Cold ablation driven by localized forces: a femtosecond electron diffraction study

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Reizo Kato

Kyoto University
Jiro Matsuo
Toshio Seki

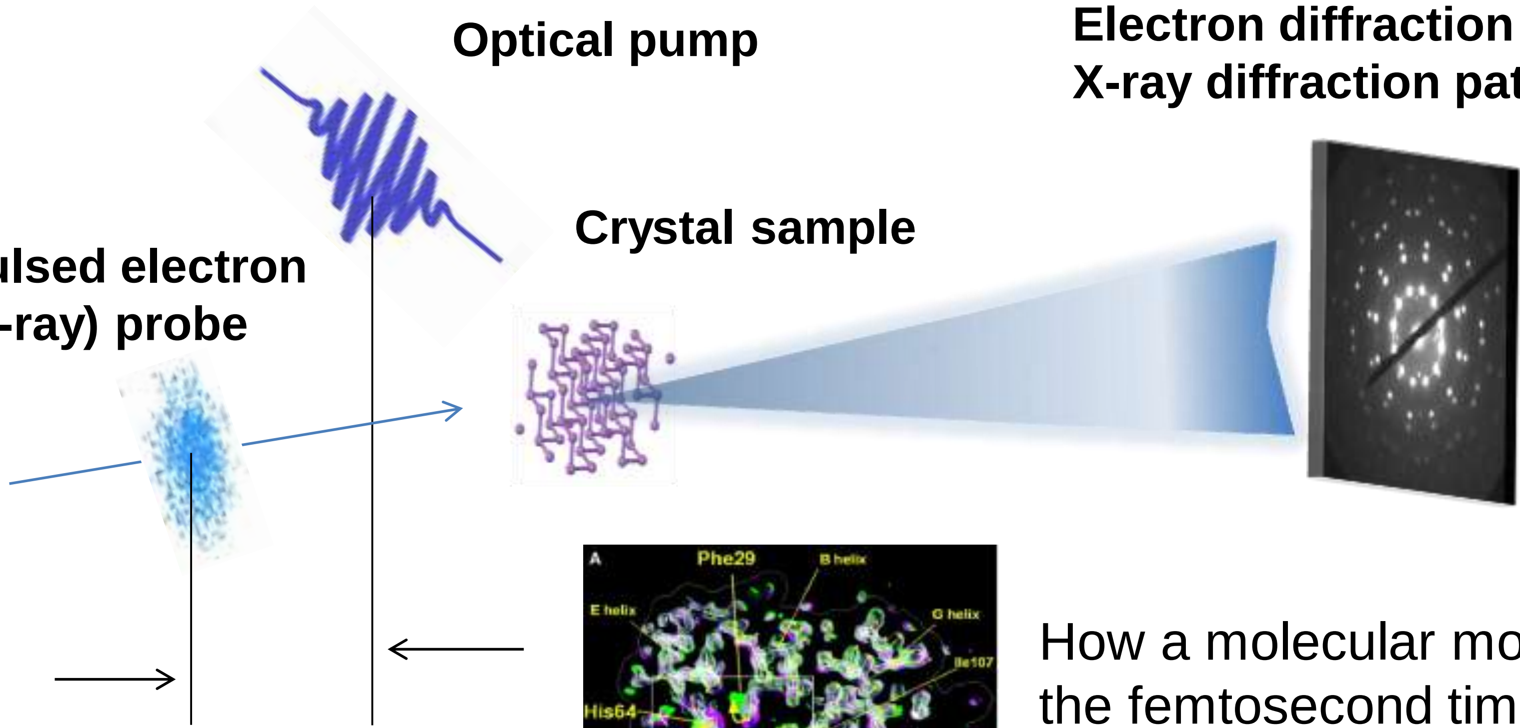
Edinburg University
Michał Kochman
Derek Wann
Carole Morrison

