Role of Ultrafast Heterogeneous Melting in Laser Machining Dynamics

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17 September 2024

Outline

- Ultrafast Laser Machining
- X-ray Pump-probe method
- Excitations in the time domain
- Ultrafast melting of gold films
- Planned GISAXS experiments

Laser Machining speed Comparison

50μm hole drilled in Alumina plate

Tatsuhiko Aizawa and Tadahiko Inohara, Book Chapter

“heat-affected zone”

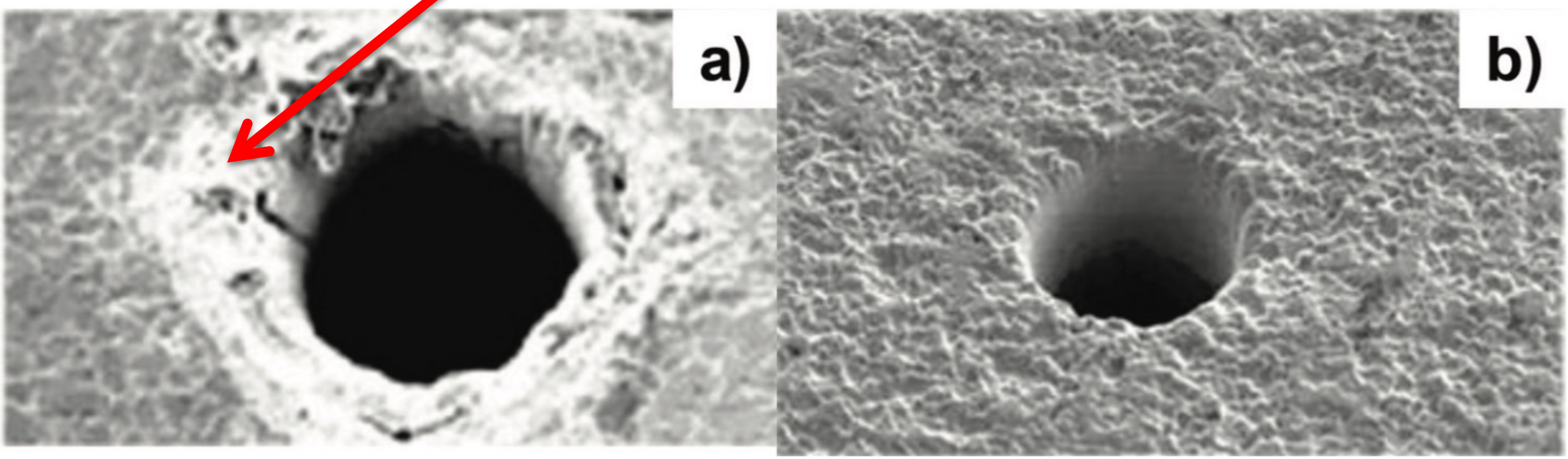


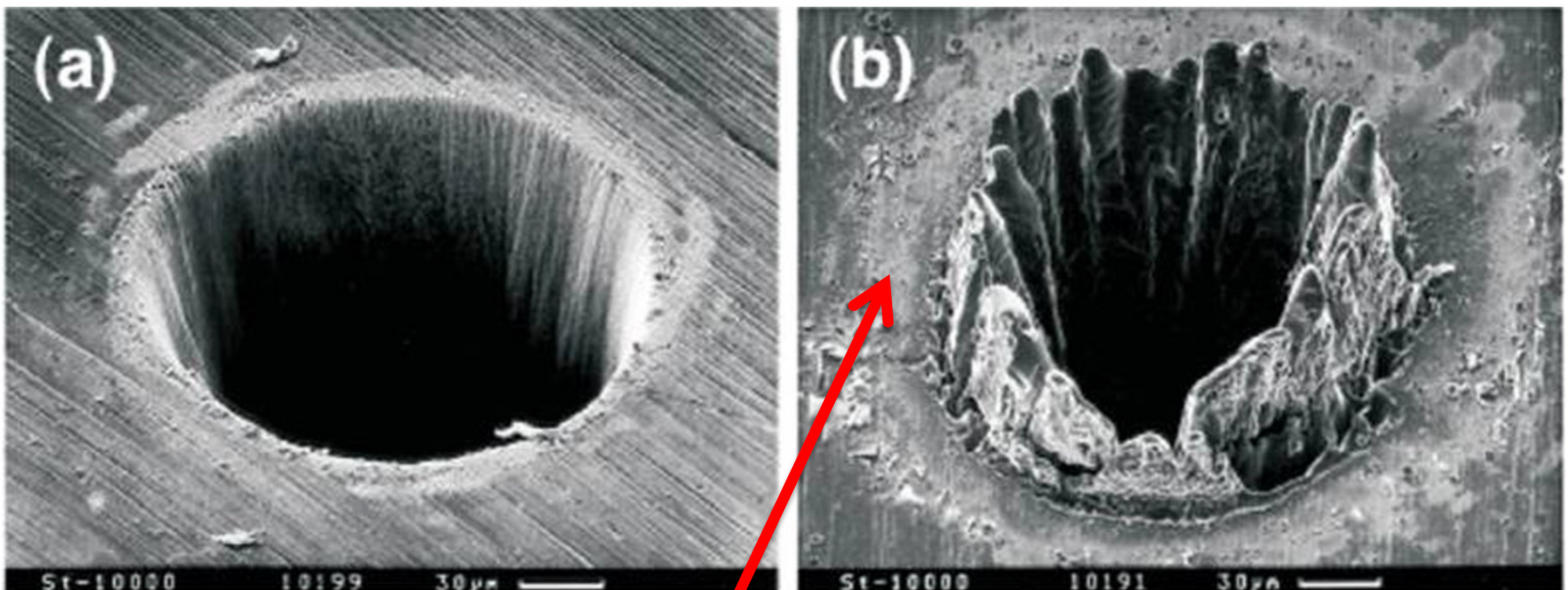
Figure 6.
Comparison of the drilled through-hole between fiber lasers and the picosecond laser. (a) Fiber laser drilling, and, (b) Picosecond laser drilling.

Laser Machining speed Comparison

100μm hole drilled in 100μm steel plate

K. Sugioka and Y. Cheng, Appl. Phys. Rev. **1** 041303 (2014)

200fs pulse, 0.5J/cm^2 | 3.3ns pulse, 4.2J/cm^2



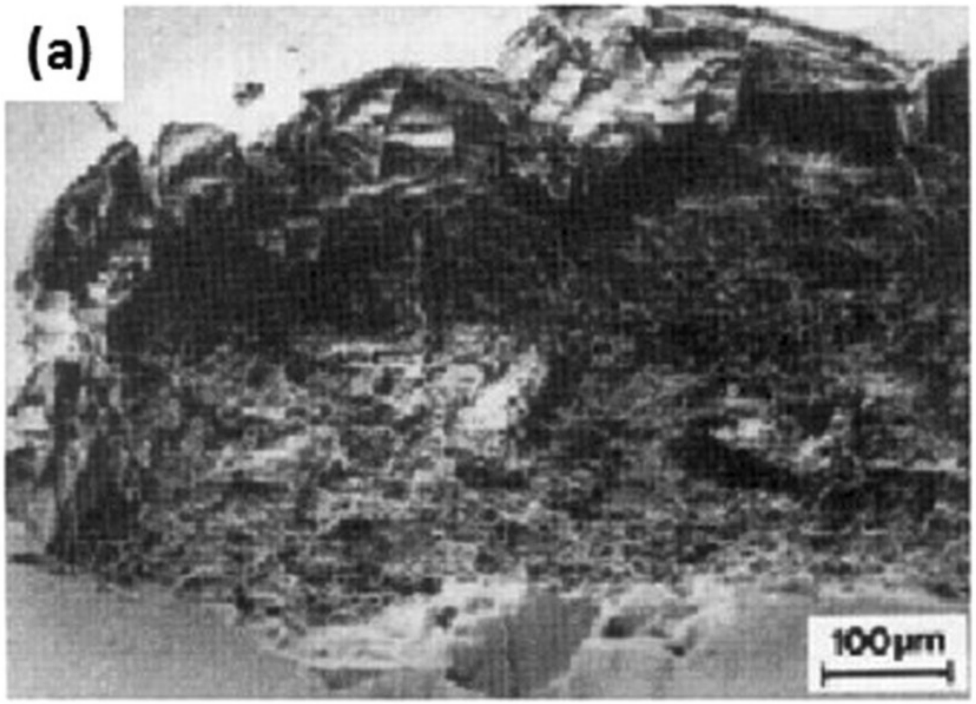
"heat-affected zone"

Laser Machining speed Comparison

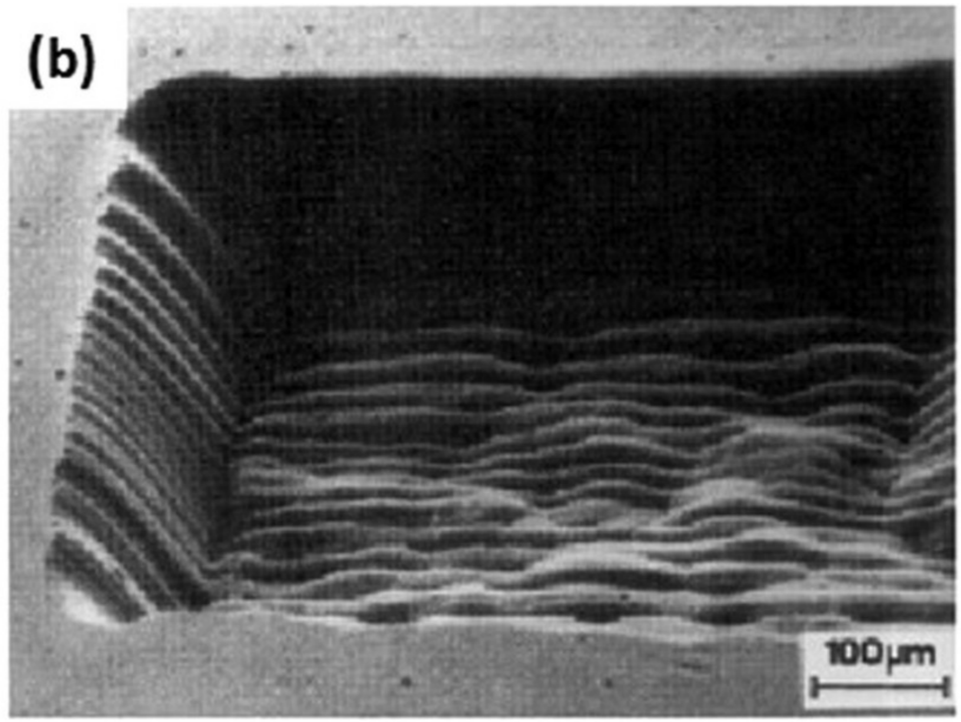
SEM of laser machined NaCl

Multiphoton Absorption of 248nm (NaCl is transparent)

K. Sugioka and Y. Cheng, Appl. Phys. Rev. **1** 041303 (2014)

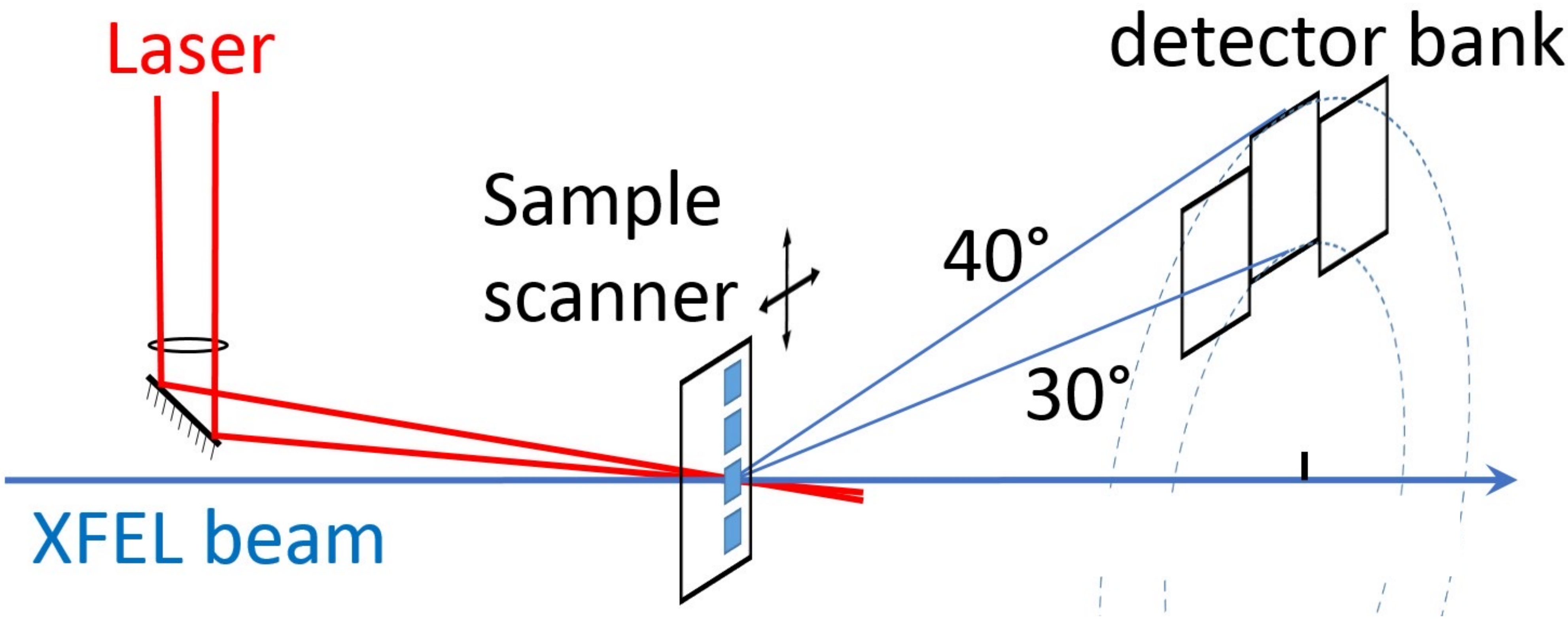


Nanosecond laser (16ns)

