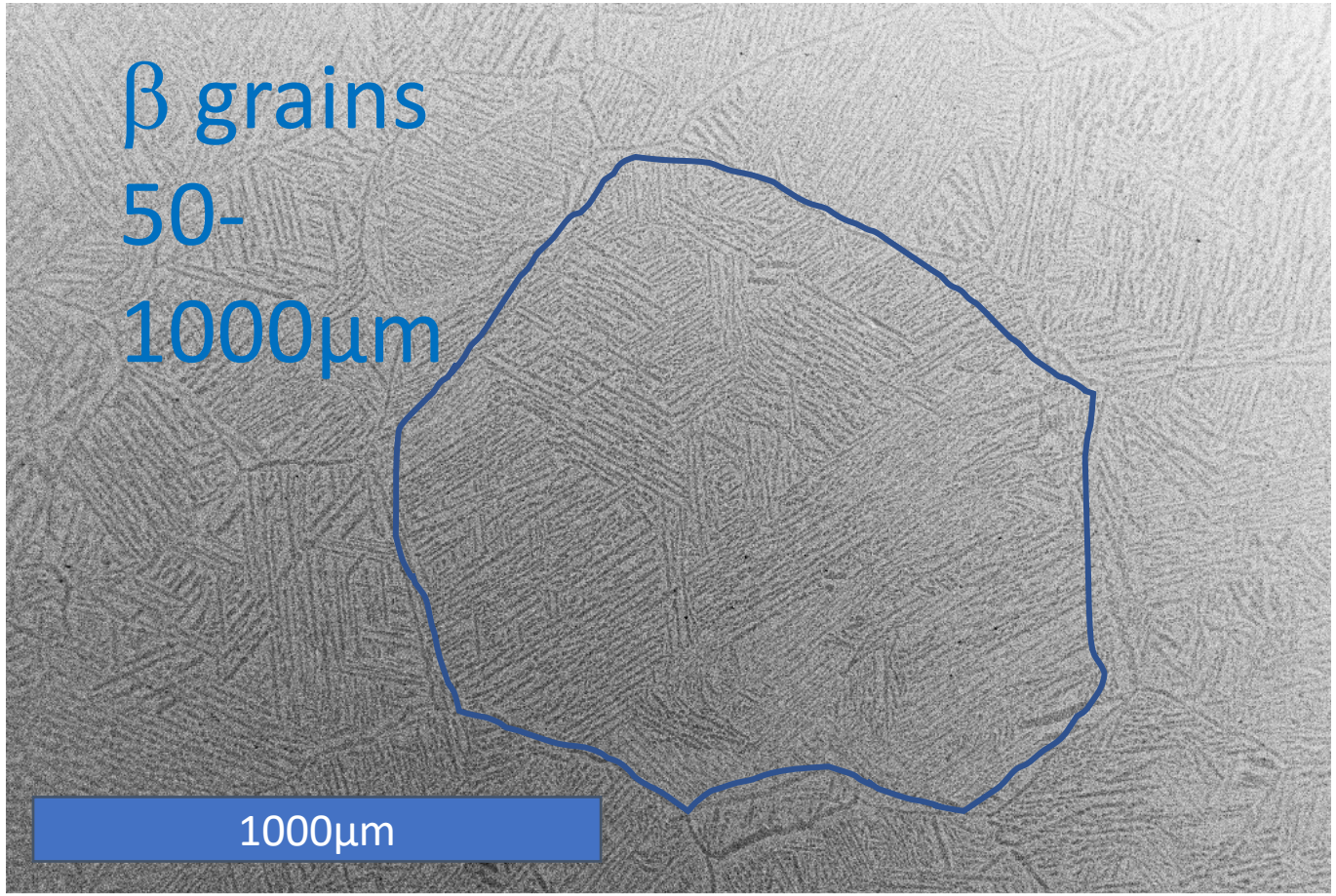
A microstructure on two scales



β Can be control via recrystallization

α Can be controlled via nucleation and growth during heat treatment

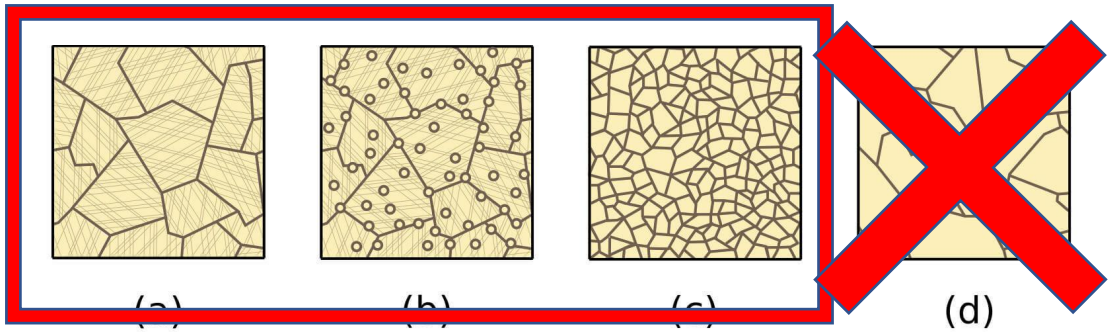
A microstructure on two scales



β Can be control via recrystallization

Focus of this paper

Recrystallization in Ti alloy



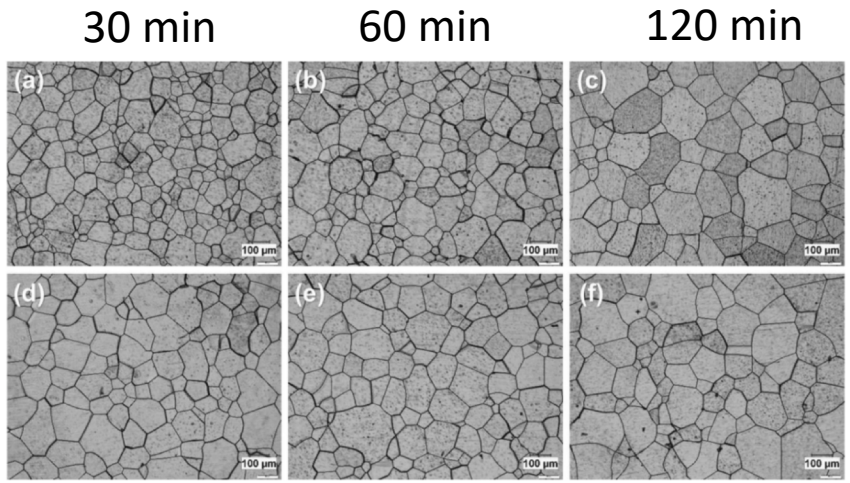


Fig. 5. Light optical microstructures of Ti-4733 (a, b, c) and Ti-5553 (d, e, f) samples after isothermal annealing at 850 °C for (a, d) 30 min, (b, e) 60 min and (c, f) 120 min.

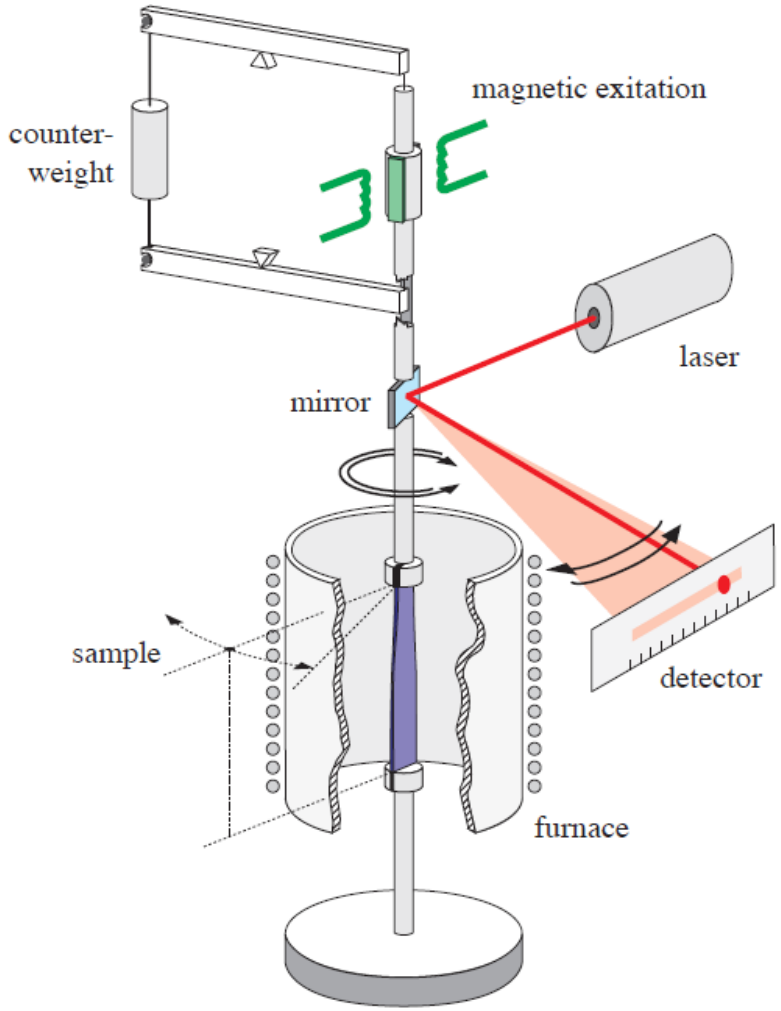
Sadeghpour, S., Javaheri, V., Abbasi, S. M., & Kömi, J. (2020). The effect of phase stability on the grain growth behavior of beta titanium alloys. *Physica B: Condensed Matter*, 412315.