Outline

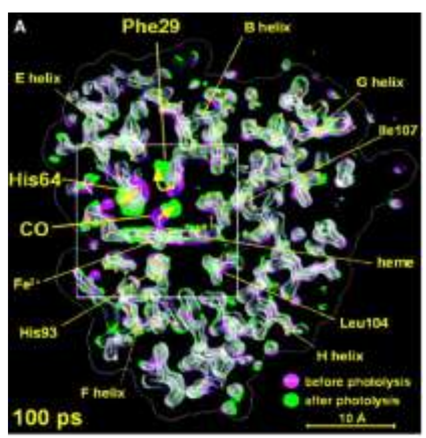
- **Electron diffraction setup**
  - **Motivation**
  - **DC gun, RF gun, Relativistic gun**
  - **Pulse characterization**
- **Science with electron diffraction**
  - **Single-shot experiment**
    - **KI Cold ablation driven by localised forces**
  - **Multiple-shot experiment**
    - **$Pt(dmit)_2$ Coherent phonon in large lattice material**

Femtosecond electron diffraction

Optical pump
Electron probe method



Optical delay Δτ
30 um = 100 fs

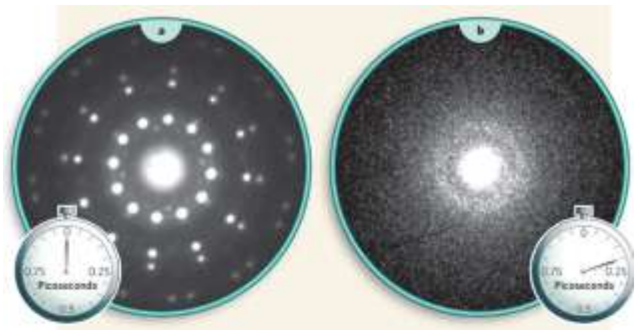


How a molecular moves at the femtosecond time scale?

F. Schotte, et. al., *Science* 300, (2003) 1944–1947.

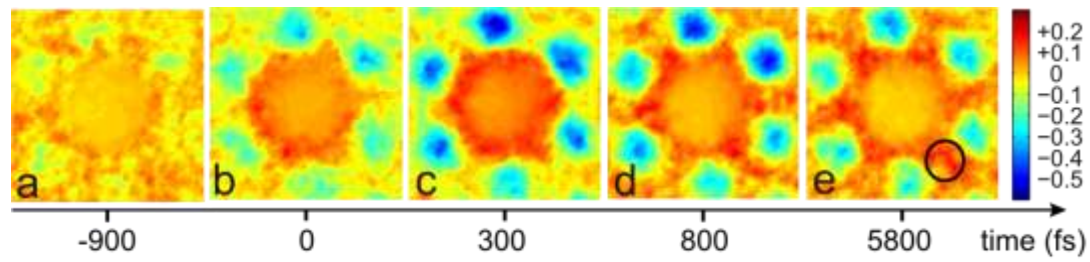
Electron diffraction studies from Toronto