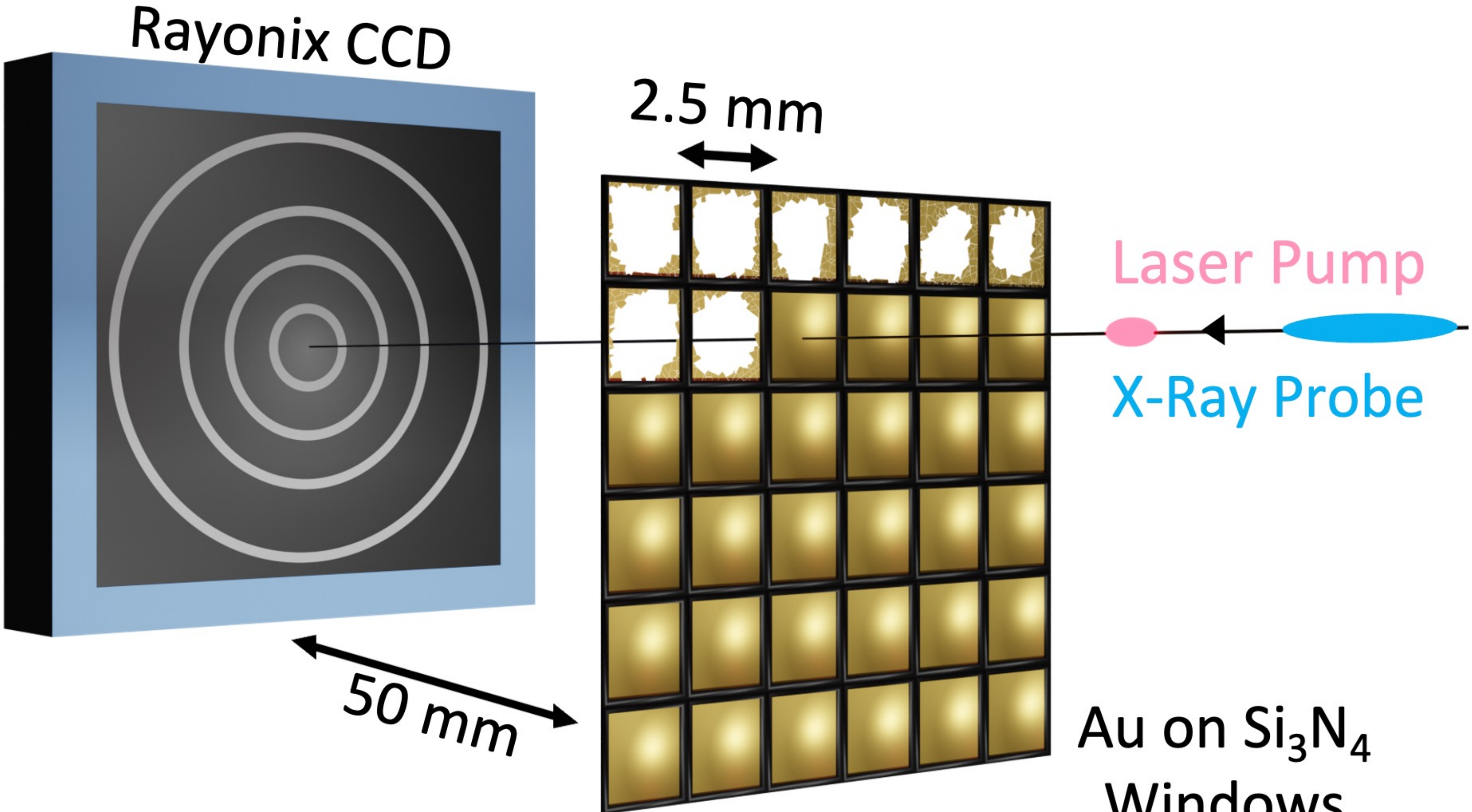


Femtosecond laser (300fs)

Pump-probe Method using Sample Scanner



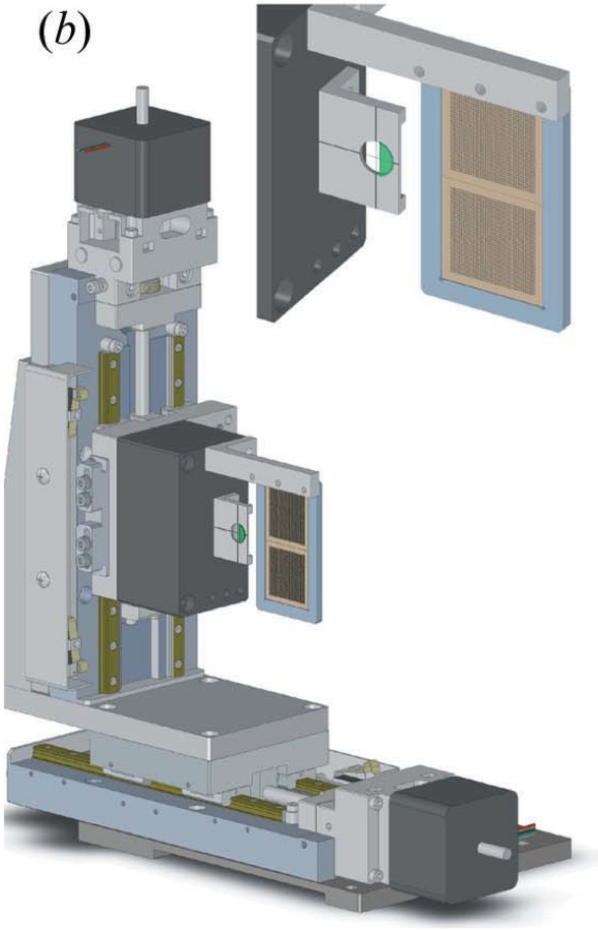
"Diffract and Destroy" setup

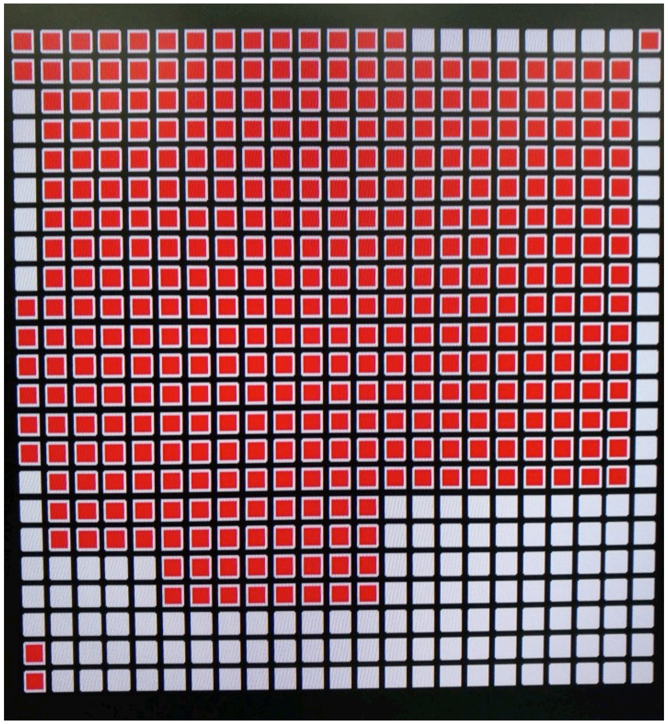


Scan Stage for MAXIC chamber

Changyong Song et al, J. Appl. Cryst. **47** 188 (2014)