- Cycle of deformation and annealing → recombination of dislocations → creation of new grains boundaries → grain refinement
- T and t are key parameters
- It would be nice to detect recrystallization

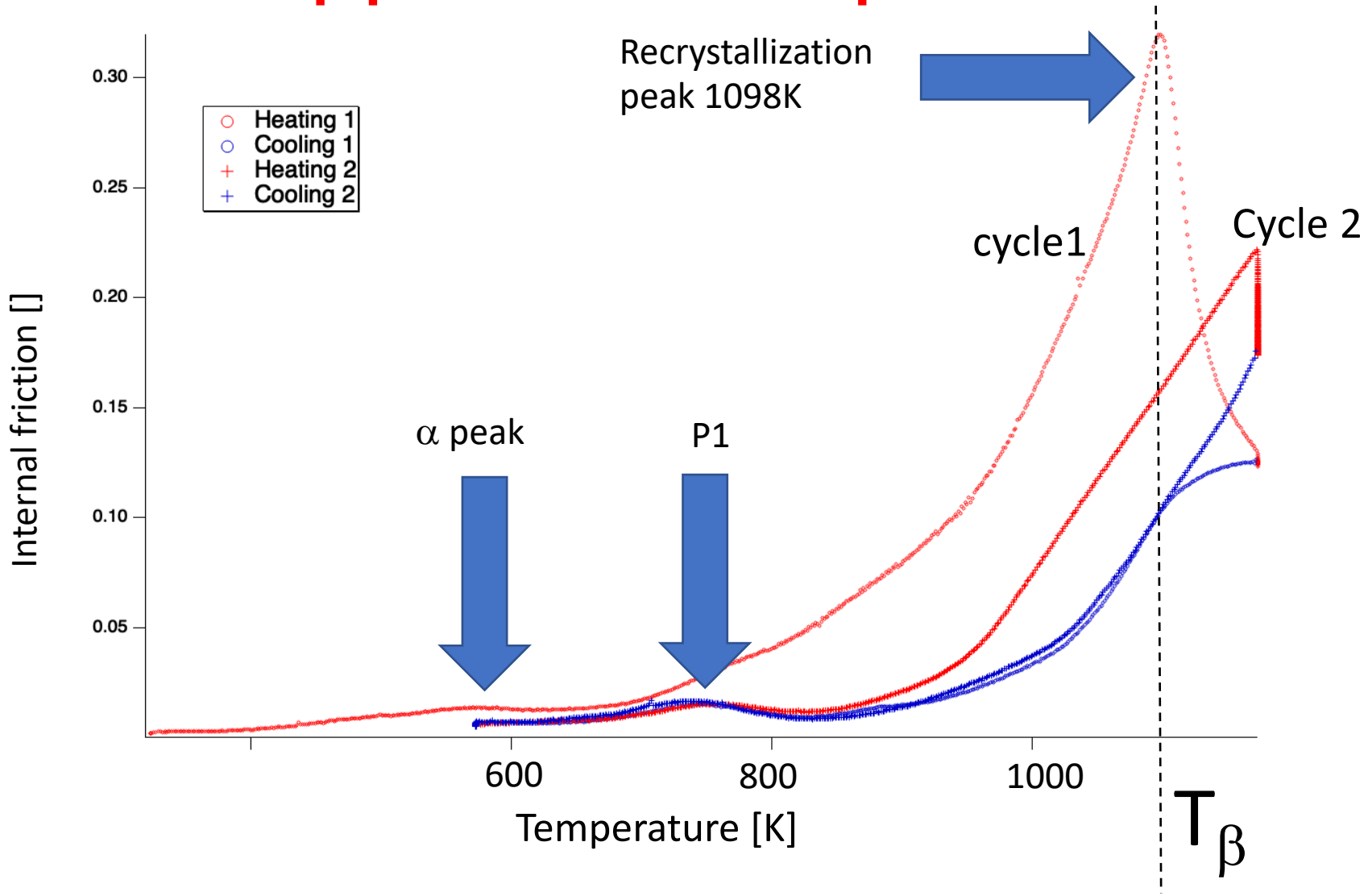
Set up used

%mass	Al	V	Mo	Cr
Ti 5553	5	5	5	3
Ti 4733	4	7	3	3

- Frequency: 1 Hz
- Heating rate: 1 K/min
- Pressure: 10^{-6} bar
- Homogenised at 950°C for 1 hour under Ar
- Cold rolled from 2mm to 1mm

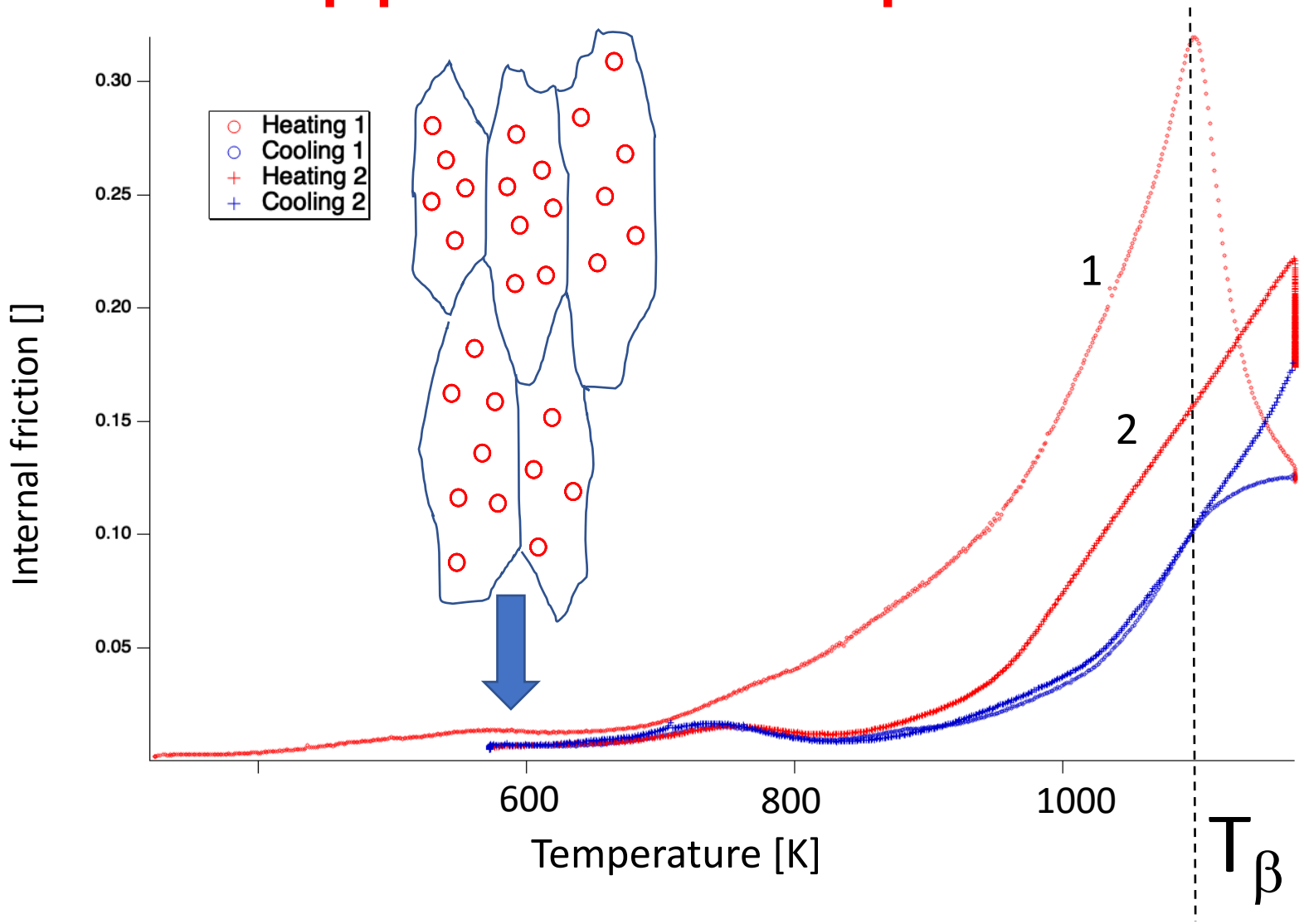


What happens in the pendulum ? (Ti5553)



- Heating cycle of a deformed sample
- 3 peaks can be identified
- The recrystallization peak is only present during the first heating

What happens in the pendulum ?