Al, Au, Bi, Si melting



G. Sciaini et al, Nature **458**, 56 (2009).

TaS_2 CDW

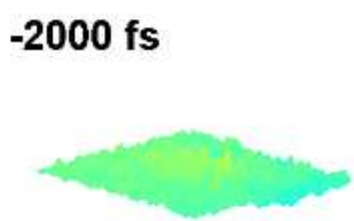


M. Eichberger et al, Nature **468**, 799 (2010).

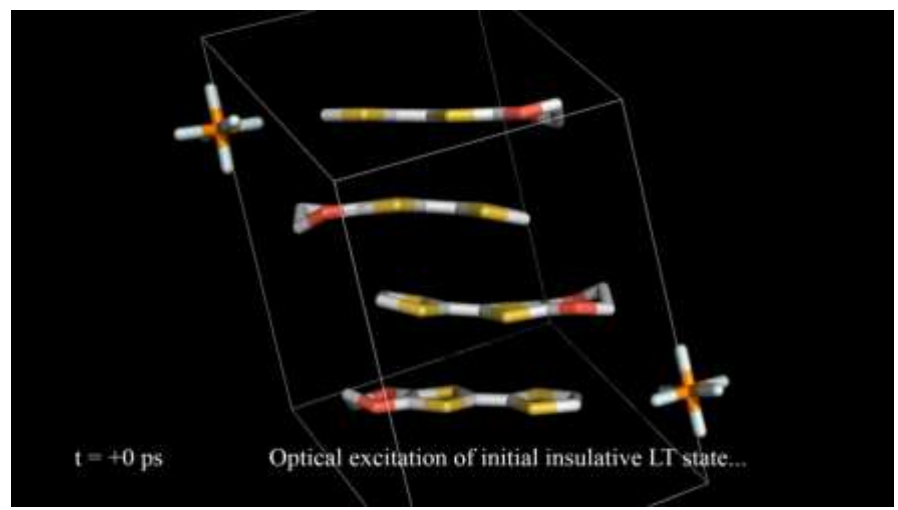
$(EDO\text{-}TTF)_2\ PF_6$

Diarylethene

Phase transition



M. Gao et al, Nature **496**, 343 (2013).



Electron vs X-ray

	Electrons (100 keV)	X-ray (10 keV)
Wavelength [Å]	0.04	1.2
Mechanism of radiation damage	Secondary electron emission	Photoelectric
Ratio (inelastic/elastic) scattering events	3	10
Energy deposited relative electron per elastic event	1	>1000
Elastic mean free path	1	$10^4 – 10^5$
Coherence length	1 – 10 nm	>1 µm