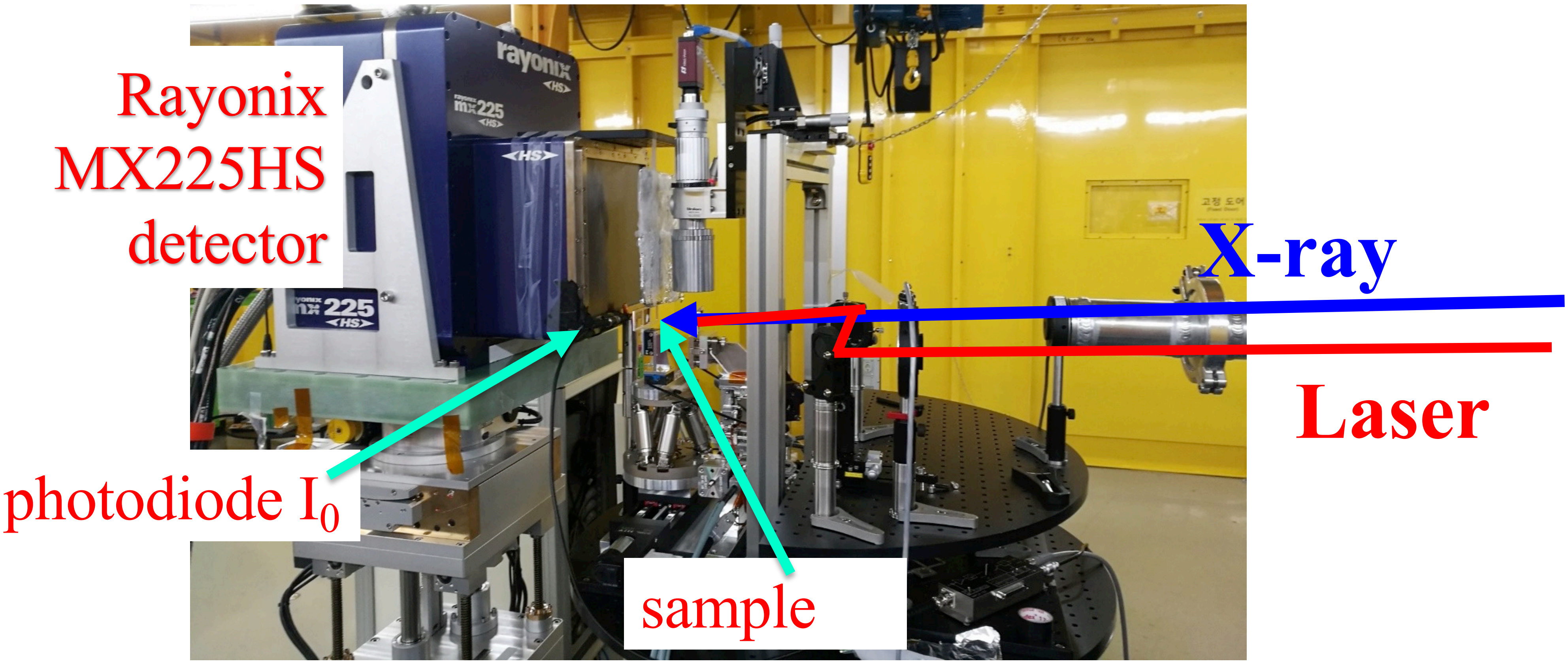
Daewoong Nam, scanning software



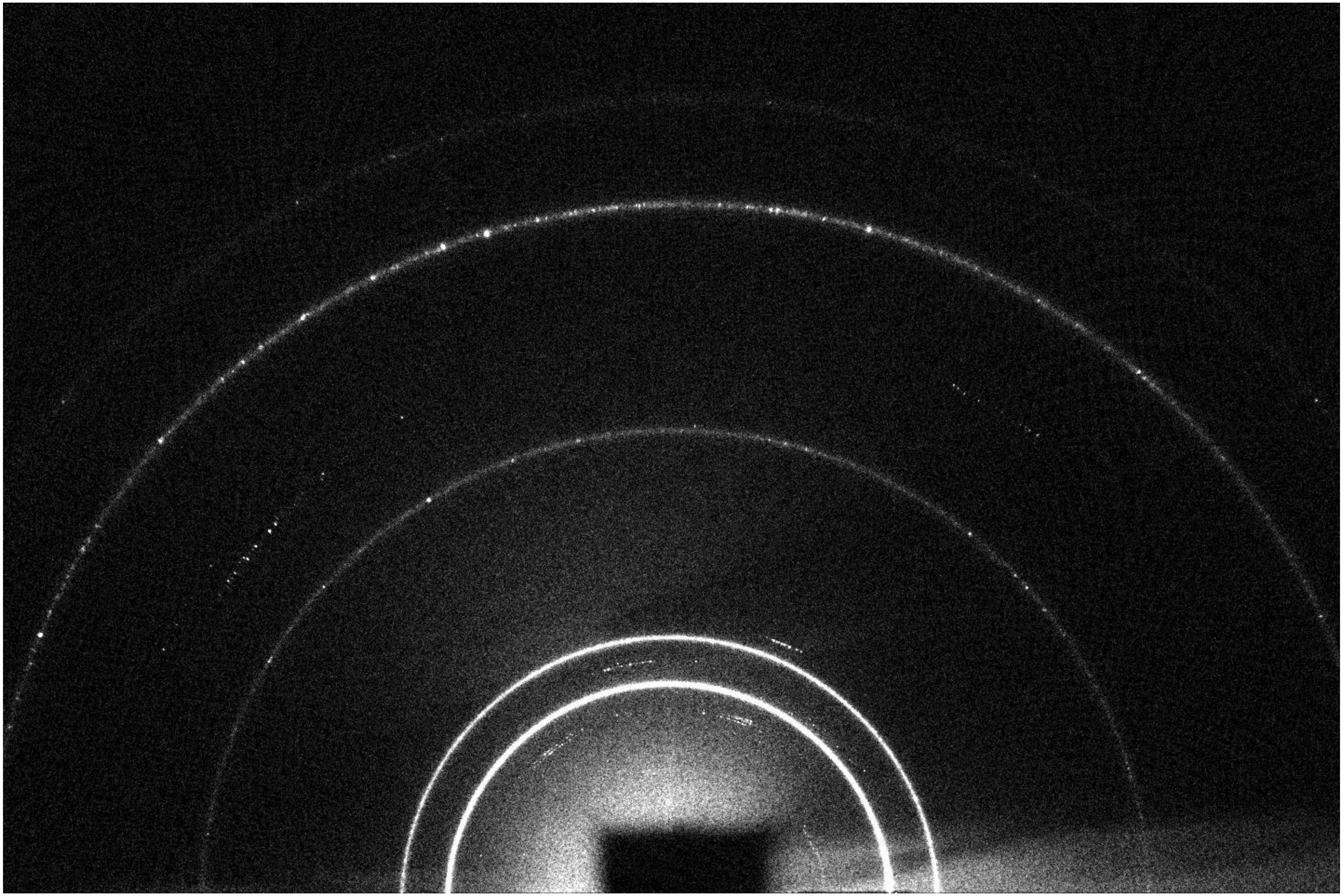


23x23 windows

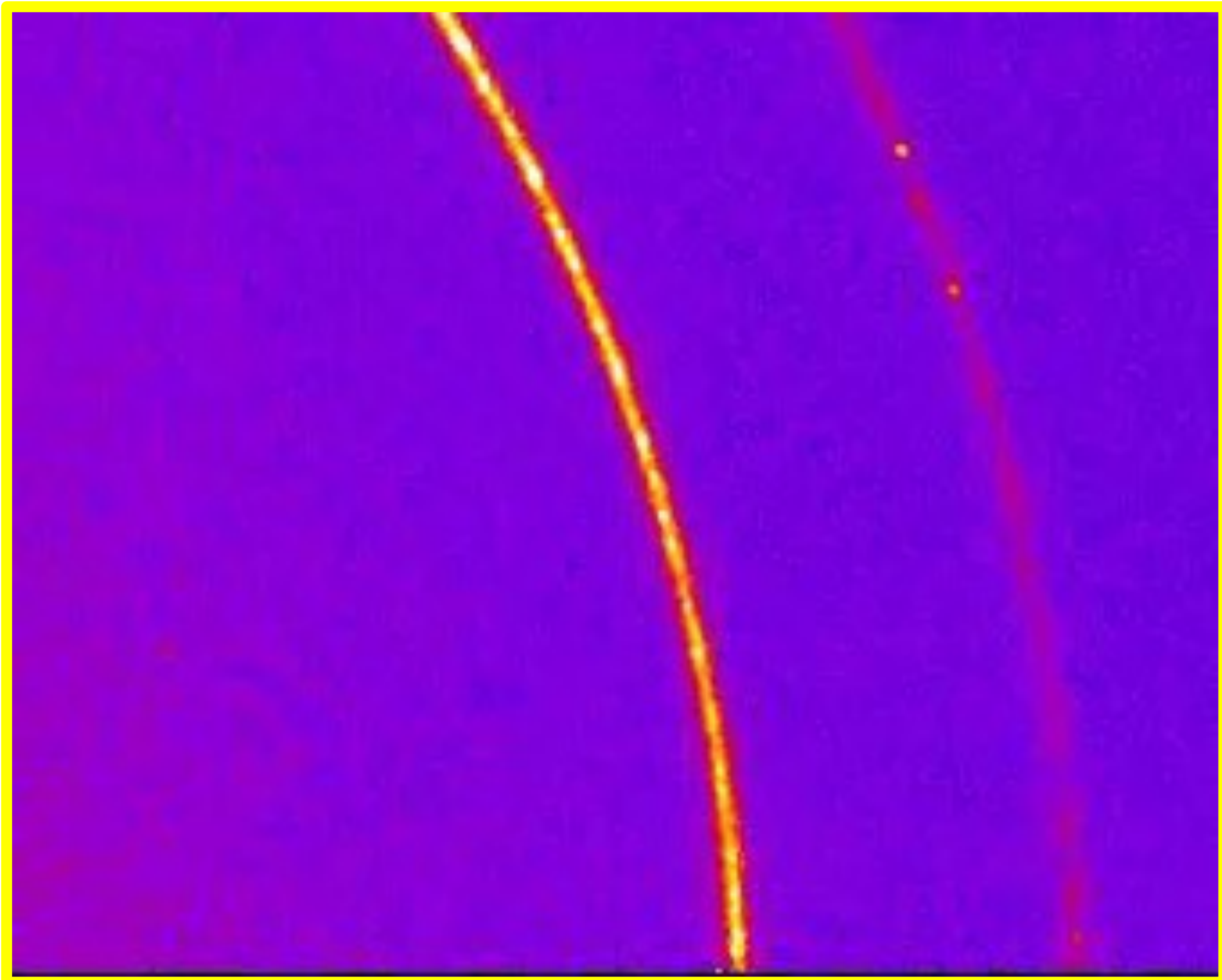
Experimental set-up at PAL-XFEL September 2017



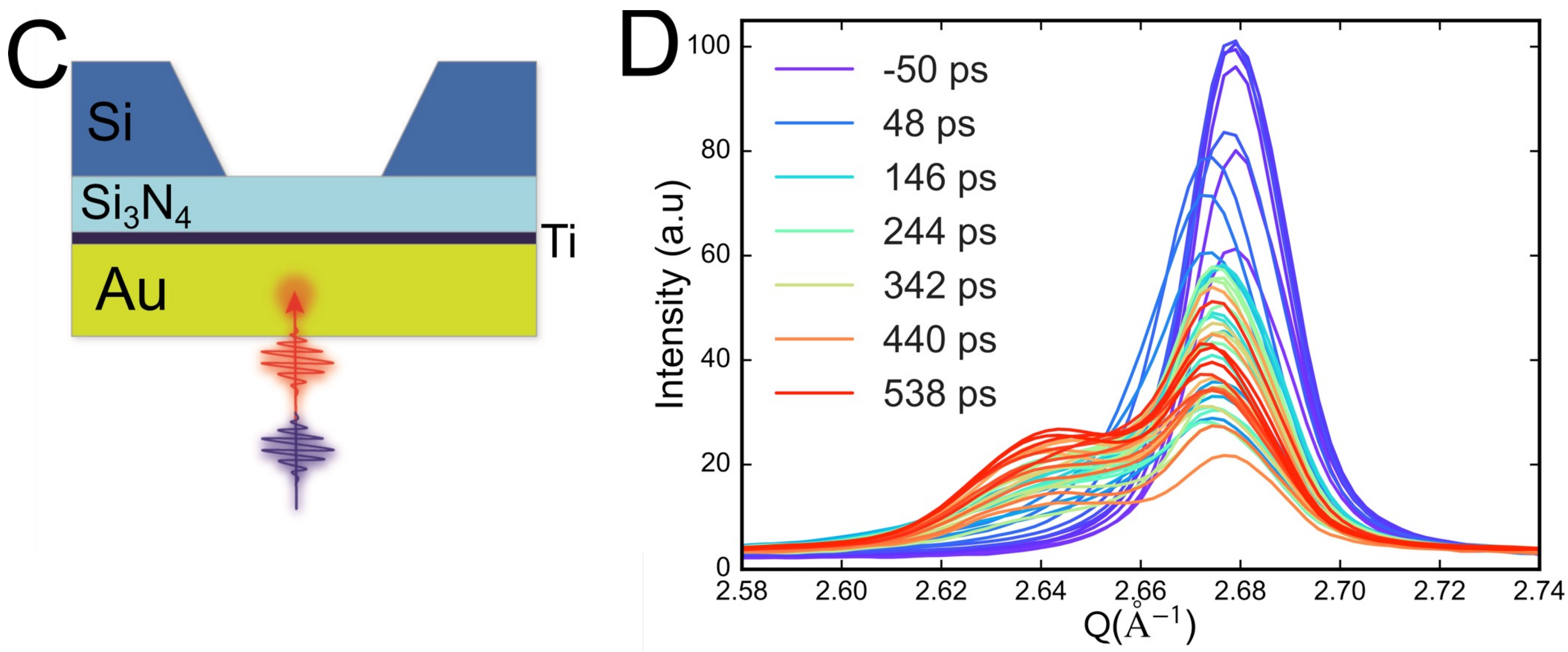
Raw data #397 300nm film



Raw data #396 300nm film, 254 mJ/cm^2

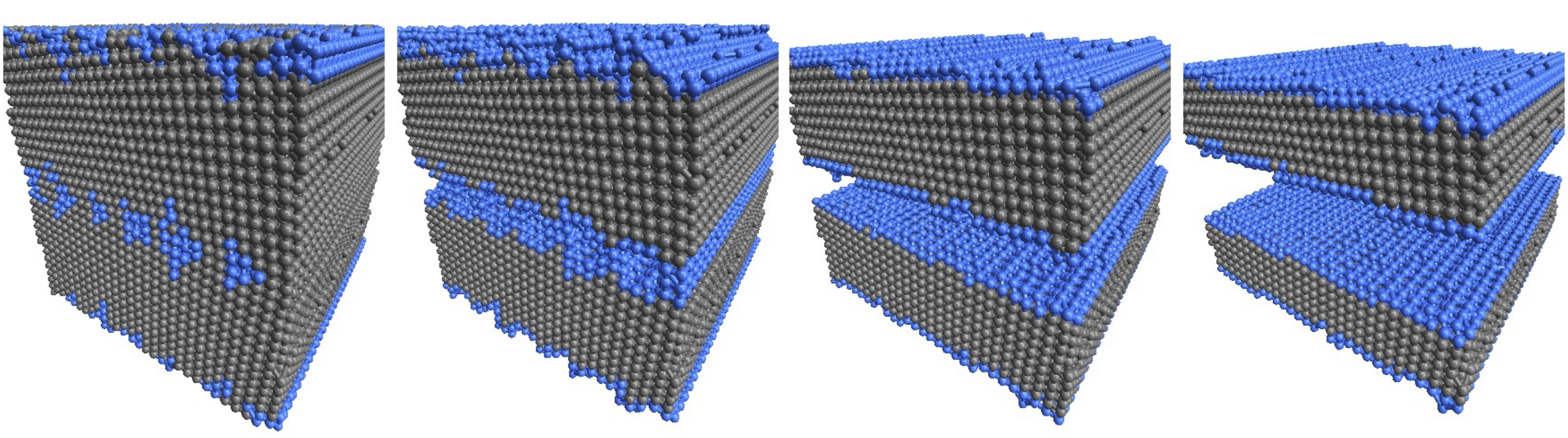


Thin Film Sample Format



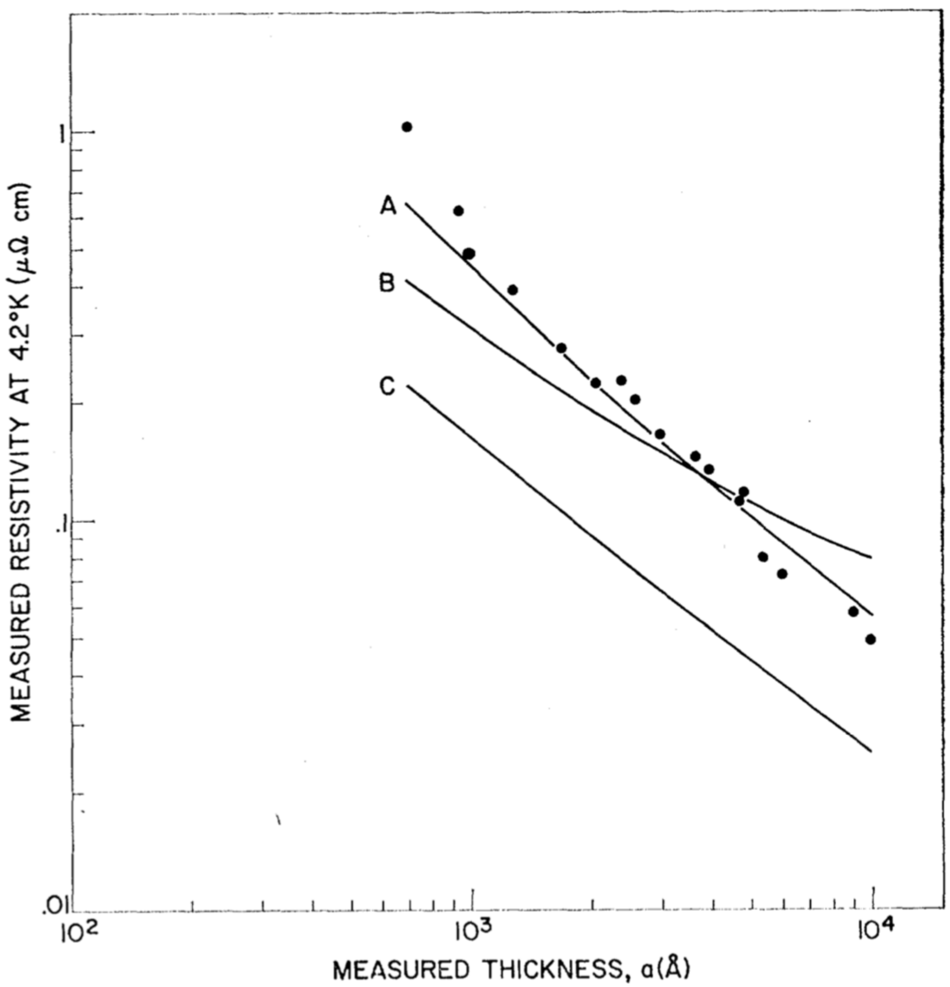
Force-Field Simulation of GB melting

J. Berry, K. Elder and M. Grant, PRB 77 224114 (2008)



Resistivity of Al Thin Films

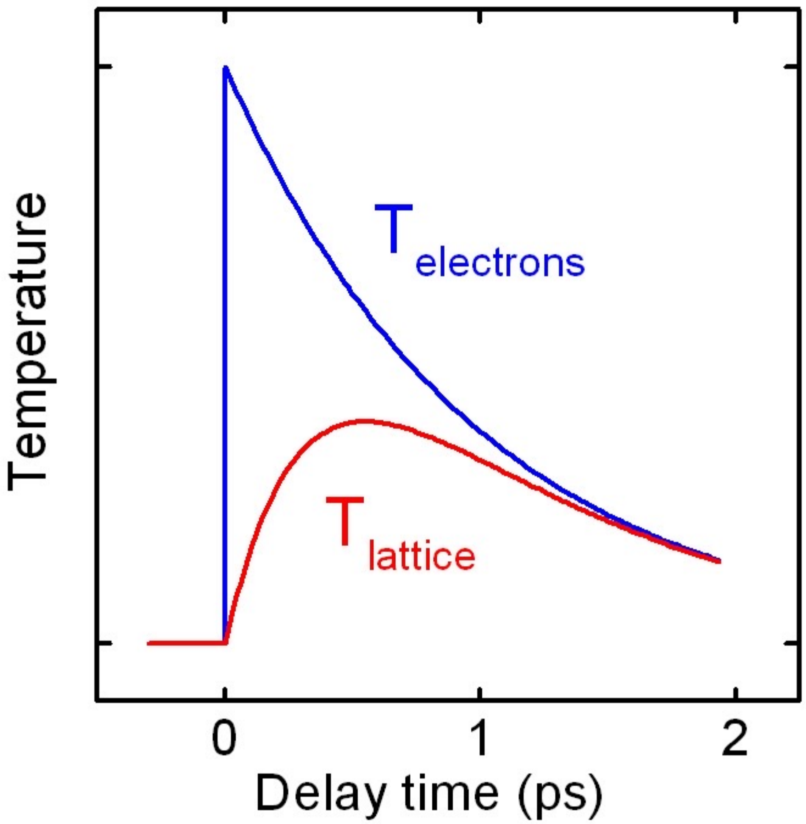
A. F. Mayadas and M. Shatzkes, PRB **1** 1382 (1970)