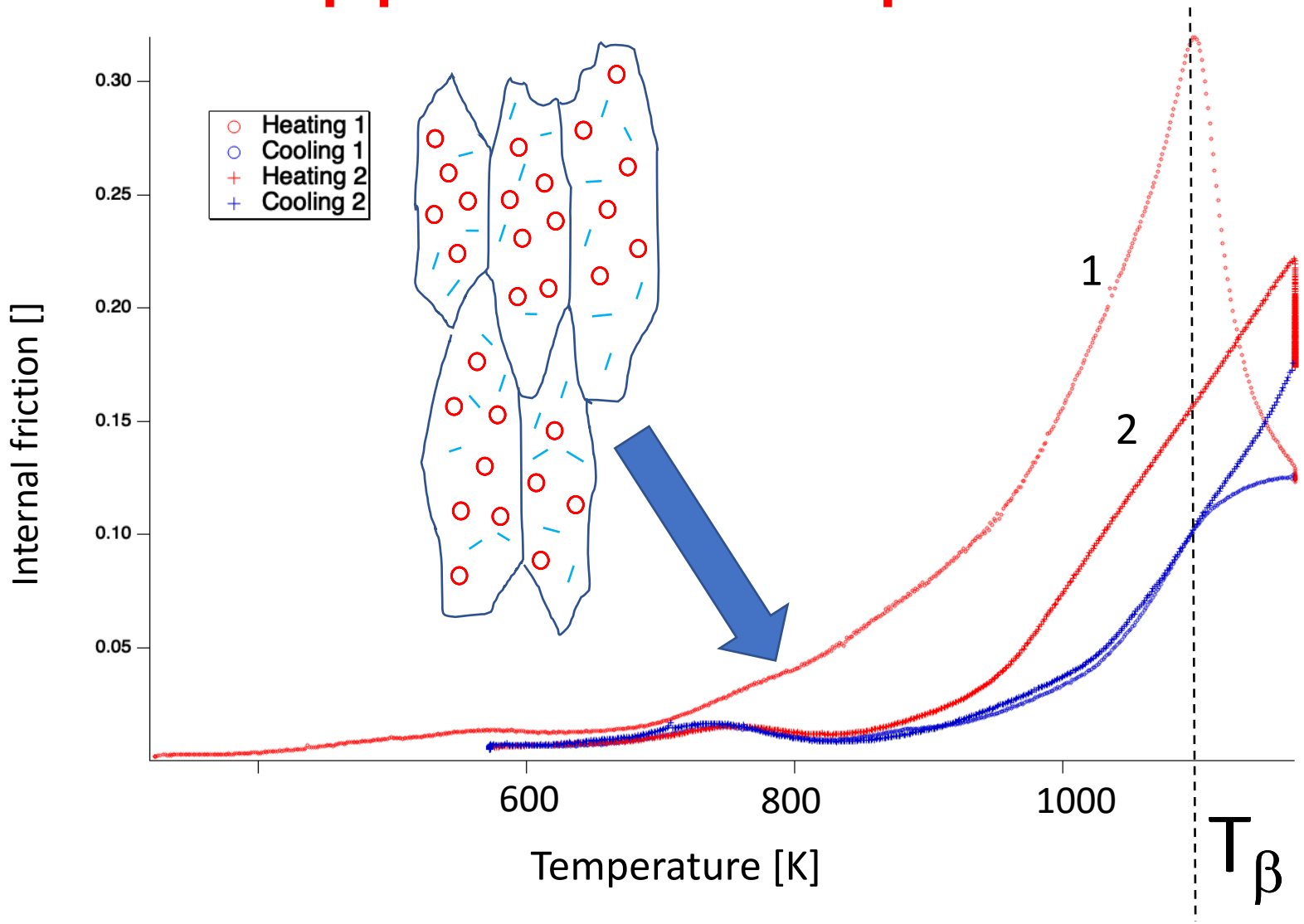
600 K

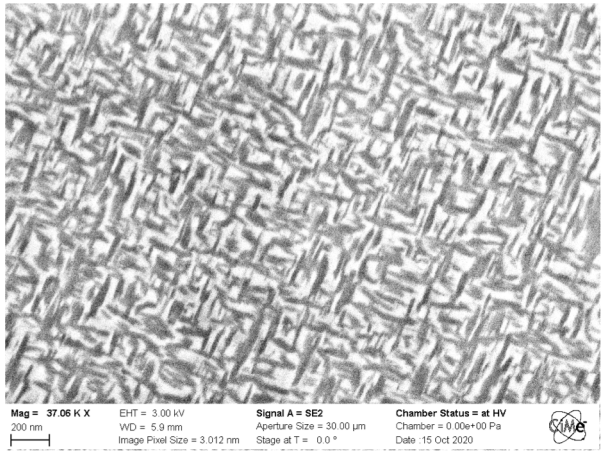
Dislocations

Grain boundaries

α Lamella

What happens in the pendulum ?





α grains 200nm

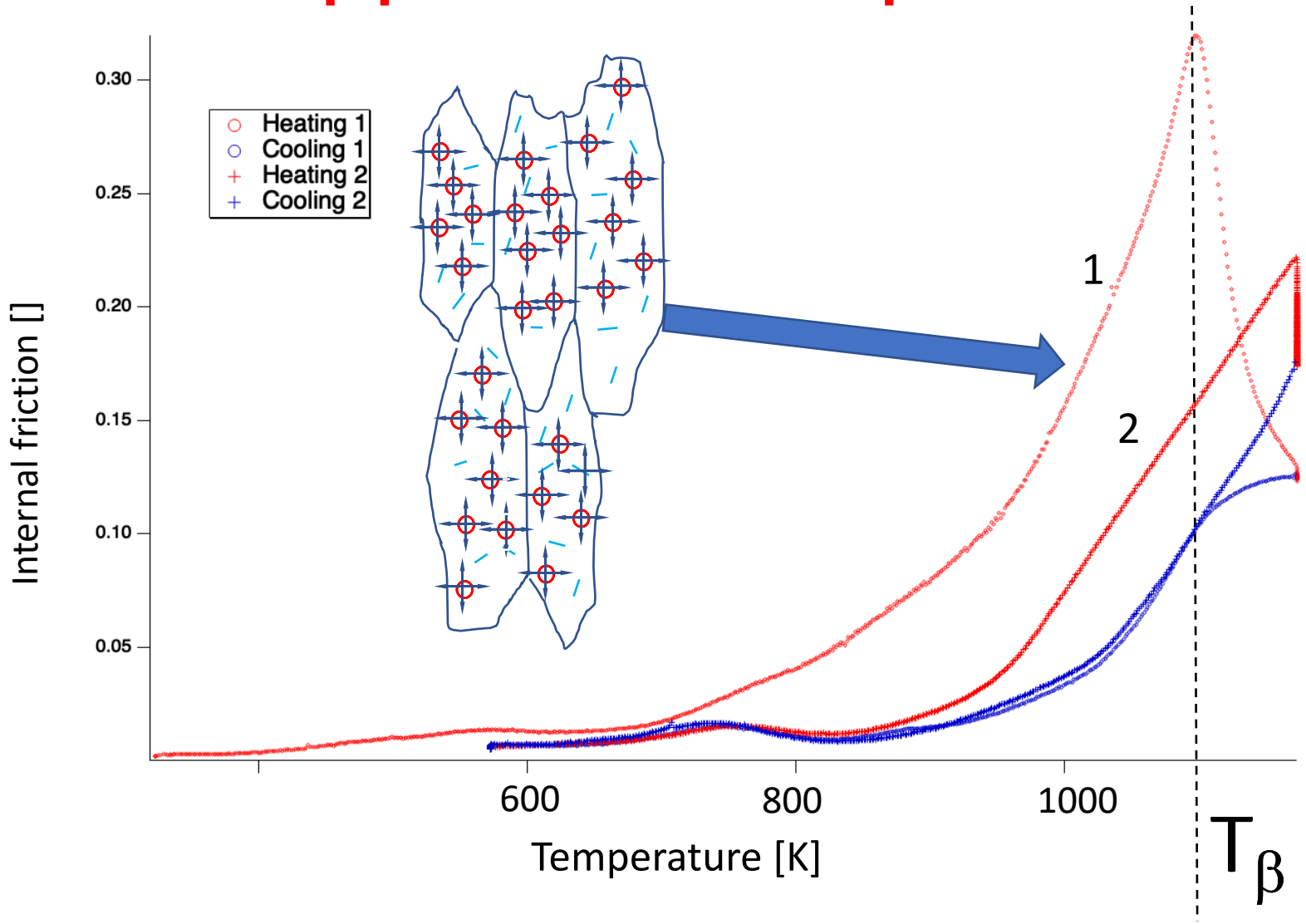
800 K

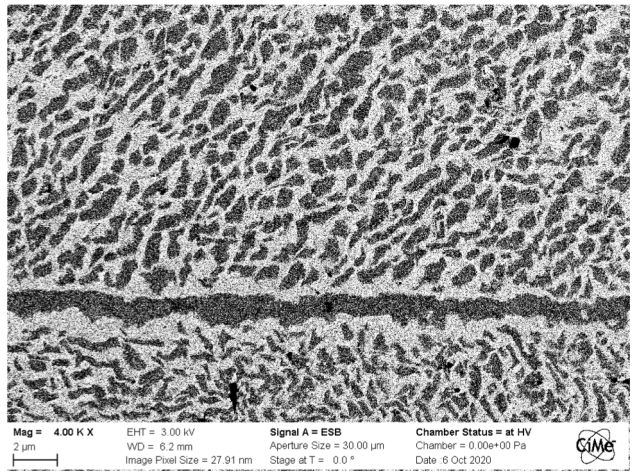
Dislocations

Grain boundaries

α Lamella

What happens in the pendulum ?





α grains 1-2 µm

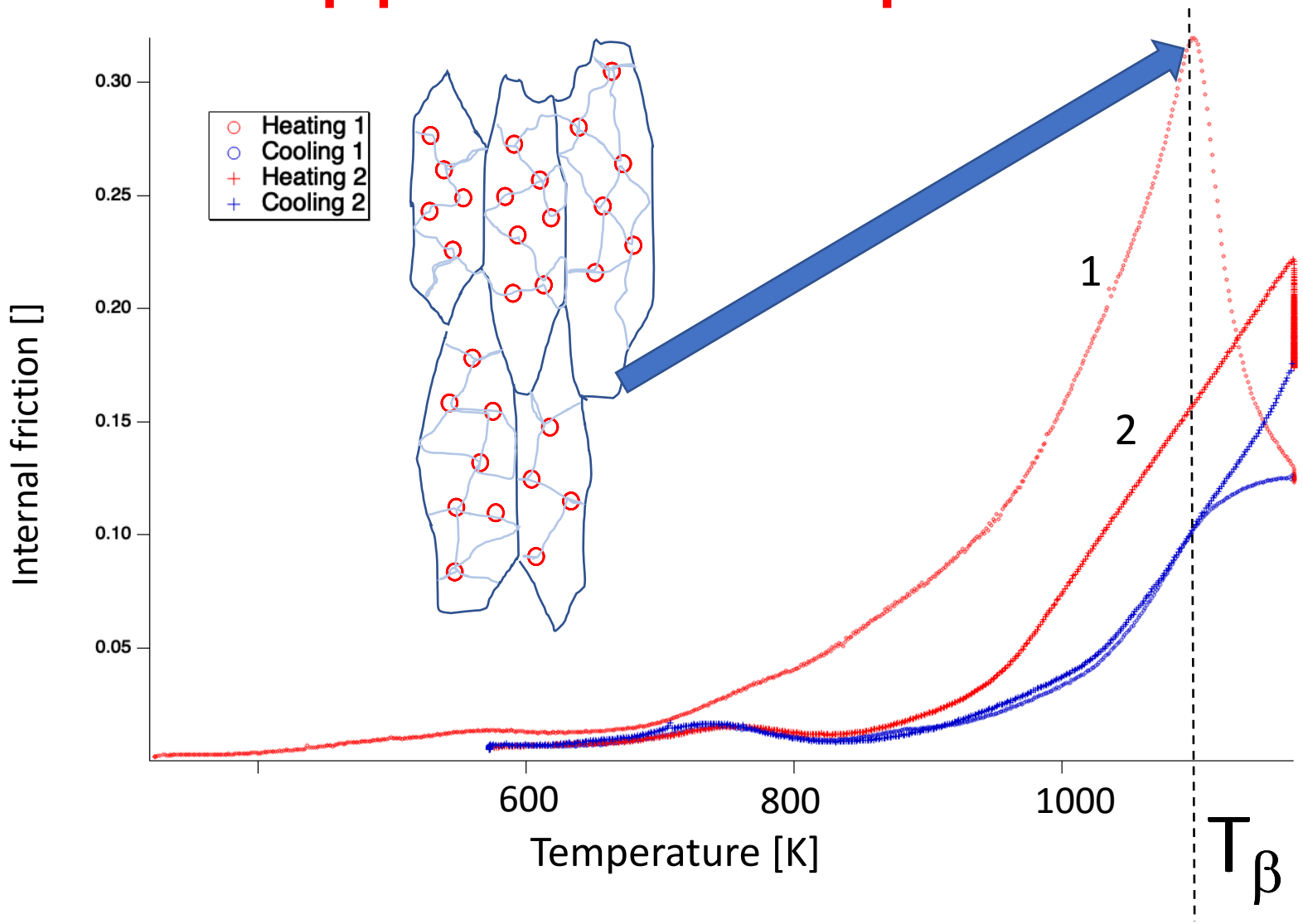
1000 K

Dislocations

Grain boundaries

α Lamella

What happens in the pendulum ?