XFEL and Electron gun

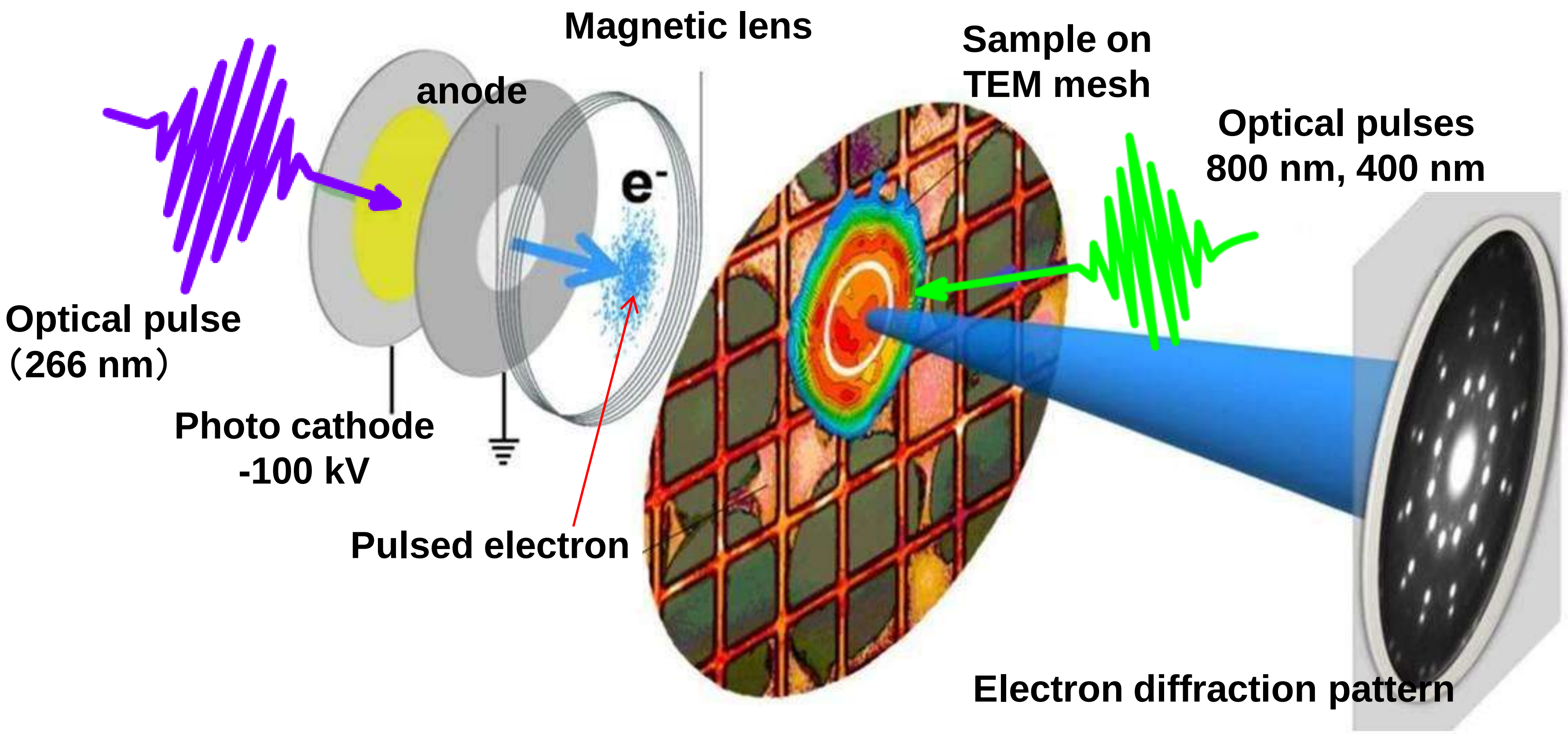

SACLA/ Spring8


LCLA/ Stanford


European XFEL/ DESY


~100 keV DC electron gun/ Hamburg

DC Femtosecond electron diffraction

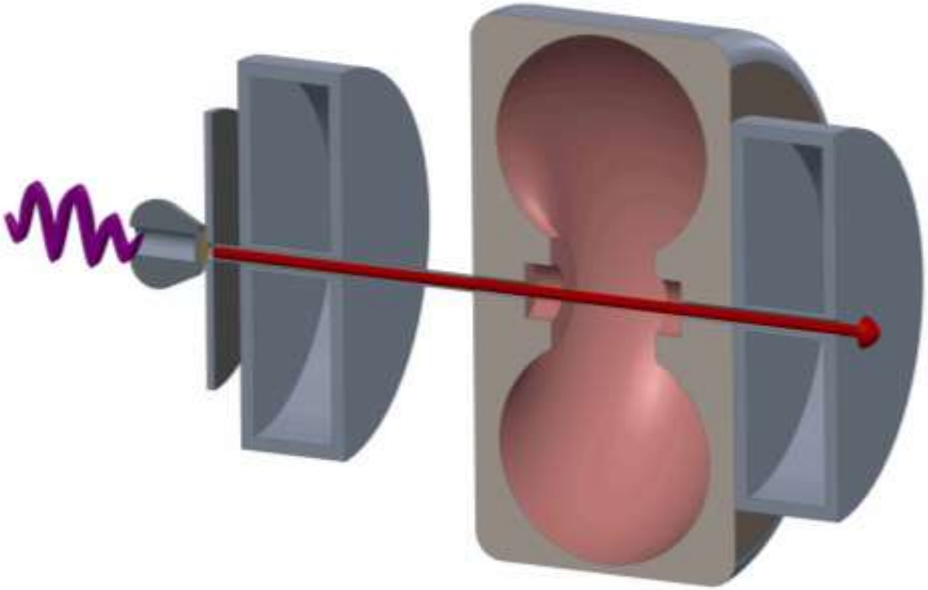


Accel voltage : 90 – 120 kV

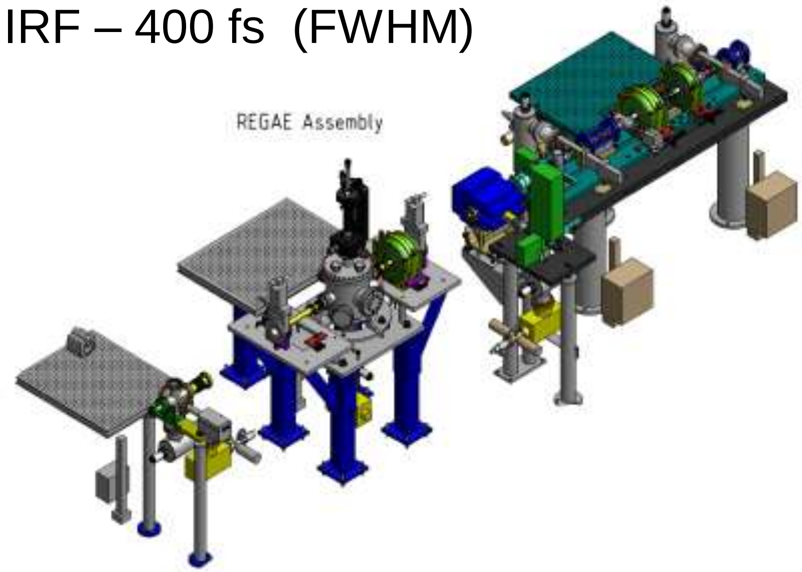