- "Universal curve" of MFP vs electron energy
- Thermal MFP removed at low temperature
- Grain size proportional to thickness (model)

"Two-temperature" model

I.K. Robinson et al, Journal of Optics **18** 054007 (2016)
J.K. Chen et al, Int J. Heat Transfer **49** 307 (2006)



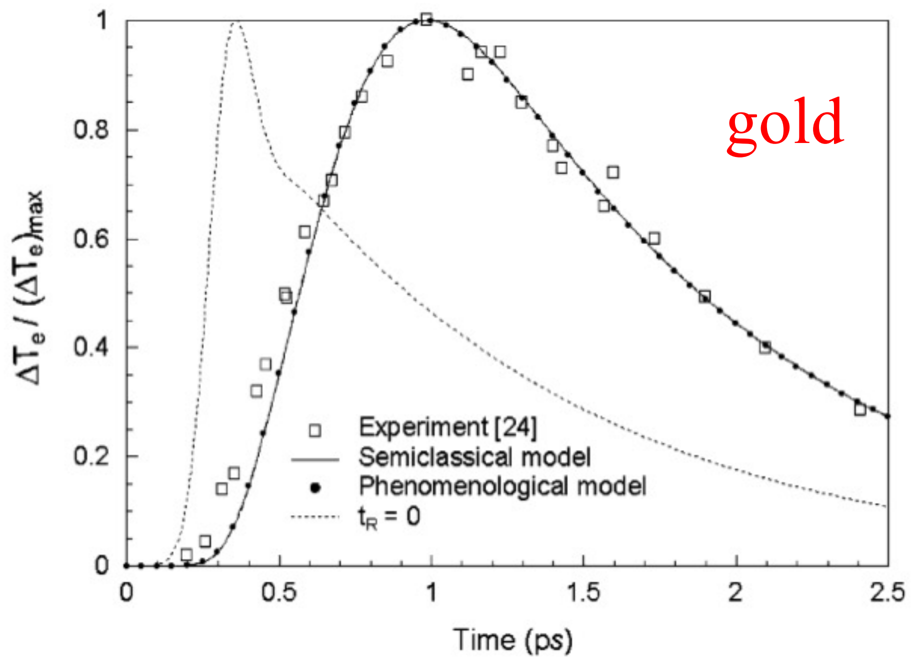


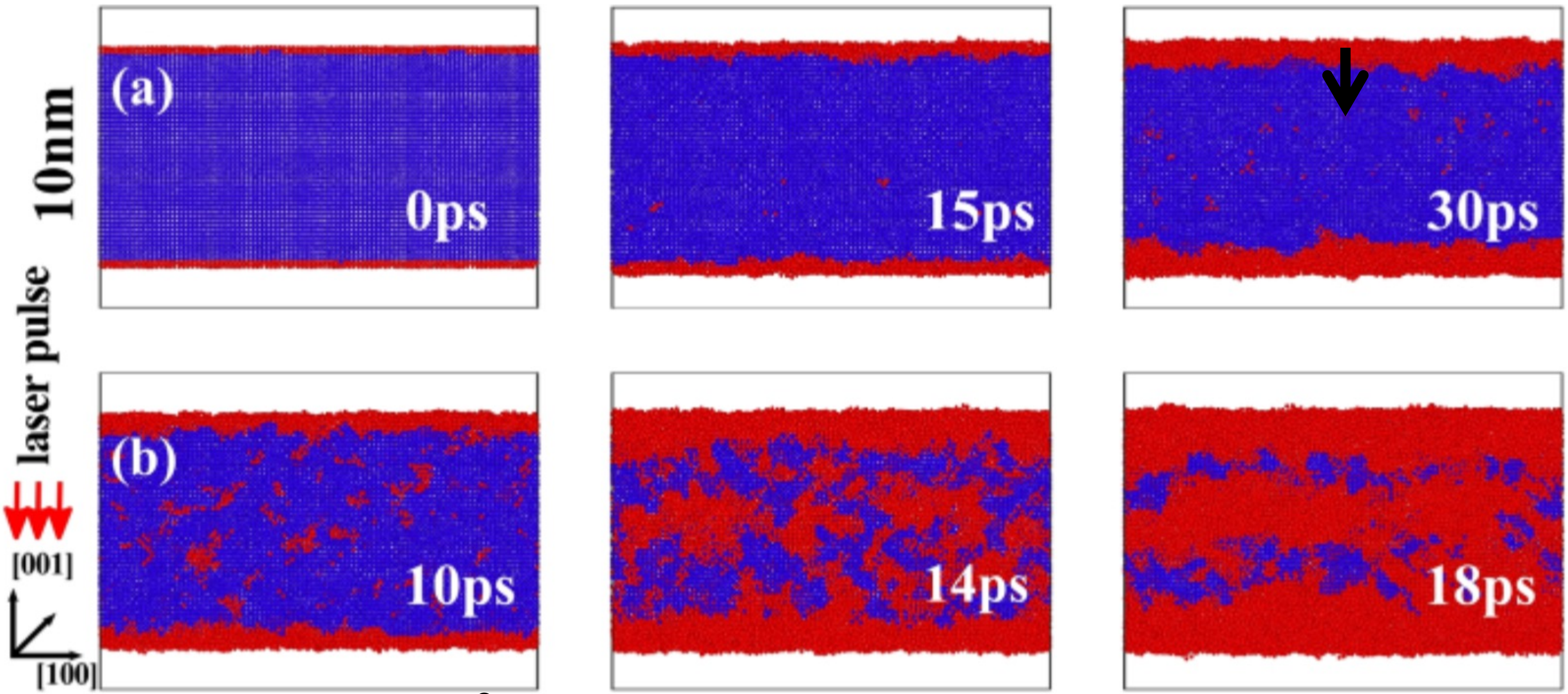
Fig. 2. Comparison of the change in electron temperature at the front surface of an 80-nm gold film irradiated by a 2.8 mJ/cm^2, 800 nm, 150-fs laser pulse.

2TM-MD (EAM) simulation Au slab

Giret et al, APL **103** 253107 (2013)