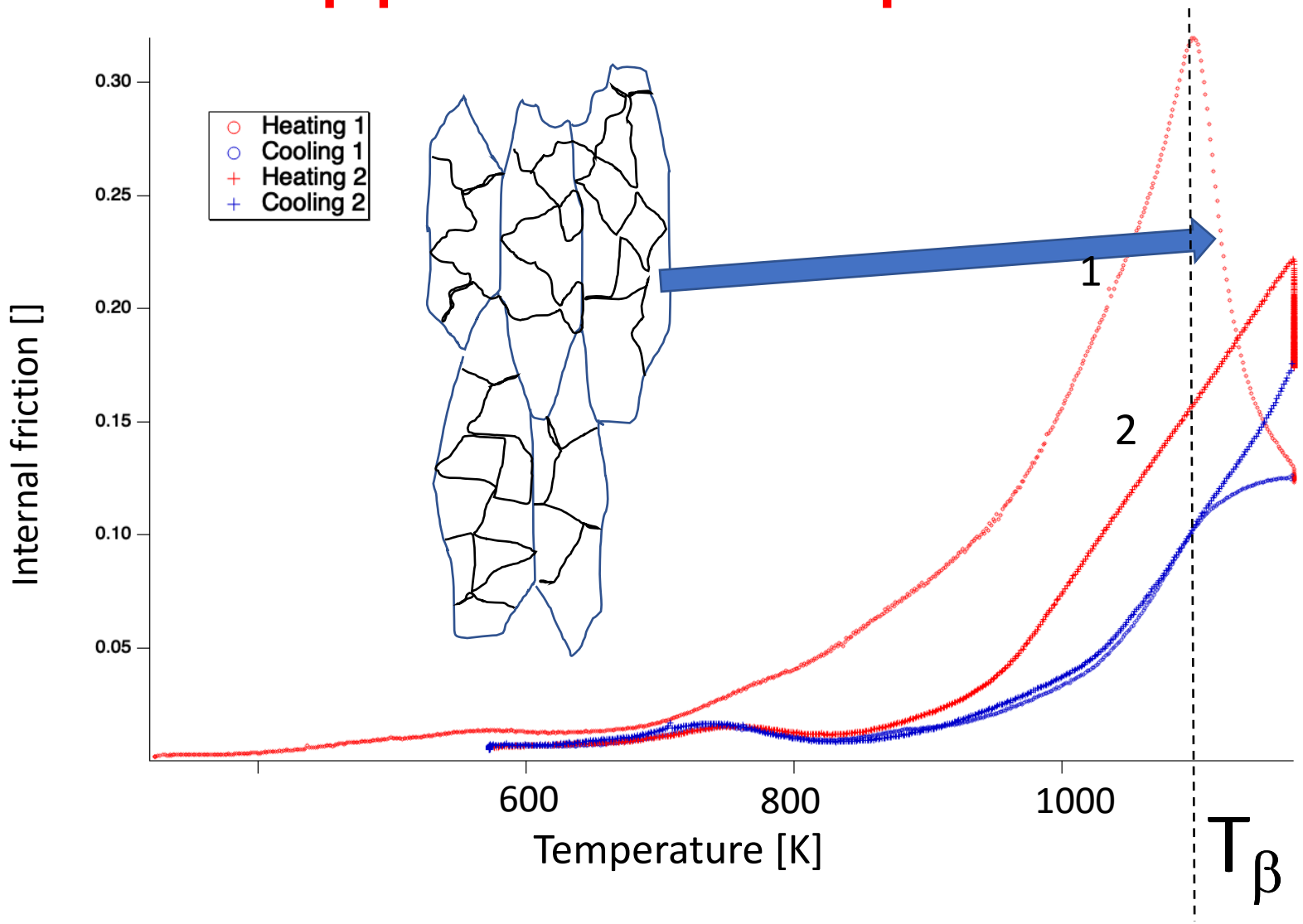
1098 K

Dislocations

Grain boundaries

α Lamella

What happens in the pendulum ?



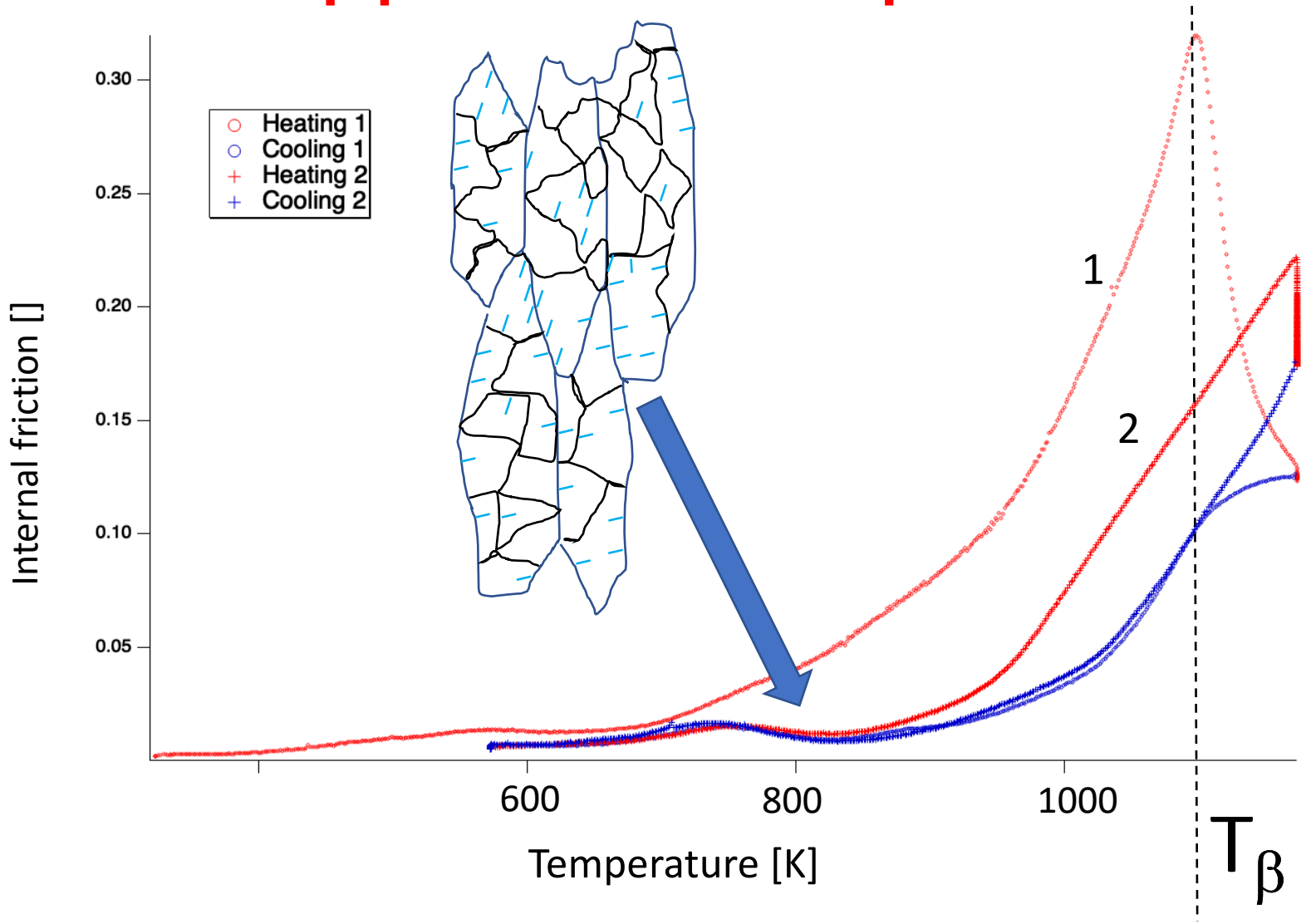
1150 K

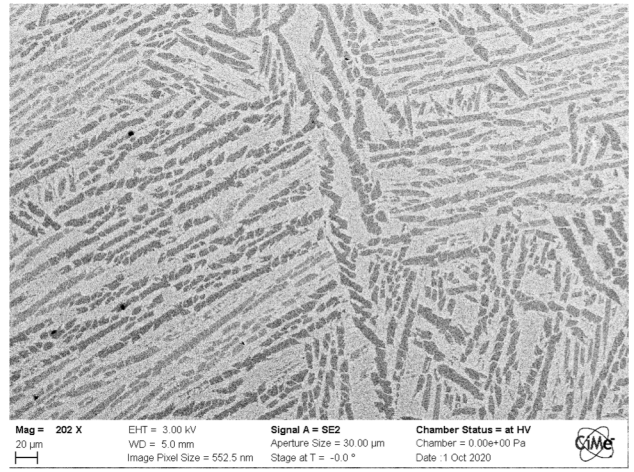
Dislocations

Grain boundaries

α Lamella

What happens in the pendulum ?