Pulse duration : 300 – 500 fs

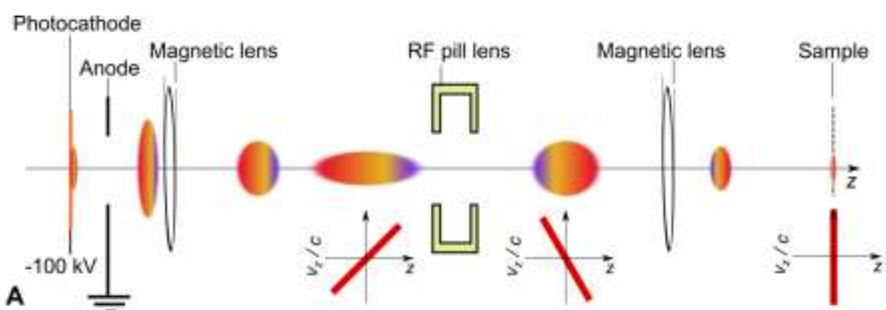
Electron density : 10^4 – 10^5 electrons/pulse

Femtosecond Electron diffraction + RF



Buncher Machine
100 keV
10 Hz
200000 e/pulse
IRF – 400 fs (FWHM)





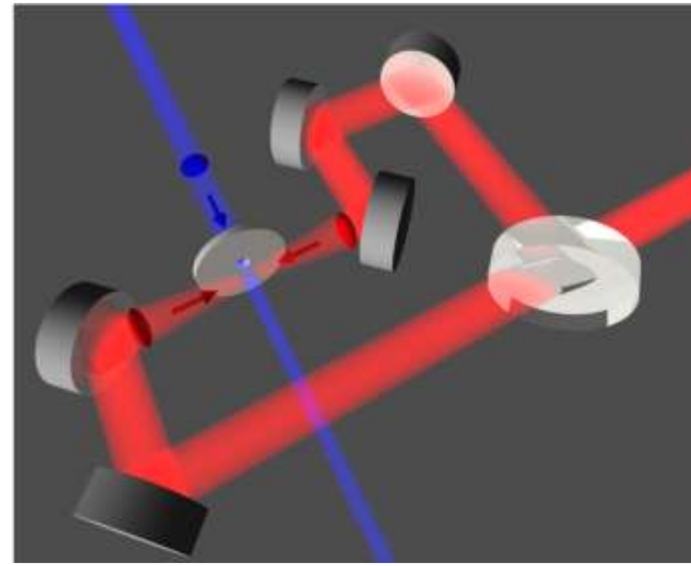
M. Gao, H. Jean-Ruel et al., Opt. Express **20,** 12048 (2012).