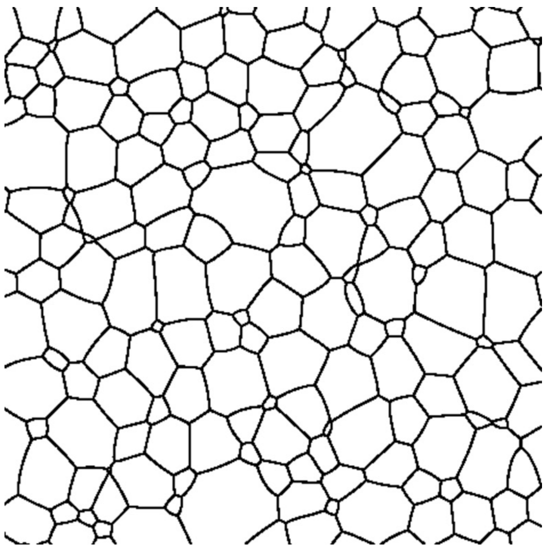
3.0 mJ/cm^2

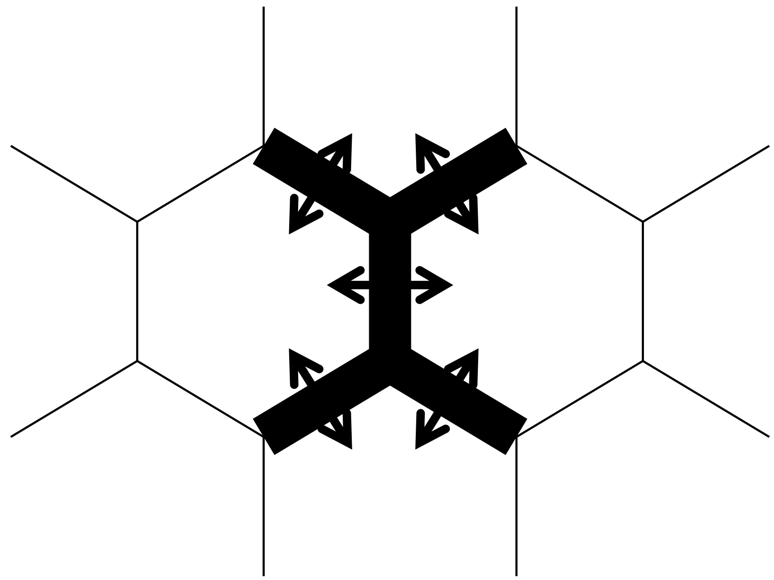
32 m/s



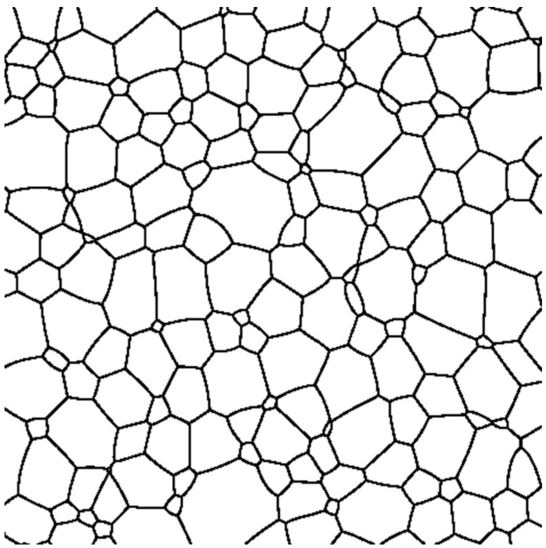
4.5 mJ/cm^2

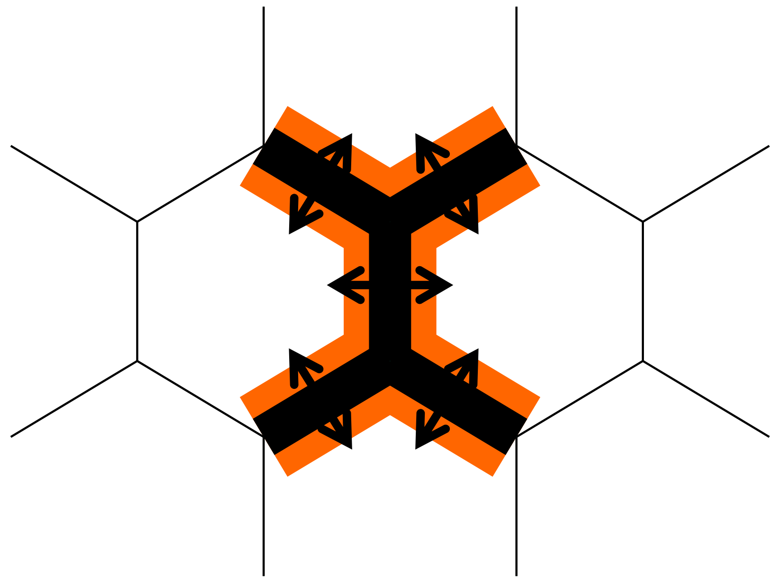
Grain Boundary Melting





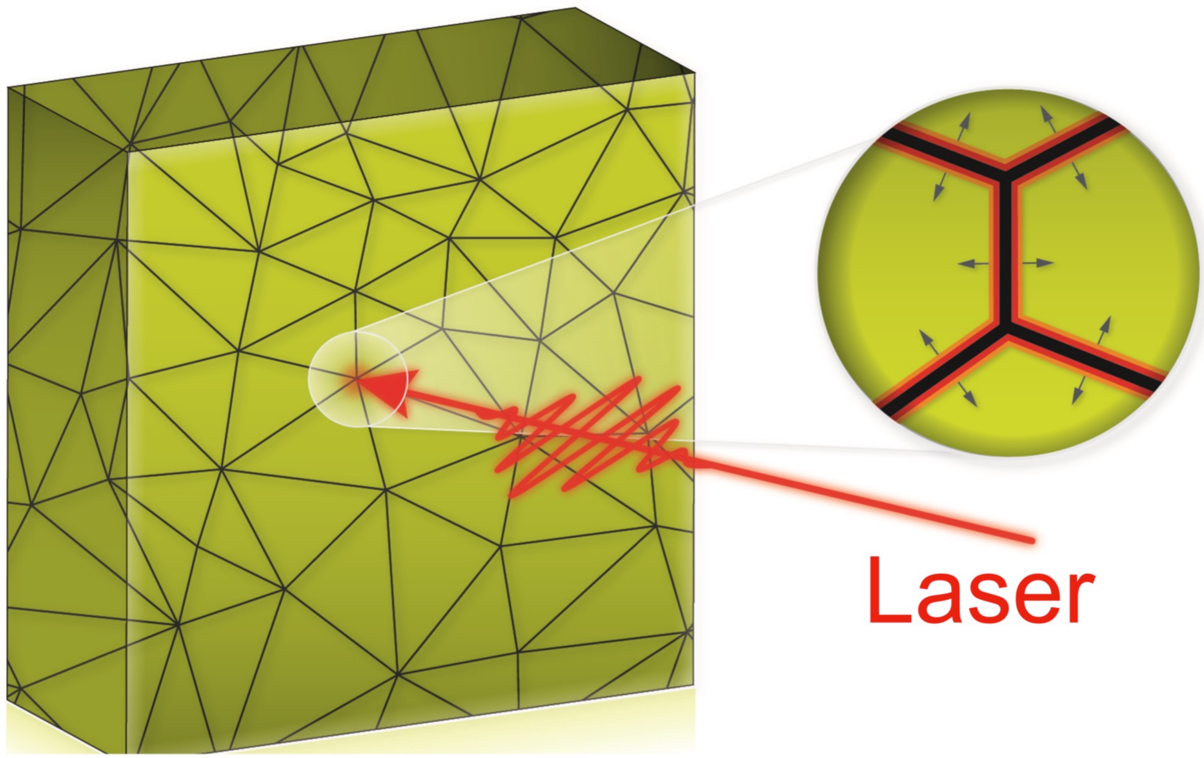
Grain Boundary Melting





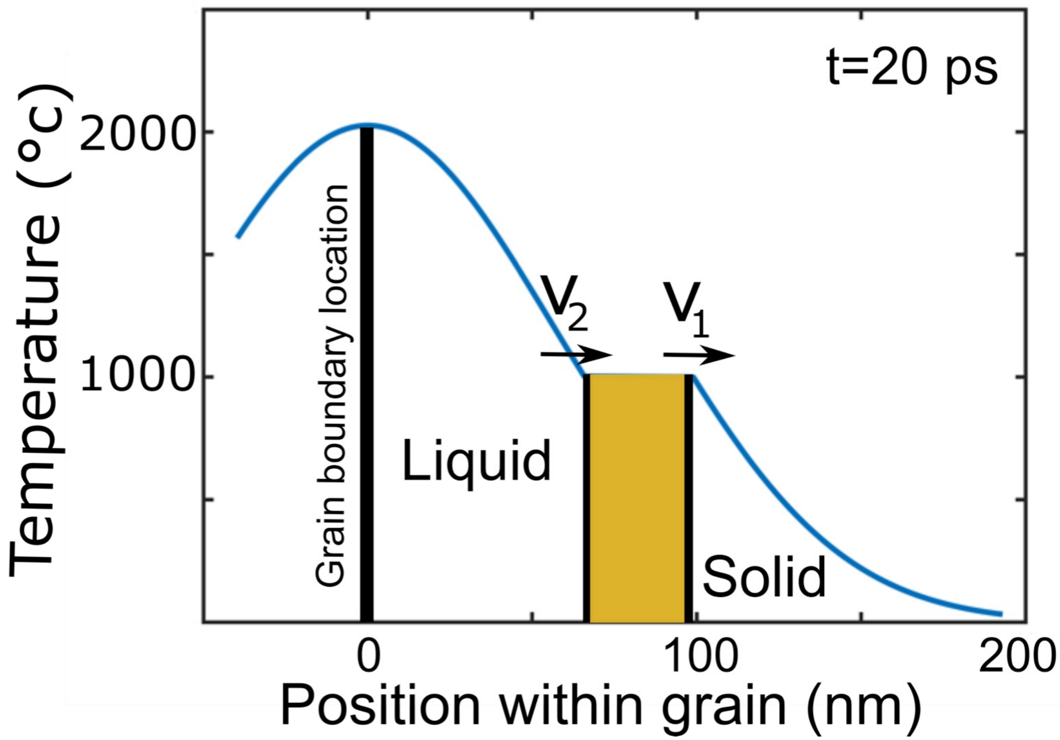
Grain Boundary Origin of Melting

T. A. Assefa et al Science Advances 6 eaax2445 (2020)

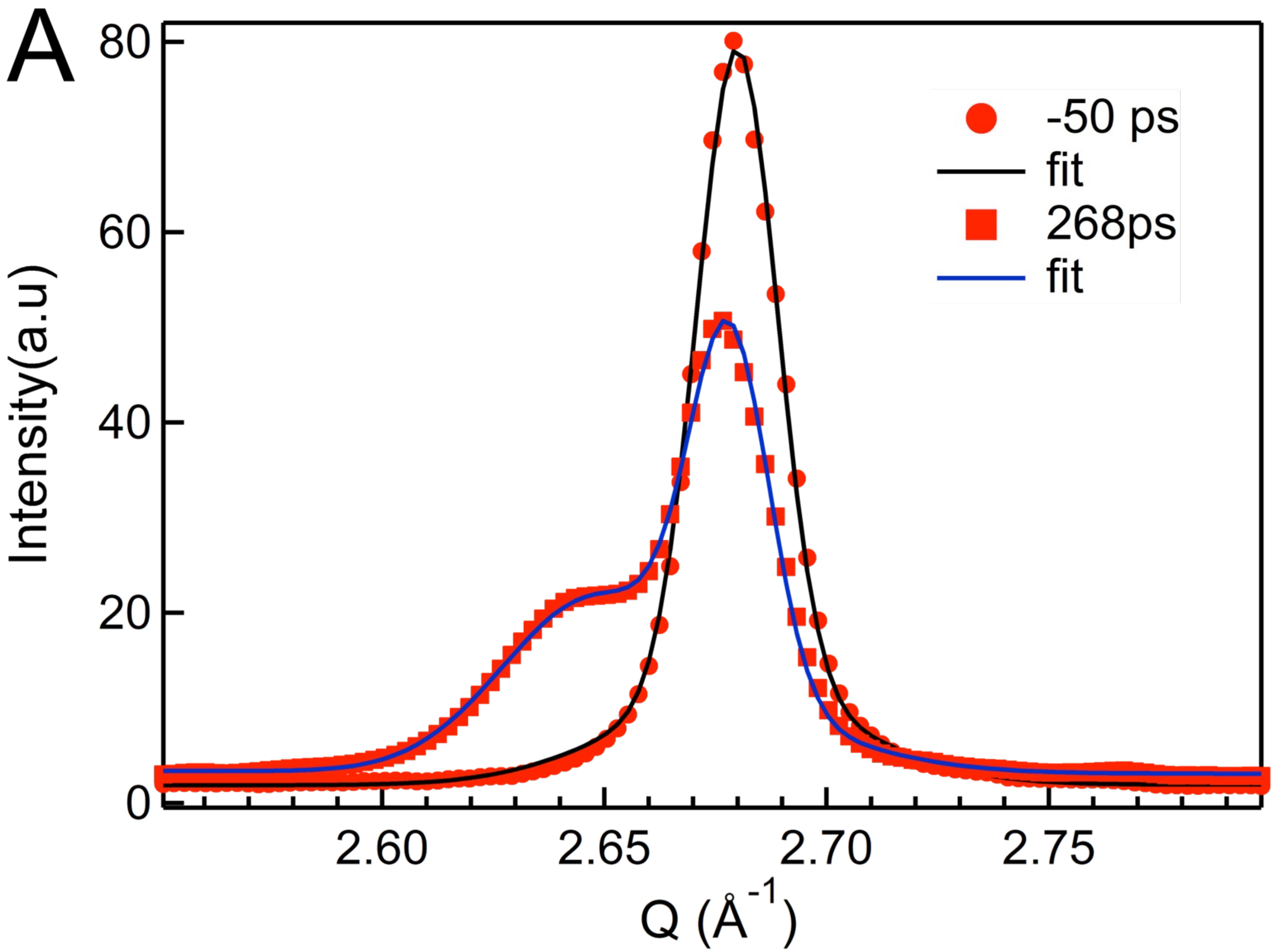


Grain Boundary Induced Melting

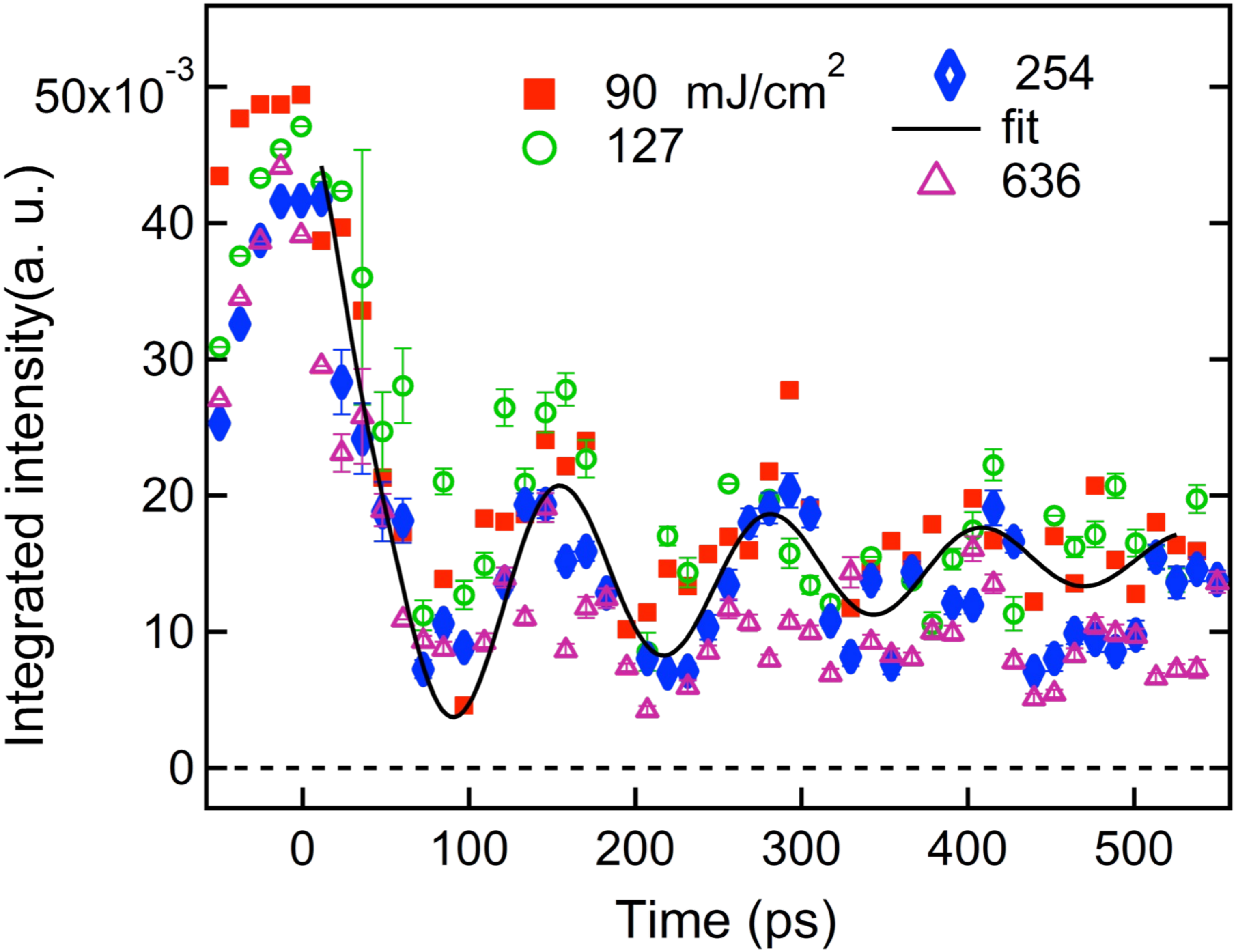
T. A. Assefa et al Science Advances 6 eaax2445 (2020)