α grains 100µm

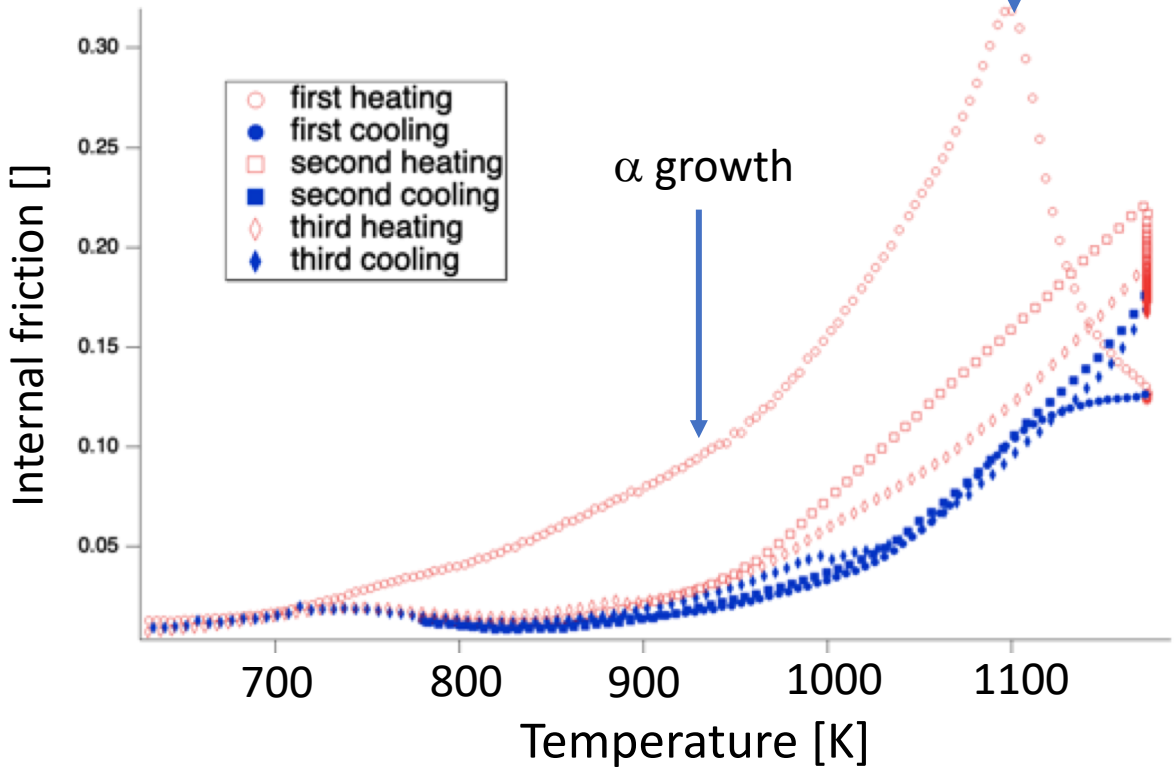
800 K (cooling)