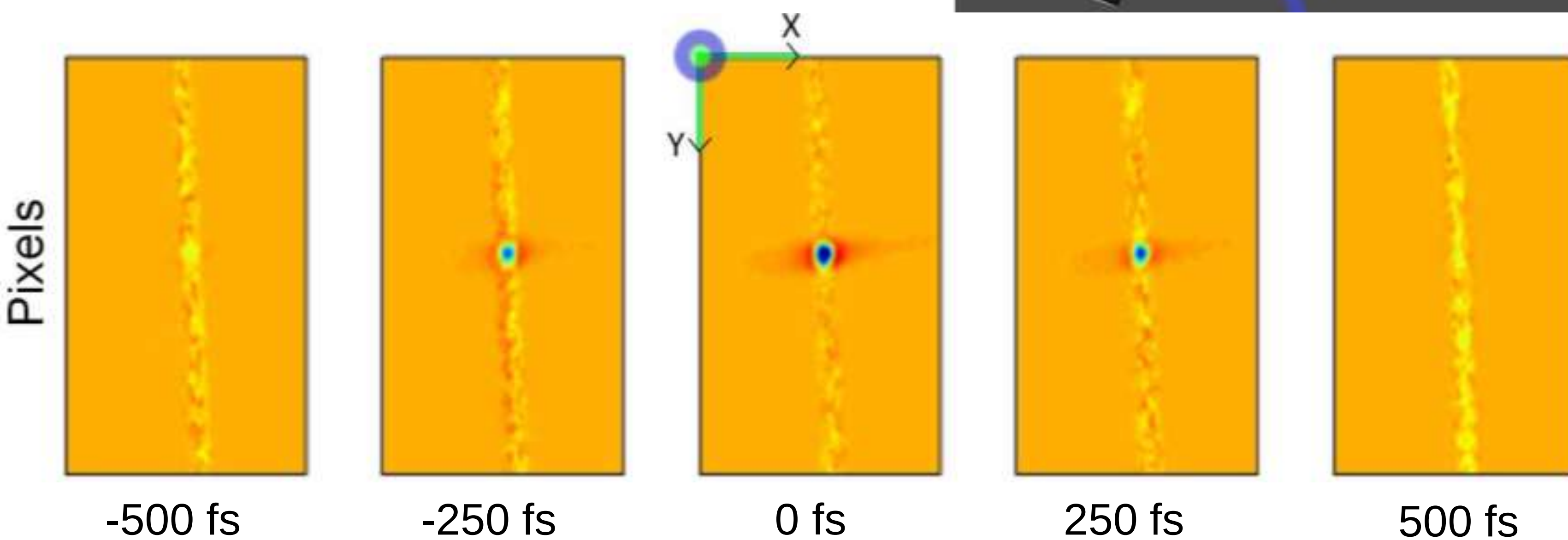
REGAE
3–5 MeV
12.5 Hz
1×10^7 e/pulse
IRF – <50 fs (FWHM)

Pulse characterization Ponderomotive

Full characterization of RF compressed femtosecond electron pulses using ponderomotive scattering

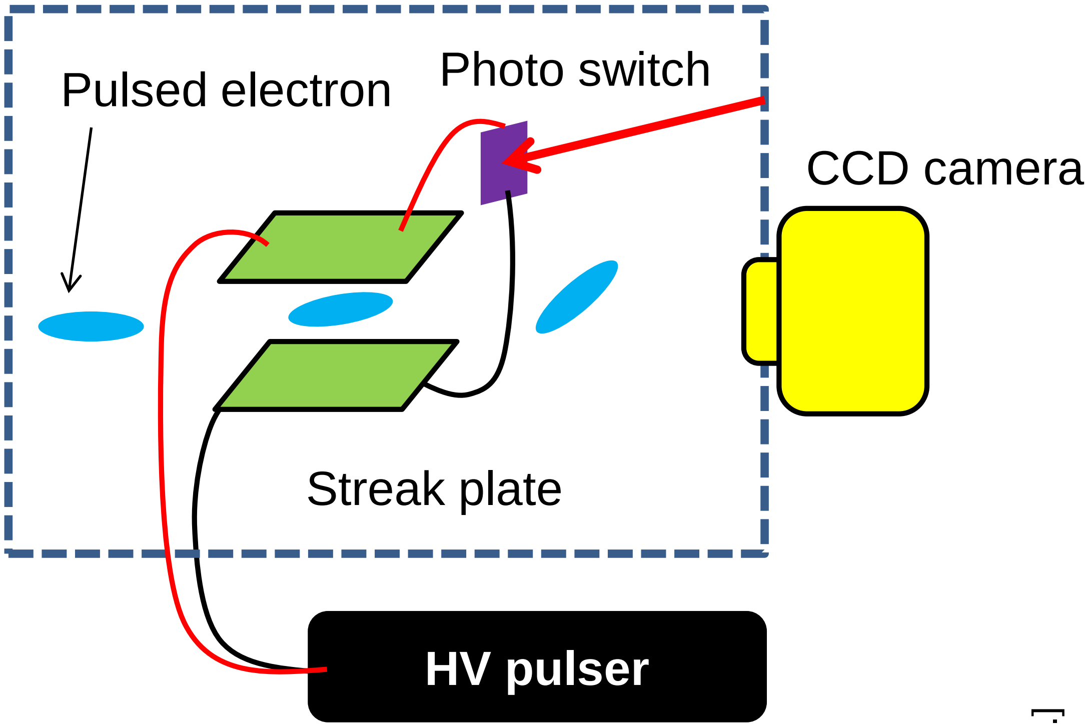
Meng Gao,[1] Hubert Jean-Ruel,[1] Ryan R. Cooney,[1] Jonathan Stampe,[3] Mark de Jong,[3] Maher Harb,[1,4] German Sciaini,[2] Gustavo Moriena,[1] and R. J. Dwayne Miller[1,2,*]