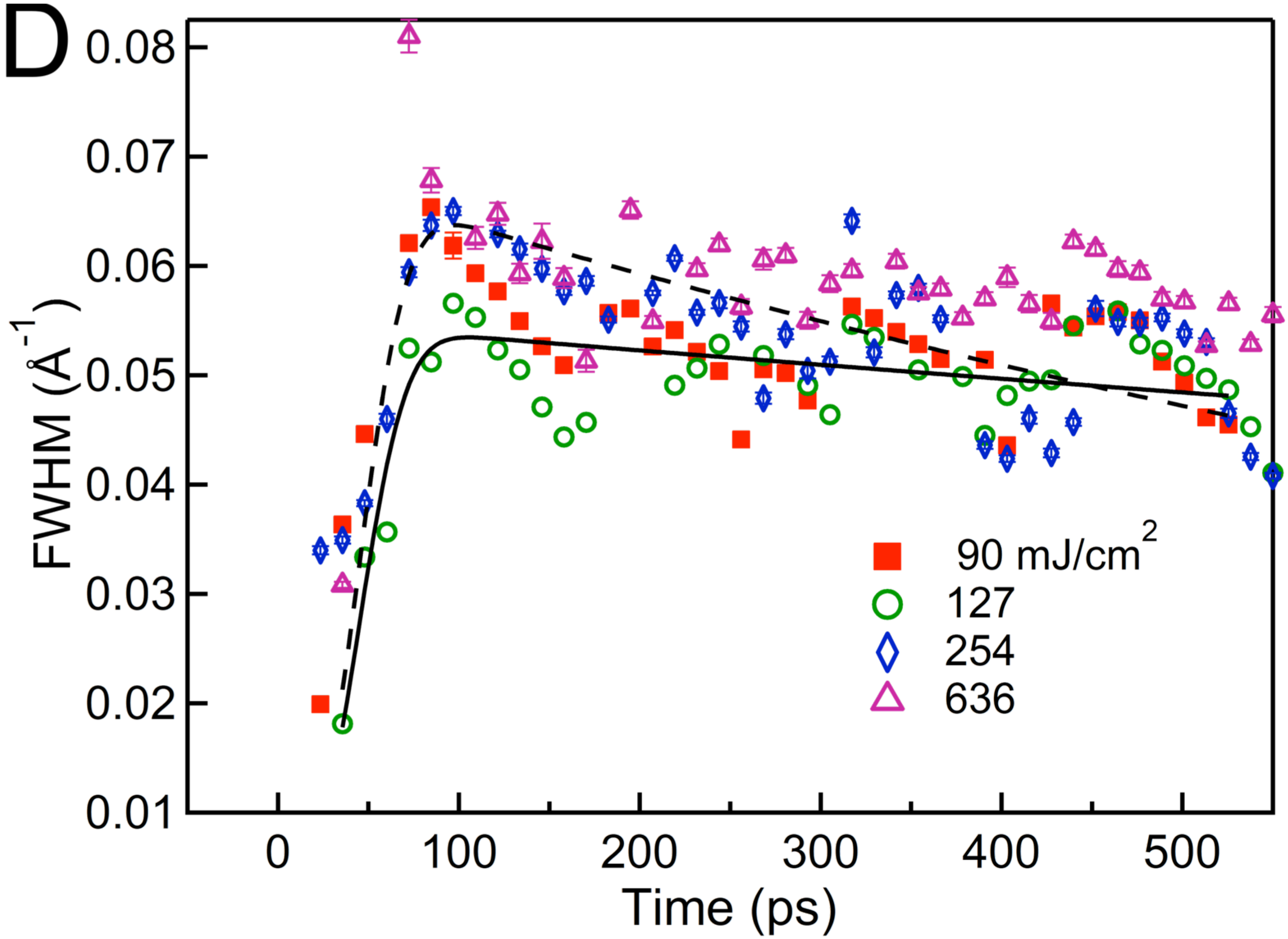
Deconvolution of Peaks



PP kinetics of Crystal Peak

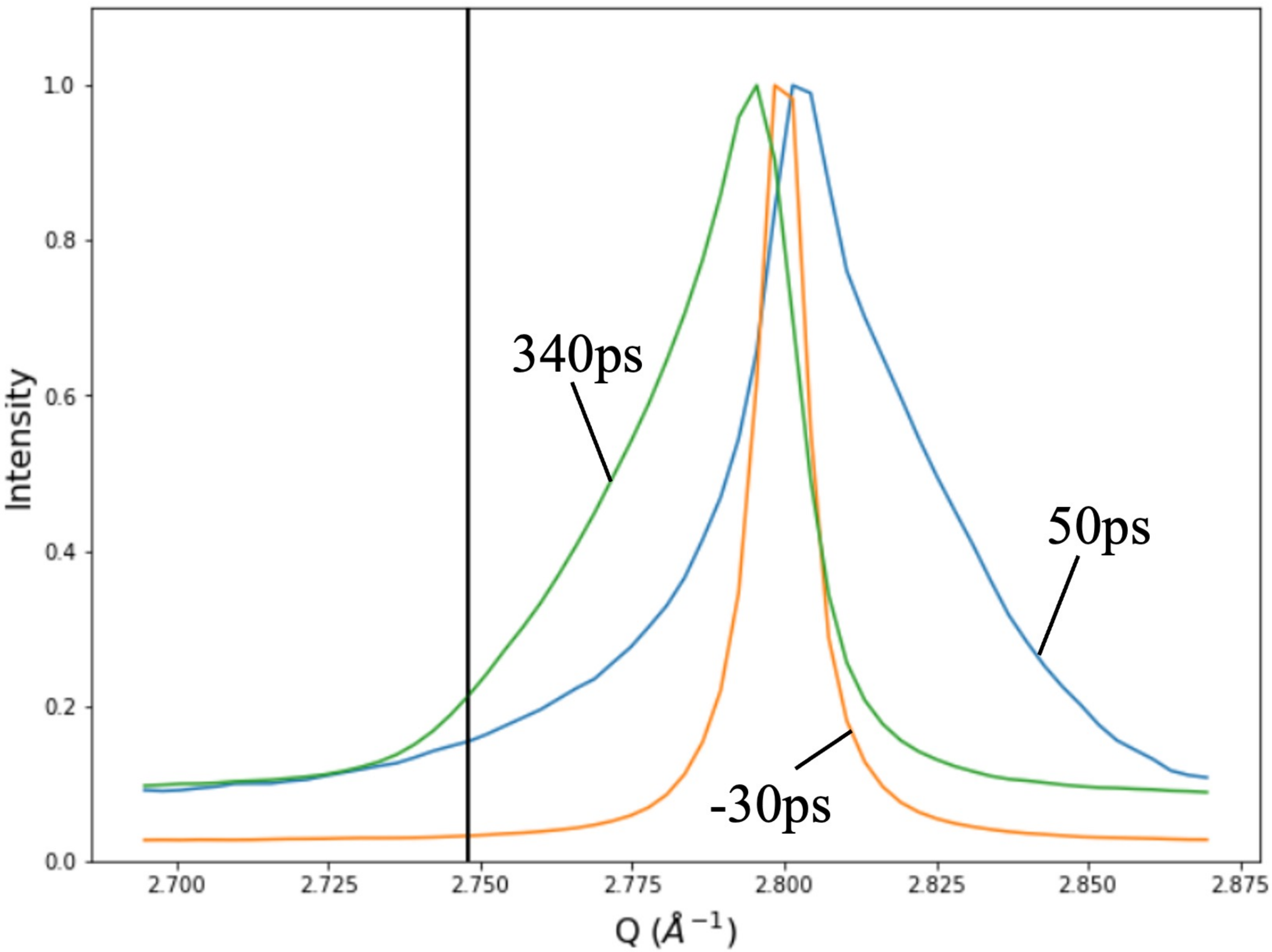


Width of Melt-Front Peak



Palladium is Different from Gold

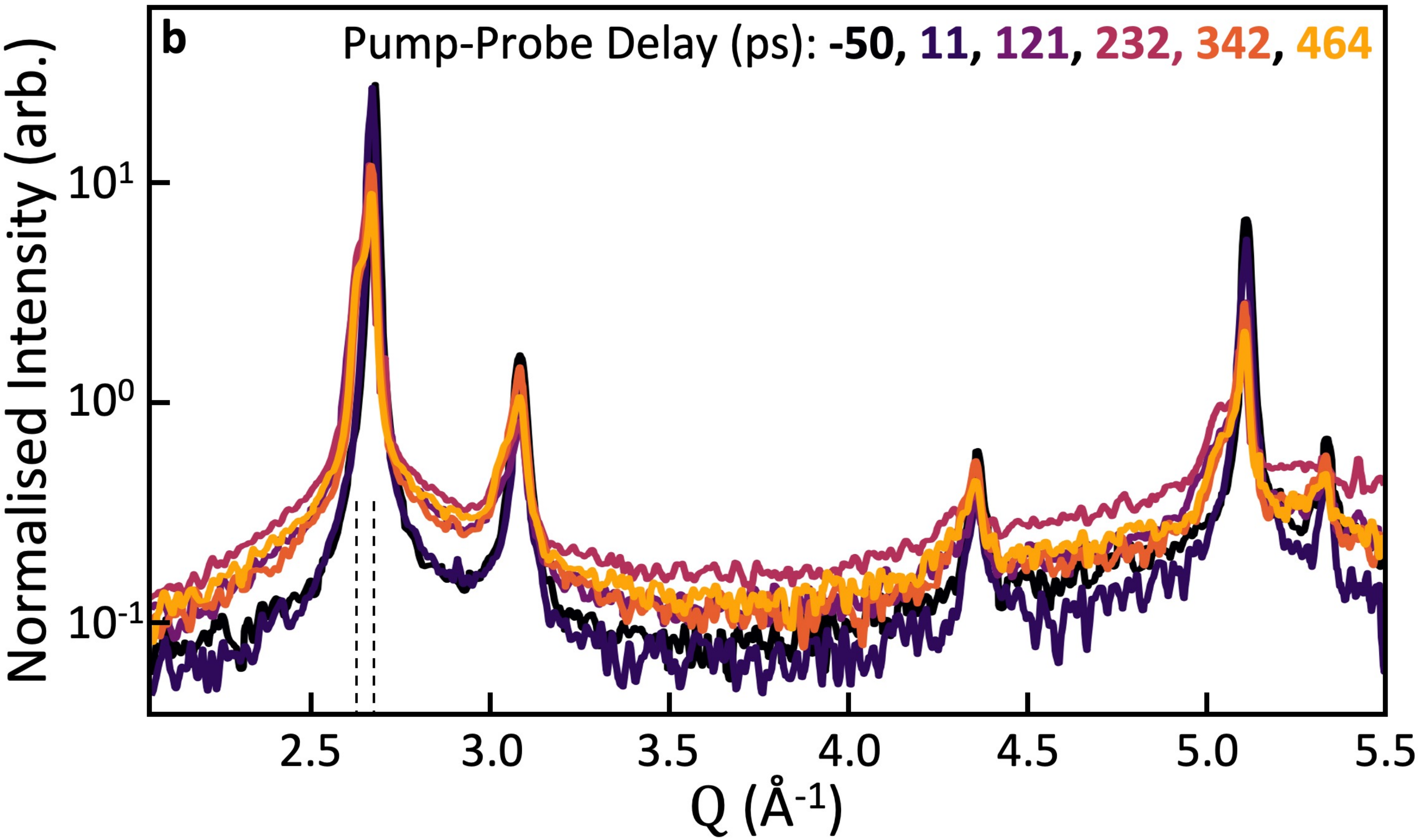
A. F. Suzana, et al, Phys. Rev. B 107 214303 (2023)

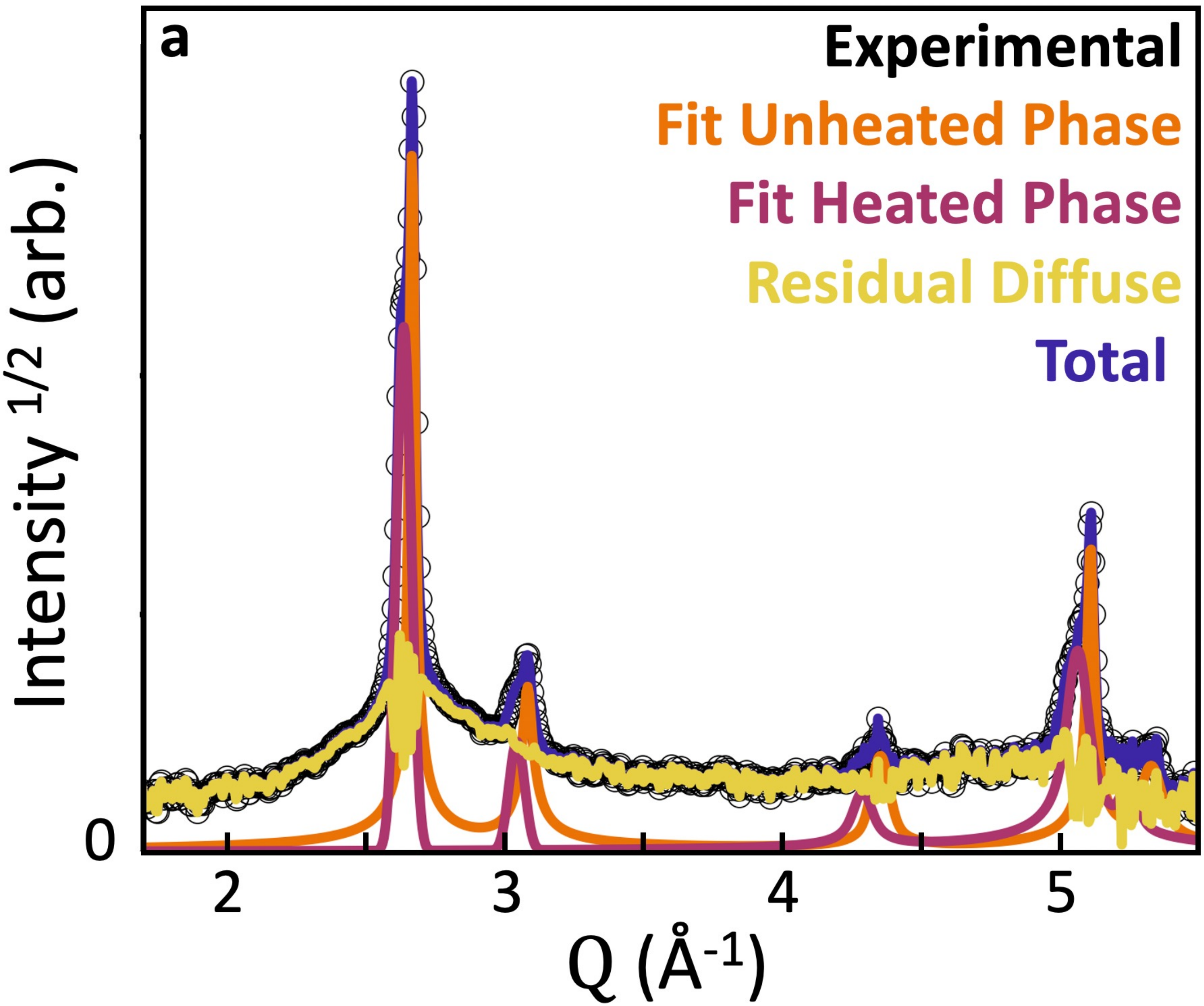


- (111) Bragg peak vs time delay
- 300 nm Pd thin film
- PAL XFEL
- laser fluence 800 mJ cm^{-2}

Excess Diffuse signal between Bragg peaks

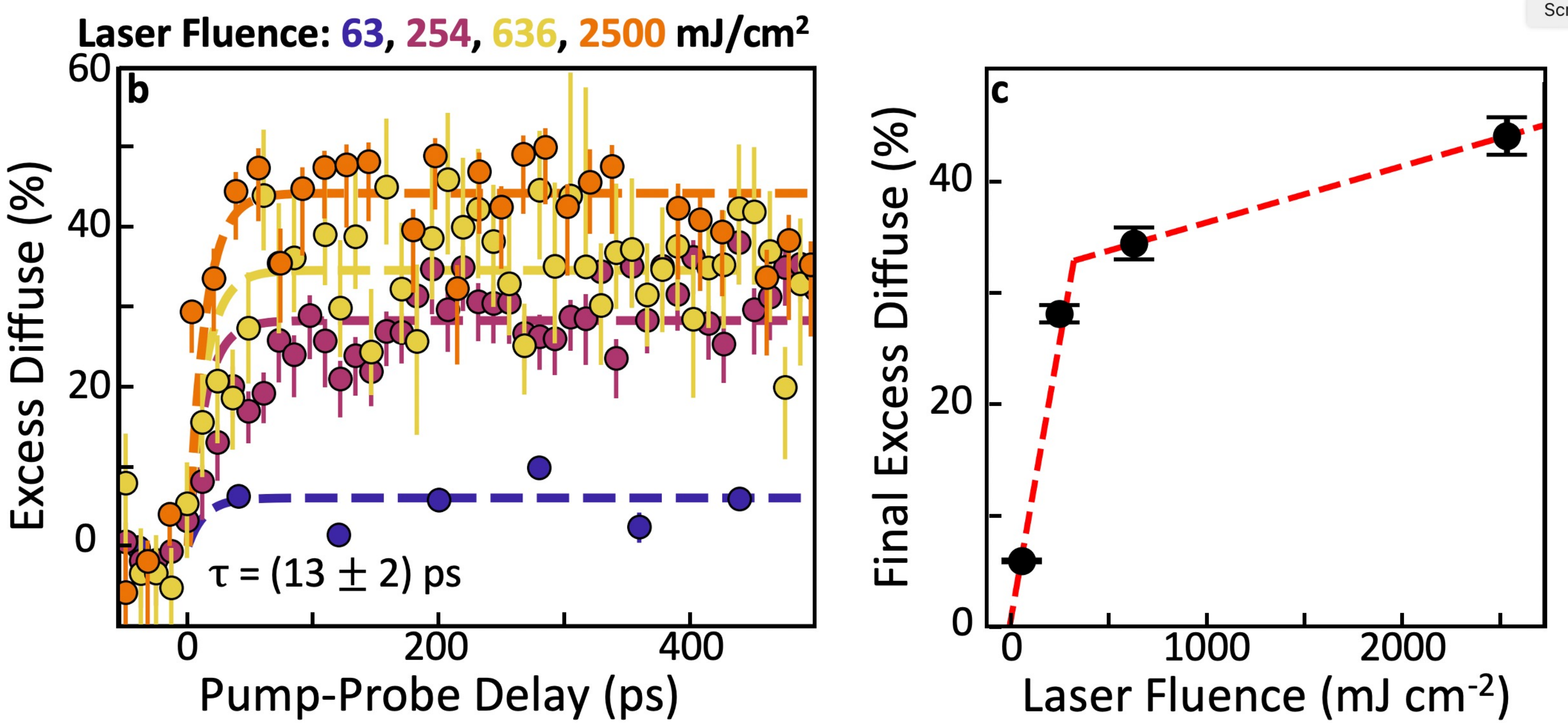
PAL XFEL, IUCrJ 10 656–661 (2023)




a
Experimental
Fit Unheated Phase
Fit Heated Phase
Residual Diffuse
Total
Intensity $^{1/2}$ (arb.)
0
2
3
4
5
Q (Å^{-1})