- Dislocations
- Grain boundaries
- α Lamella

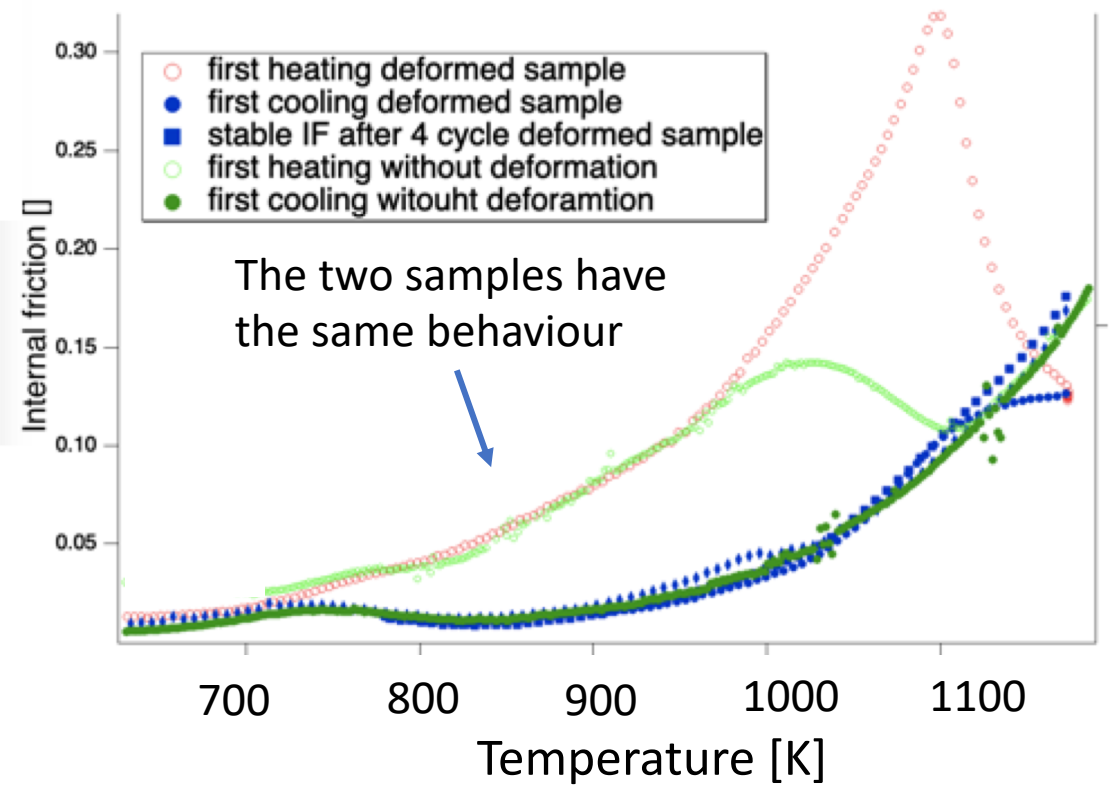
Internal friction in Ti5553

Deformed sample

Recrystallization peak

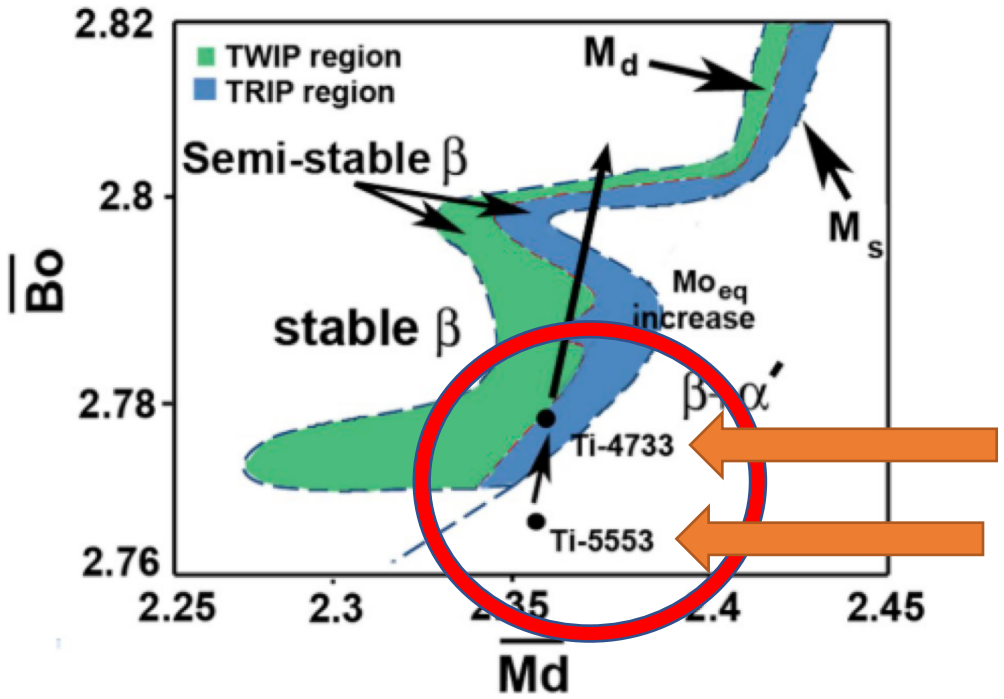


Deformed vs non deformed sample



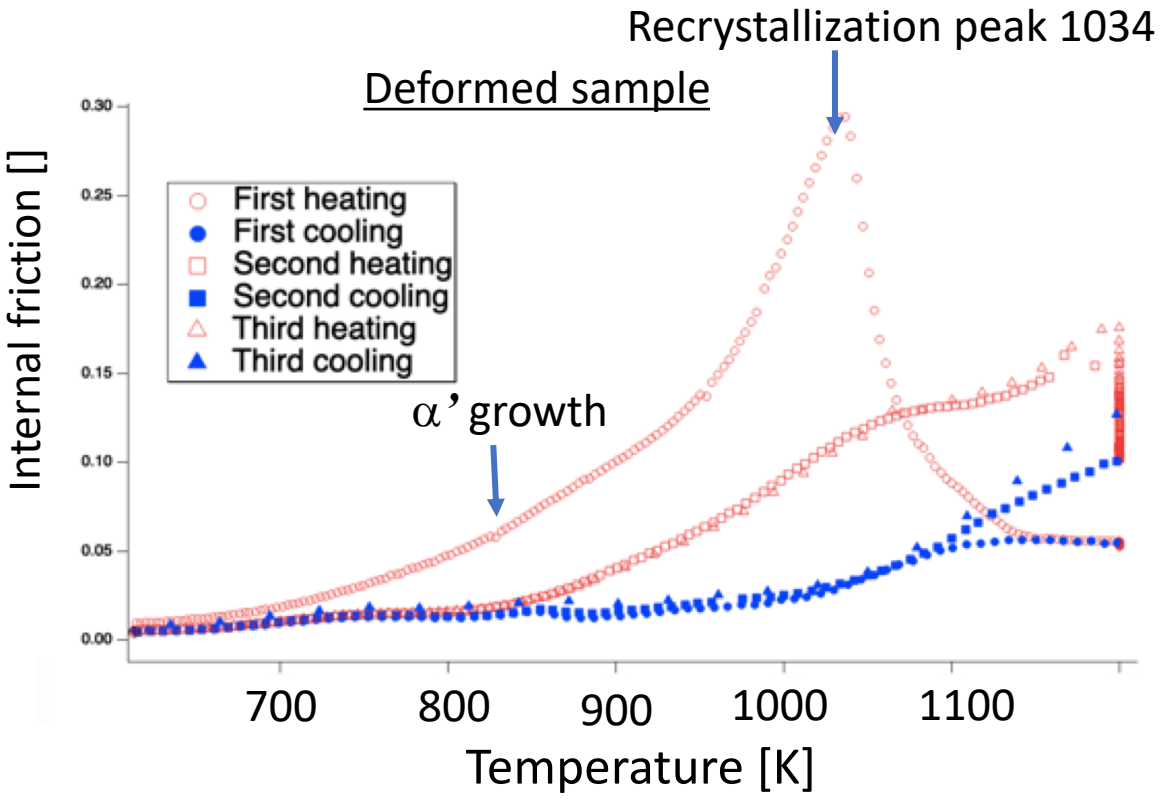
Tweak the alloy using TRIP and TWIP

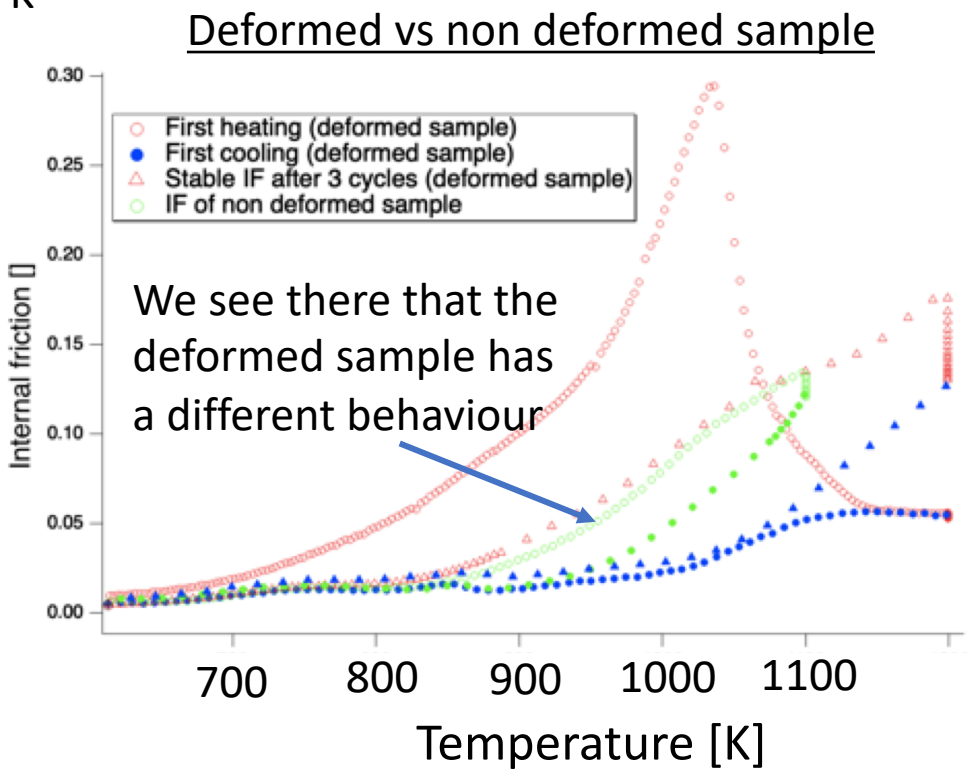
- We use the result from the molecular orbital model
- Prediction on phase stability with Bonding Order and Mean d field energy
- The diagram of phase stability matches quite well the deformation mode diagram (empiric diagram)



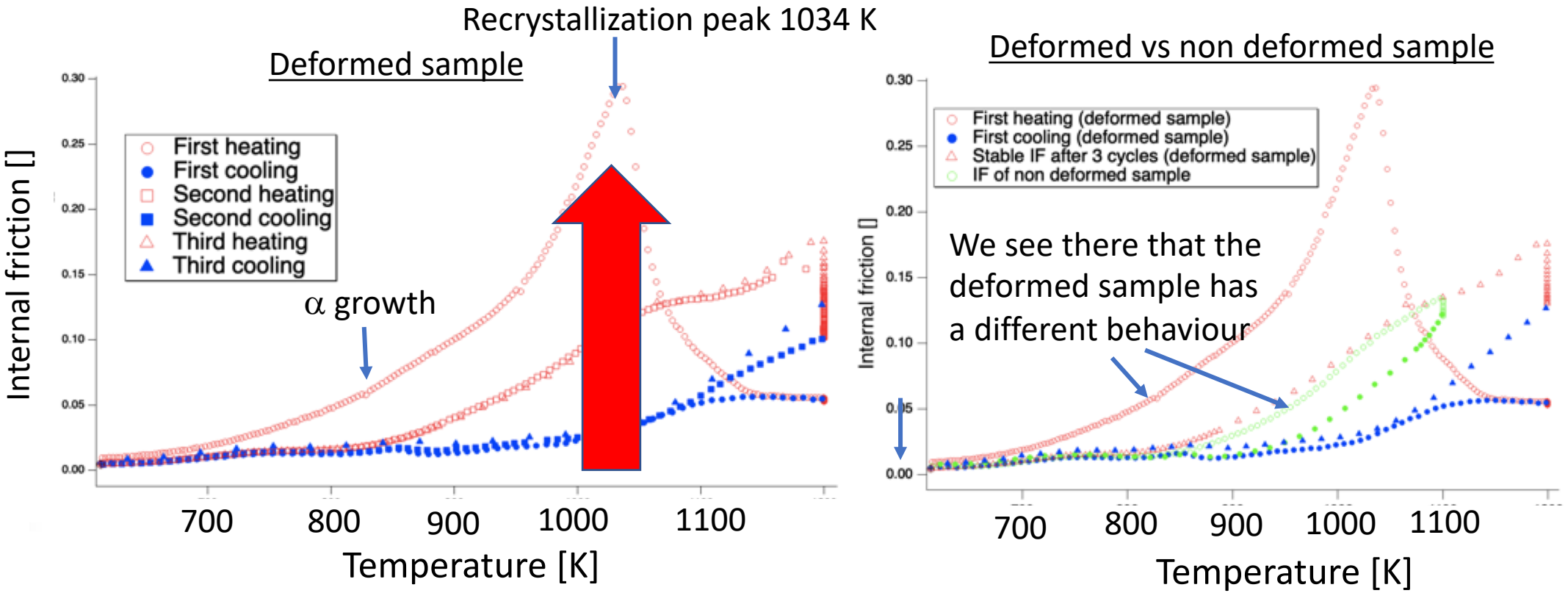
New composition → more deformation → metastable α → lower T_β