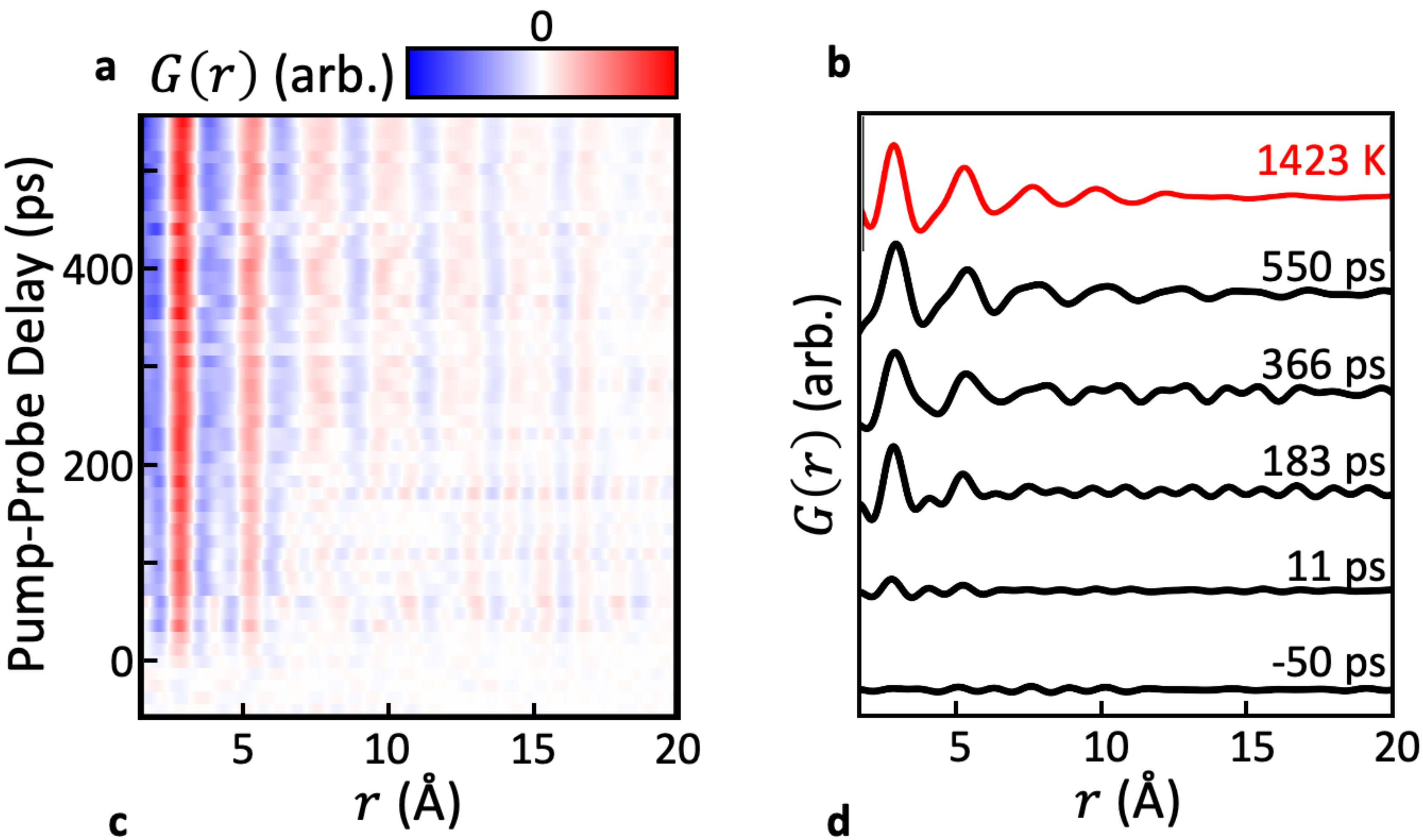
Time and Fluence dependence

PAL XFEL, IUCrJ 10 656–661 (2023)



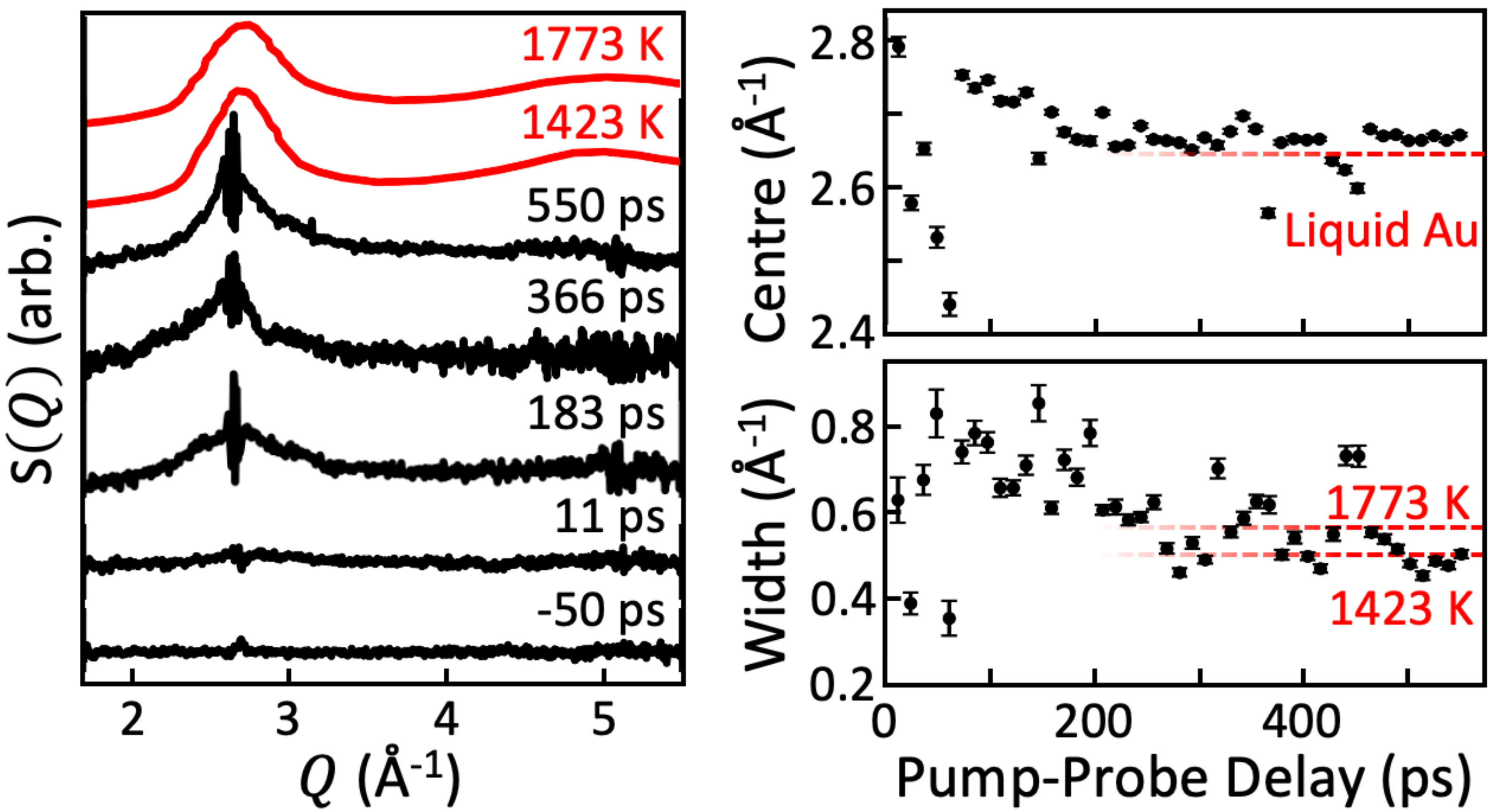
PDF evolves slightly with time

PAL XFEL, IUCrJ 10 656–661 (2023)



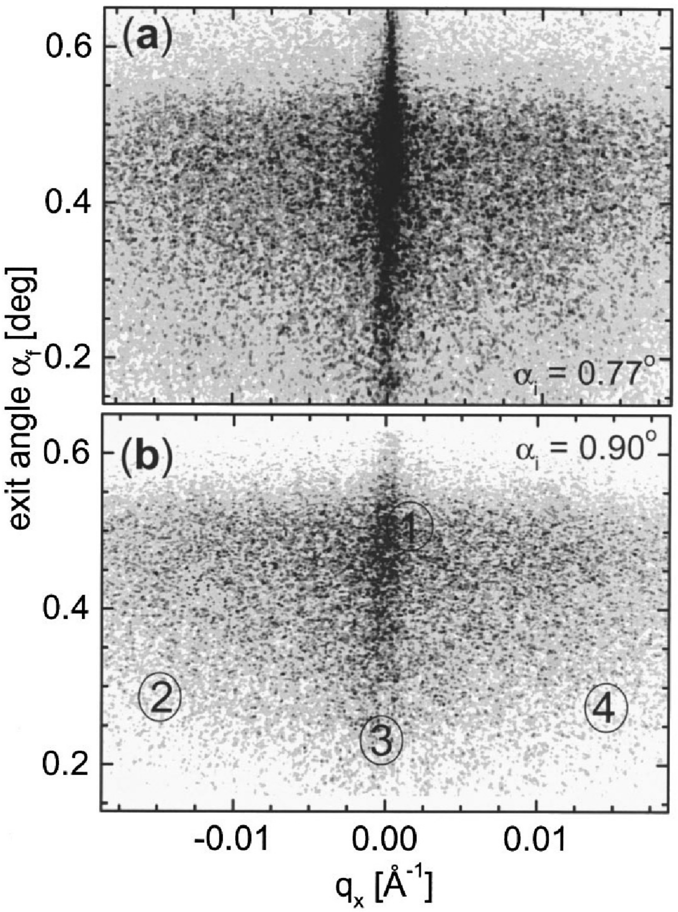
Liquid structure evolution in time

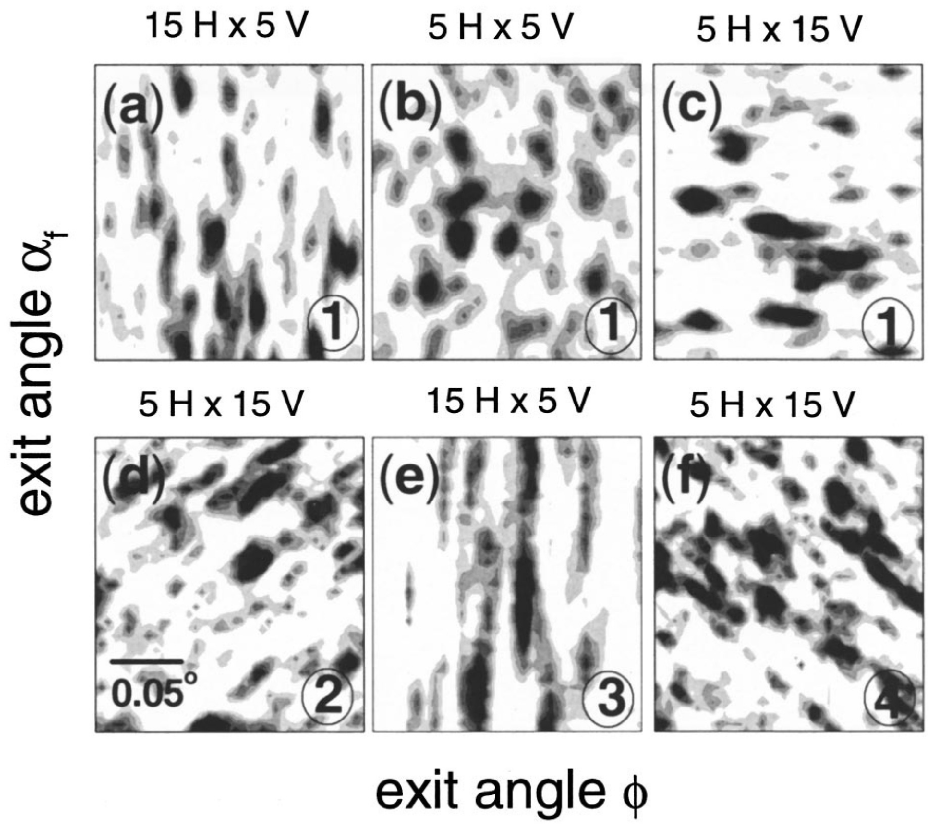
PAL XFEL, IUCrJ 10 656–661 (2023)



GISXS Geometry sees film nanostructure

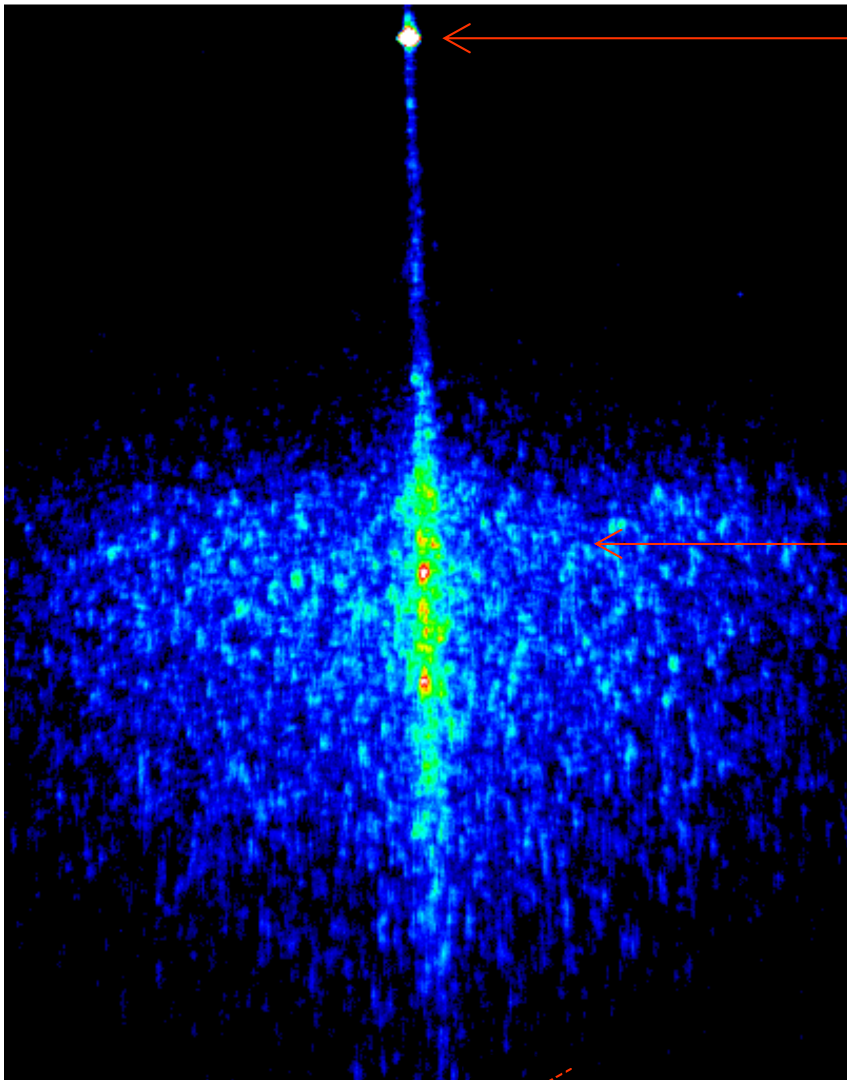
F. Pfeiffer, W. Zhang and IKR, Appl. Phys. Letters 84 1847-9 (2004)

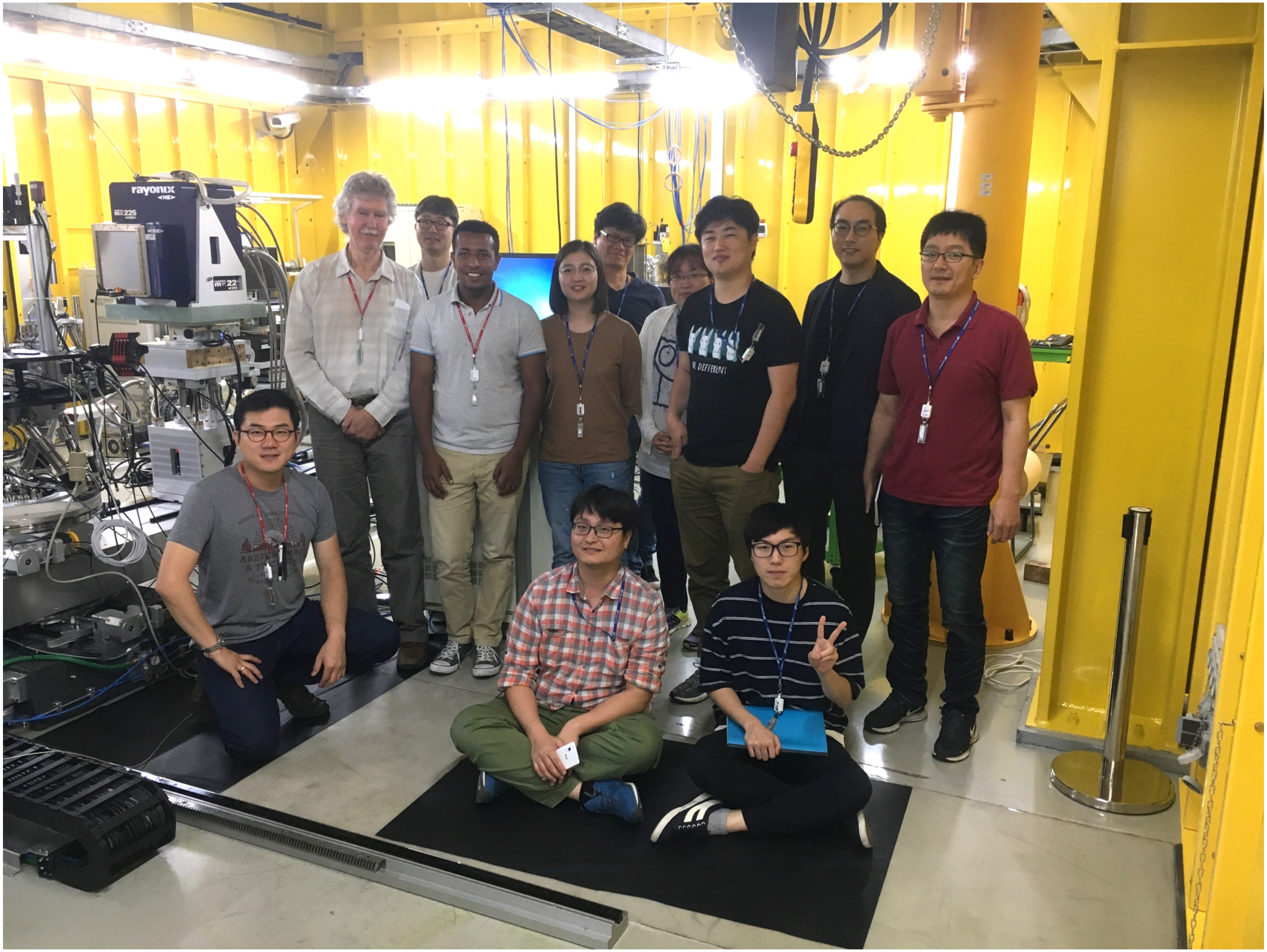




Coherent Structure in "Yoneda" Peak

Grazing-exit diffraction from a 1000A Au polycrystalline film




rayonix

PAL XFEL Control Room

Sunam Kim, Jae Hyuk Lee, Yongsam Kim, Jaeku Park, Sang-Youn Park, Intae Eom, Hyojung Hyun, Tae-Yeong Koo, Jaehun Park, Daewoong Nam and Sang Soo Kim

Role of Ultrafast Heterogeneous Melting in Laser Machining Dynamics

- Ultrafast lasers are better for machining
- Pump-probe approach to understand excitations
- Sample scanner for single-shot destructive pump
- Melt-front picture of Ultrafast melting

T. A. Assefa et al, Science Advances 6 eaax2445 (2020)

I. K. Robinson et al, IUCrJ 10 656–661 (2023)

Acknowledgements

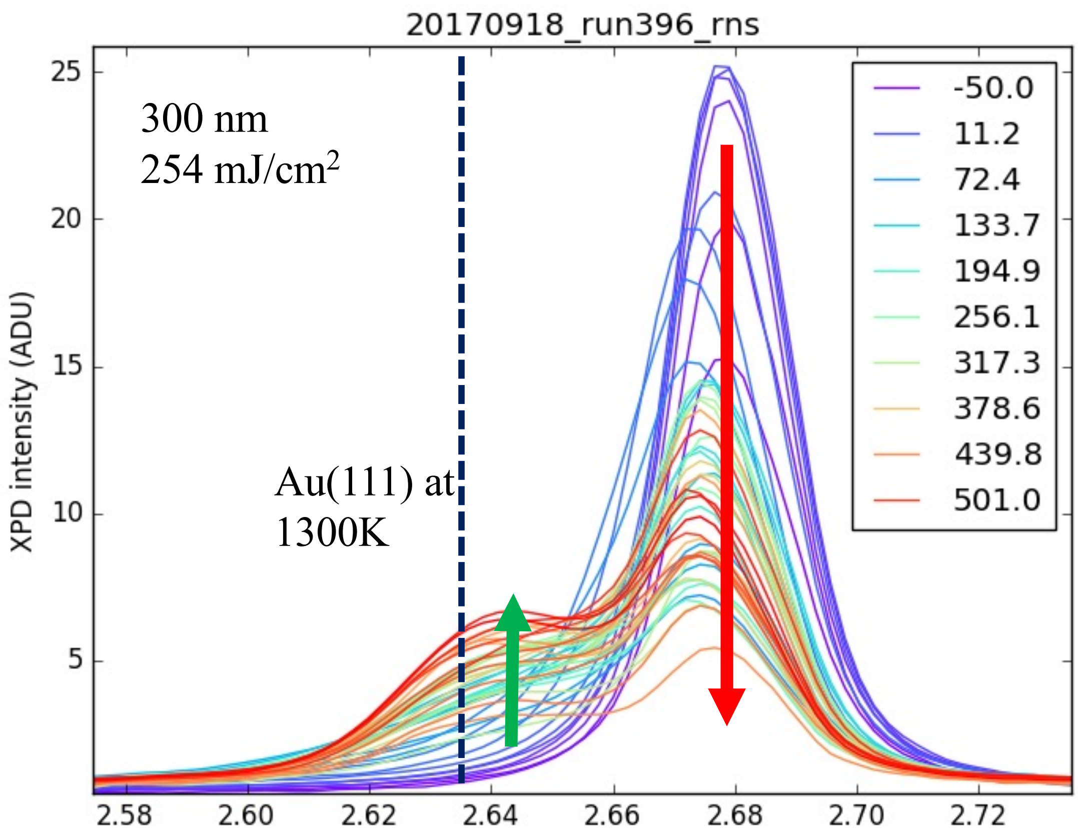
Tadesse Assefa
Jack Griffiths
Yue Cao
Emil Bozin
Pavol Juhas
Simon Billinge

Dongjin Kim
Sungwon Kim
Hyunjung Kim

Changyong Song
Heemin Lee

Sunam Kim,
Jae Hyuk Lee,
Yongsam Kim,
Jaeku Park,
Sang-Youn Park,
Intae Eom,
Hyojung Hyun,
Tae-Yeong Koo,
Jaehun Park,
Daewoong Nam
Sang Soo Kim

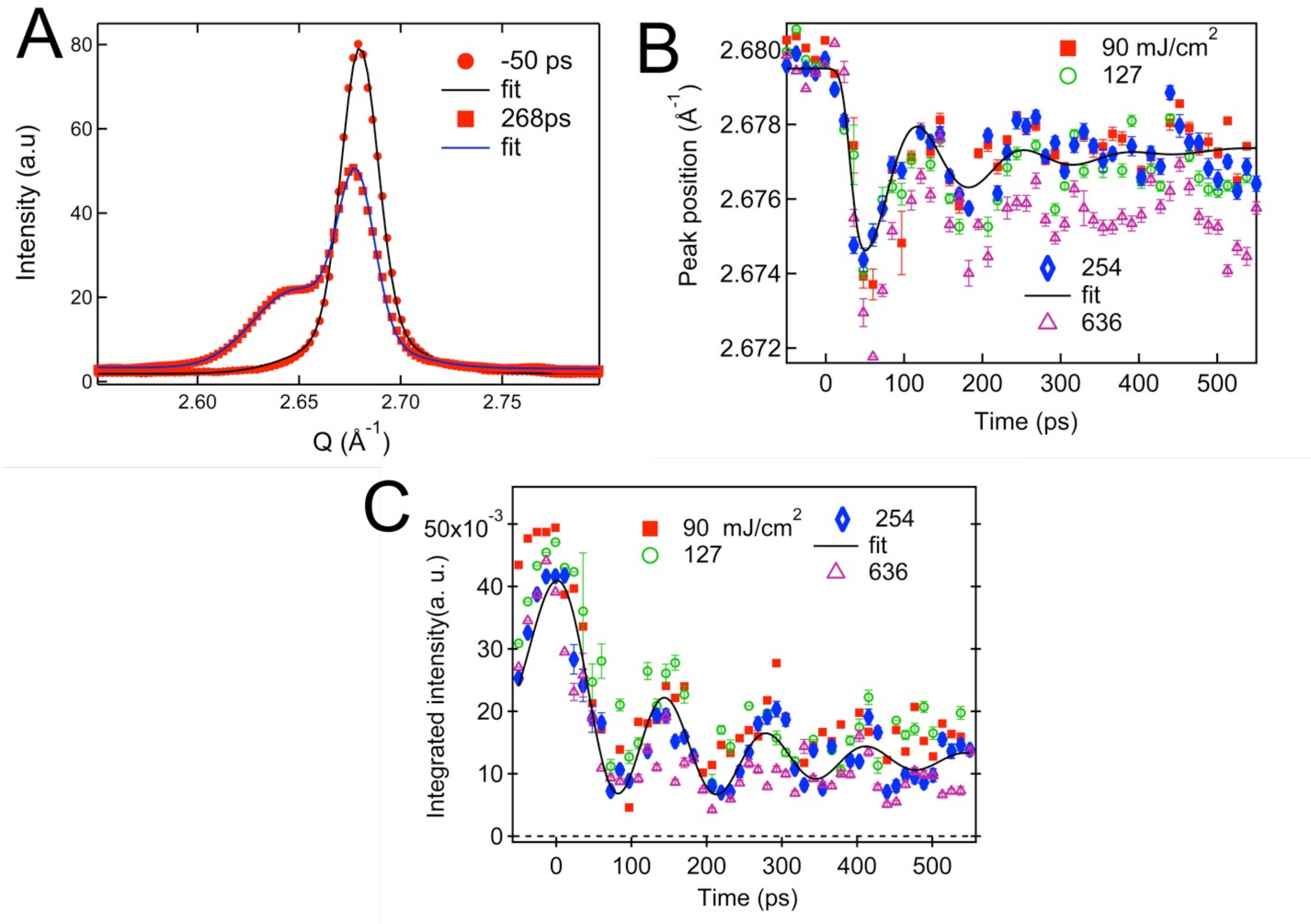
PyFAI integration around ring



Average grain size ≥ 30nm

New peak ~3x broader

Response of the Crystal 111 peak



Response of New Peak

Material trapped at the melting point