Internal friction in Ti4733



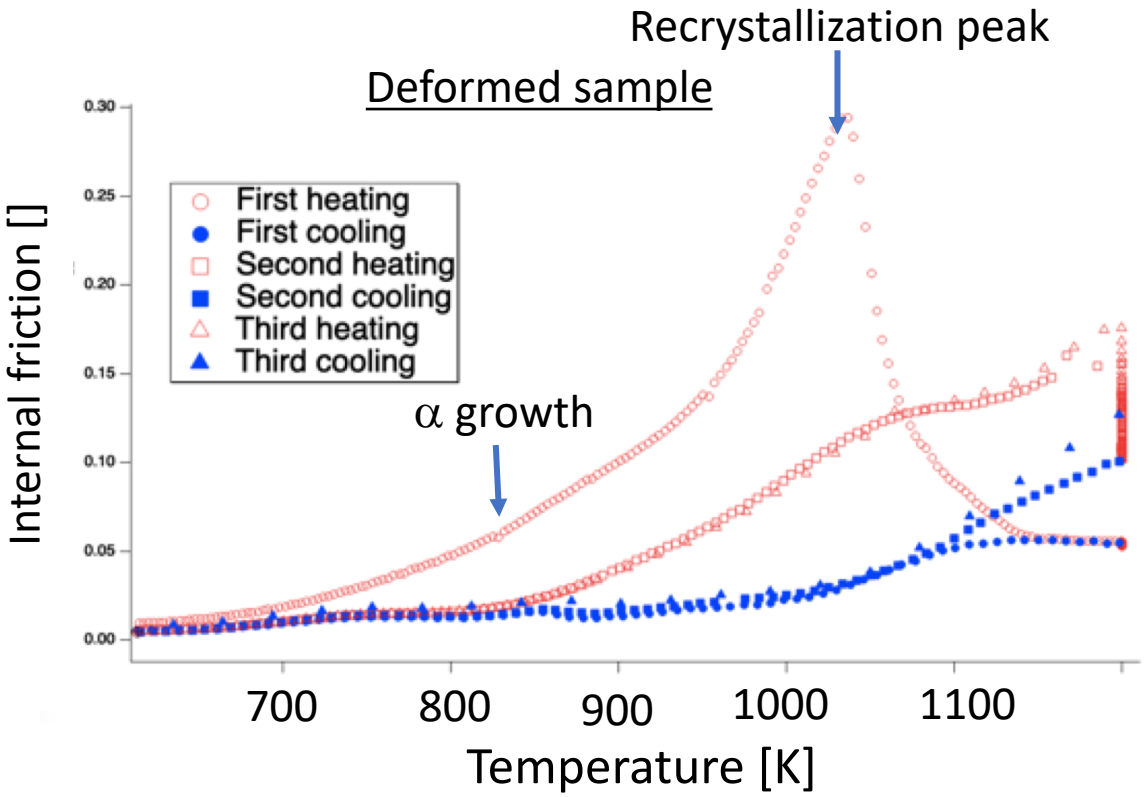


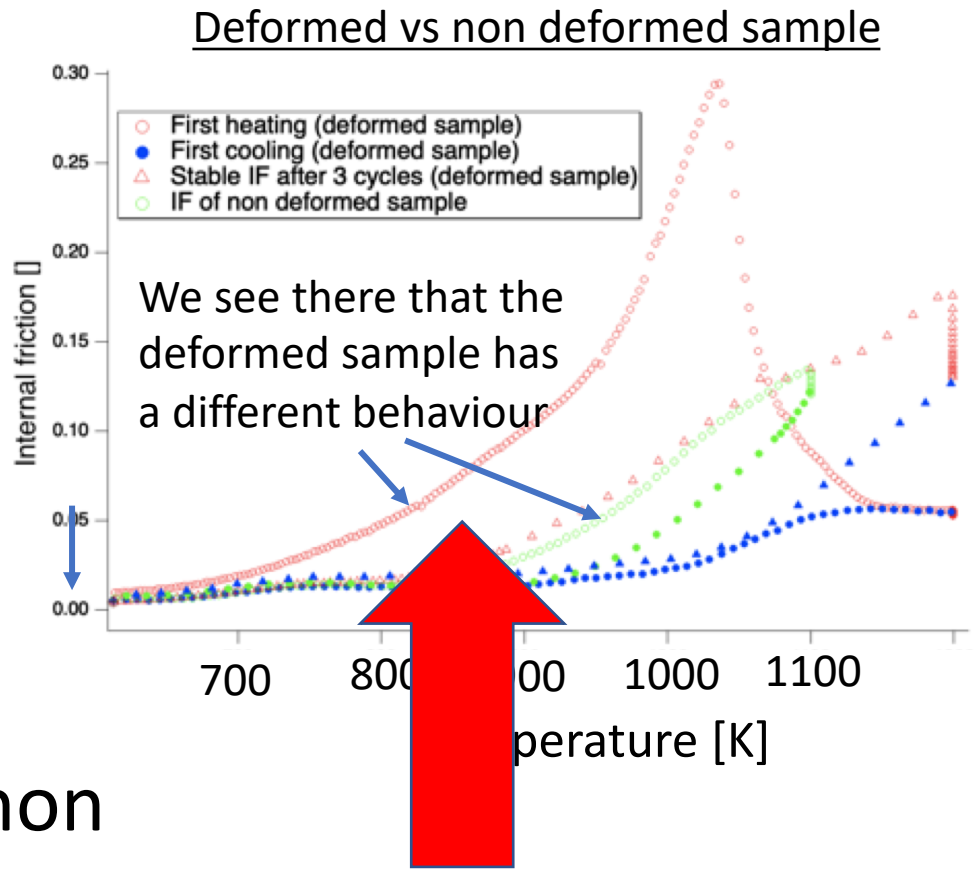
Internal friction in Ti4733



- Recrystallization peak 1034

Internal friction in Ti4733



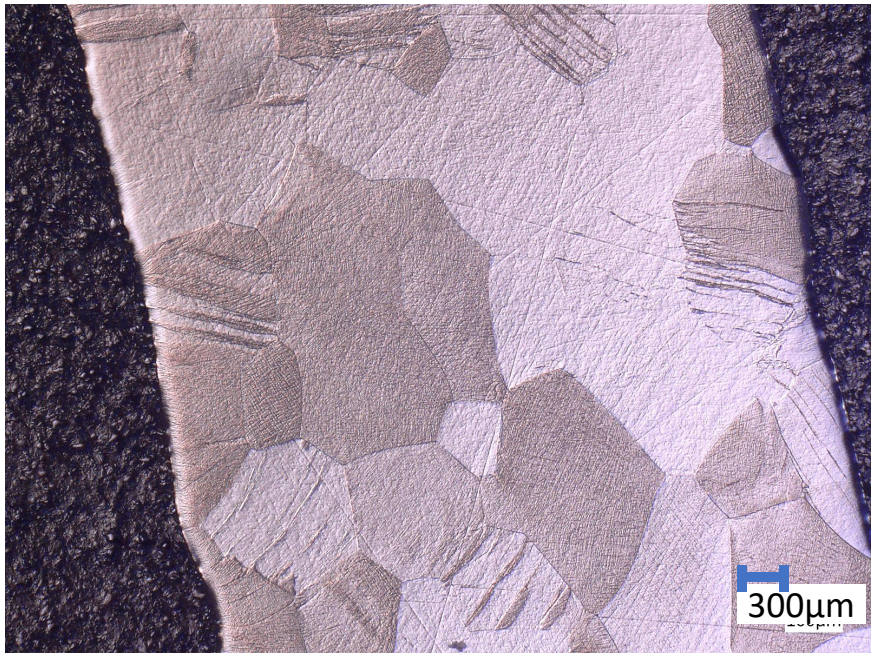


- Shift between the deformed and non deformed sample due to the α' phase

Does it work ?

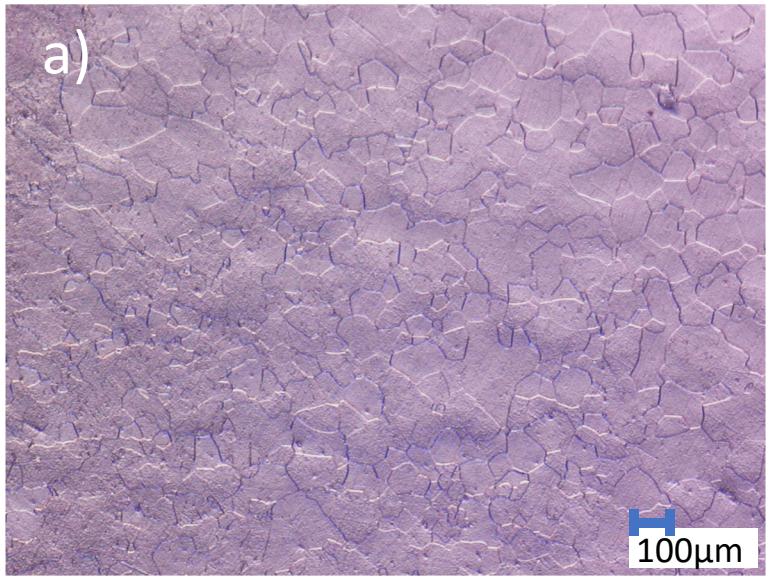
Ti5553

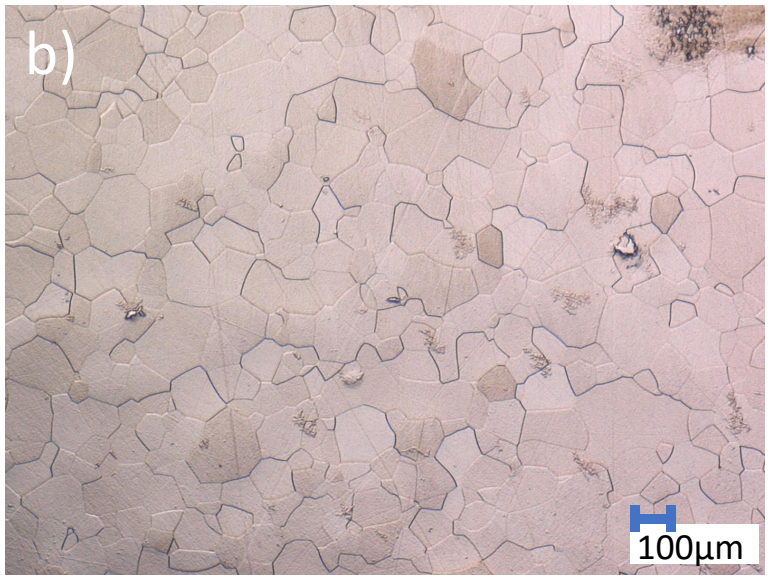
Initial state

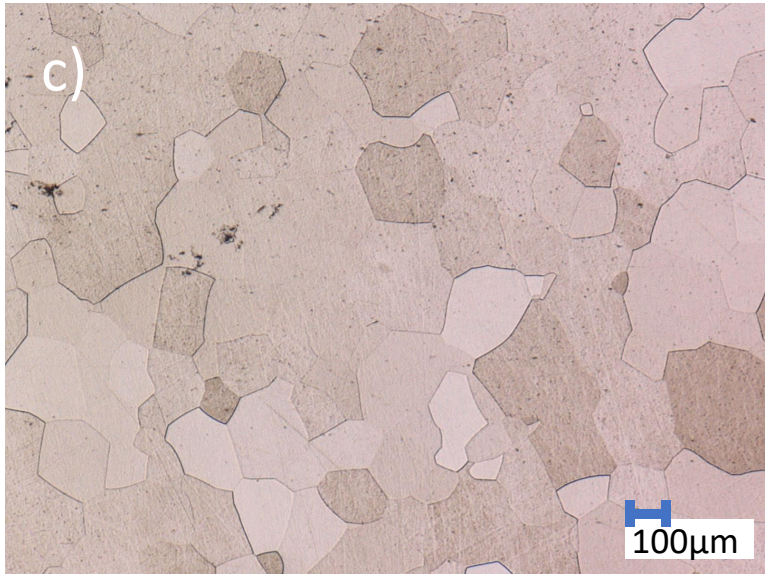


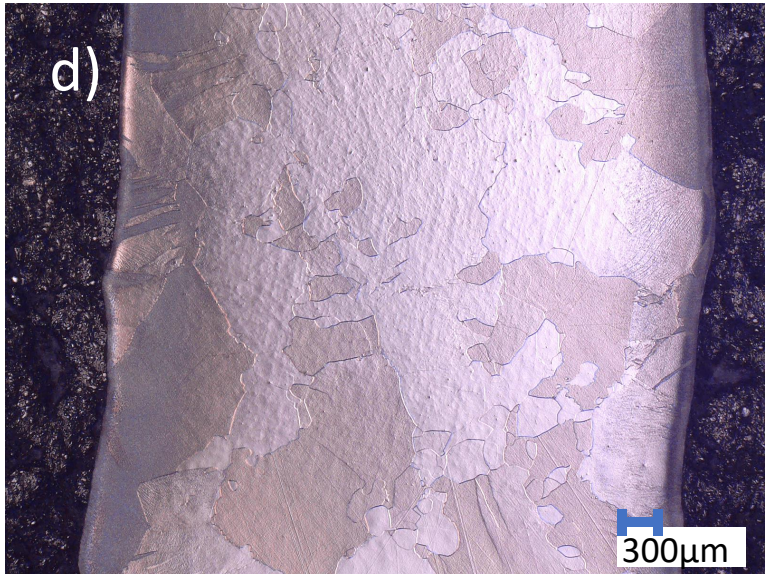
- Recrystallization occurs forming smaller grains that grow with time
- 780°C is not enough to trigger recrystallization

Ti5553 annealed at 840°C 3min (a), 5 min (b) 10 min(c) at 780°C 5min (d)









Does it work ?

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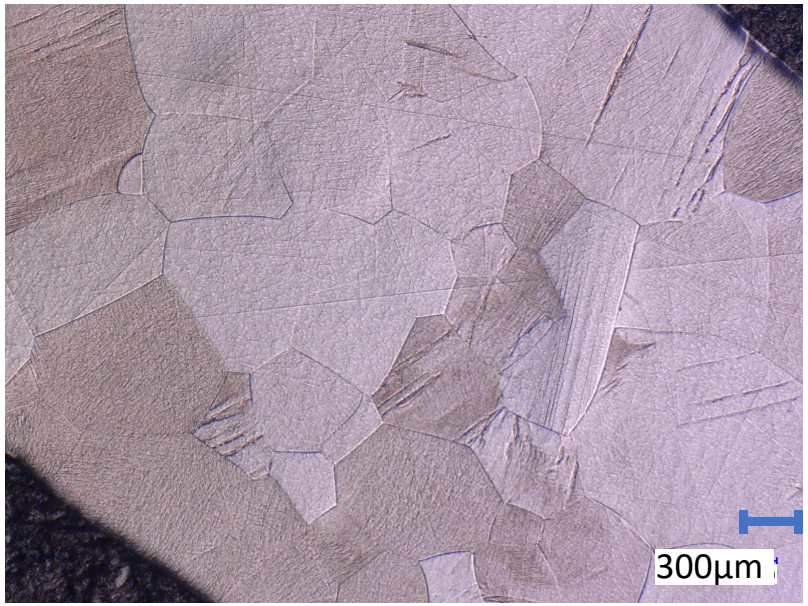
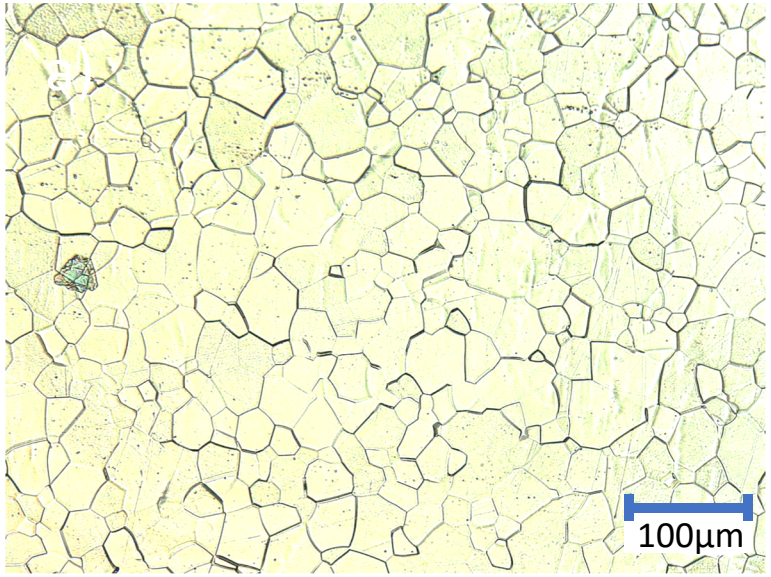
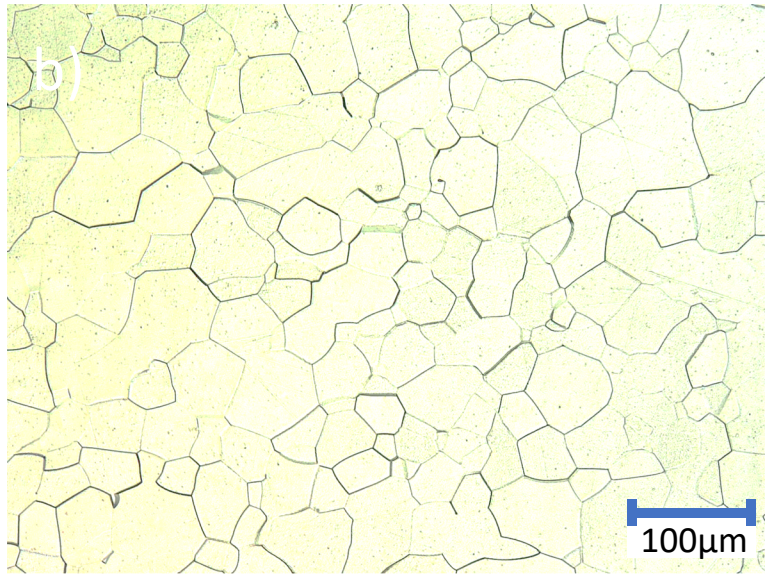
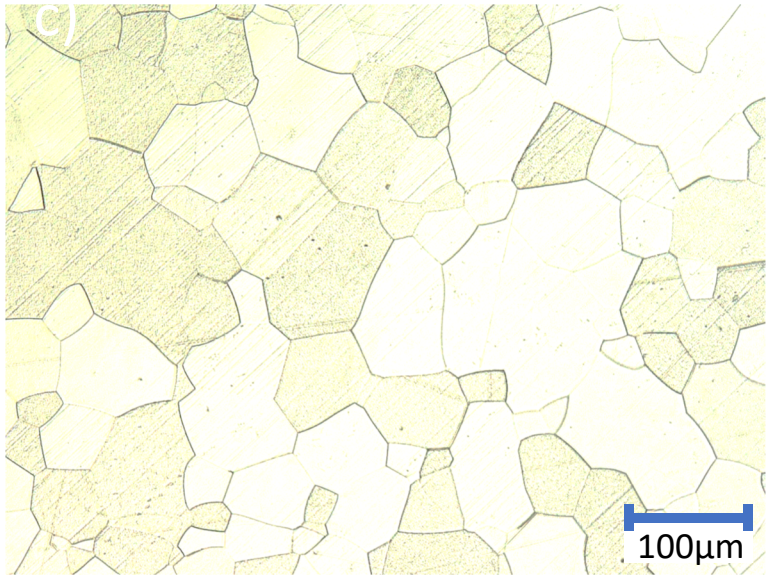


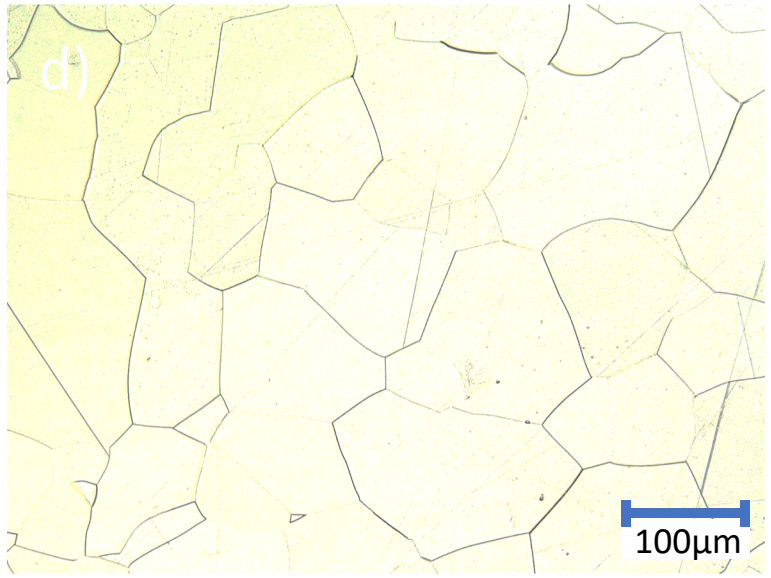
- Recrystallization occurs forming smaller grains that grow with time
- 840°C is too much and grain growth is important

Ti4733 annealed at 780°C 3min (a), 5 min (b) 10 min(c) at 840°C 5min (d)









Size of the β grains after heat treatment

	3 min	5 min	10 min	5min*
Ti5553 840°C	72 ± 22 µm	87 ± 24 µm	134 ± 35 µm	No recry
Ti4733 780°C	26 ± 9 µm	39 ± 14 µm	51 ± 18 µm	73 ± 29 µm

*At the temperature of the other alloy

- Ti4733 grains are significantly thinner that Ti5553 grains
- Lower Temperature recrystallization due to TWIP/TWIP definitely helps for grain refinements purposes.
- Results on Ti4733 show how critical the temperature is
- This give credit to the internal friction measurement method to help optimize heat treatment in Ti alloys

The differences between the two alloys:

Ti5553		Ti4733
1098 K (825°)	Temperature of recrystallization:	1034 K (760°C)
no	Presence of α' after deformation	Yes
α dissolution	Recrystallization triggered by	α' dissolution
72 µm	Minimal size of the grain after recrystallization	26 µm

Summary

- Recrystallization in β-metastable titanium alloys are triggered by dissolution of α or α' phases
- This recrystallization can be detected using internal friction measurement, which help optimizing the heat treatment
- Tailoring the stability of the α and α' phases allow a further optimization compared to previous studies

Thank you for you attention

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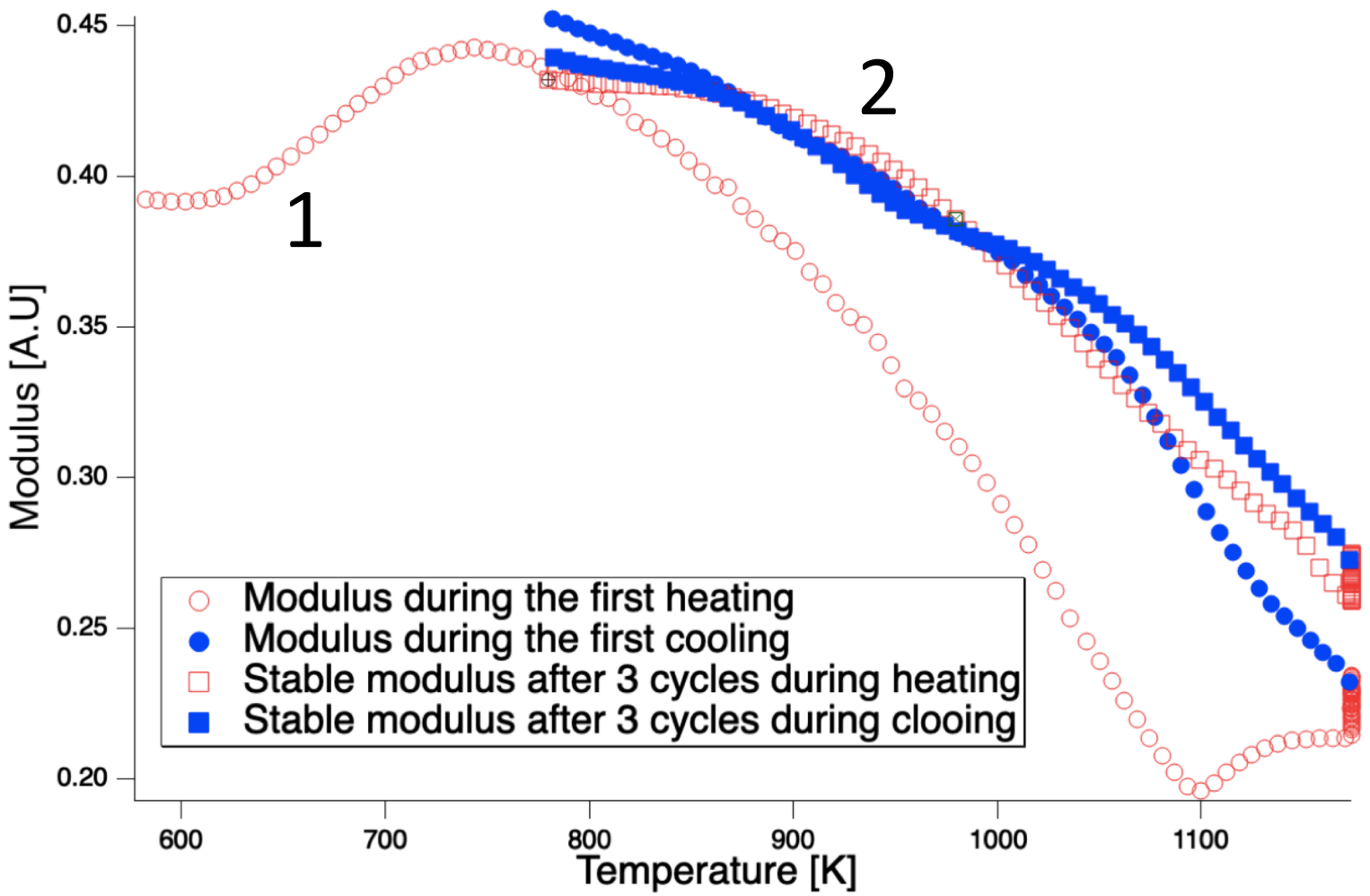
What about the modulus look like ? (Ti5553)



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What about other frequencies ?