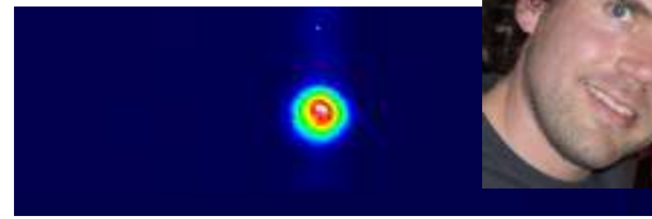




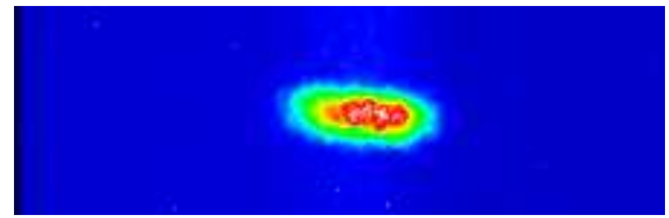
Streak camera

Günther Kassier

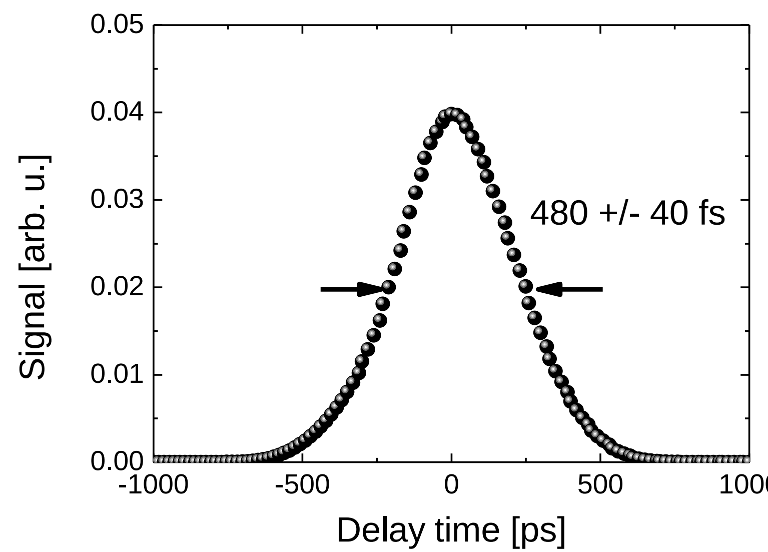


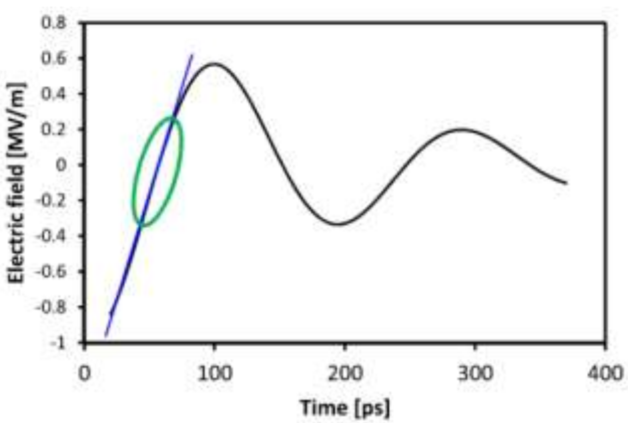


Without streak



With streak





G. Kassier et al., Appl. Phys. B 109, 249 (2012)

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  - Motivation
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  - Pulse characterization
- **Science with electron diffraction**
  - **Single-shot experiment**
    - **KI   Cold ablation driven by localized forces**
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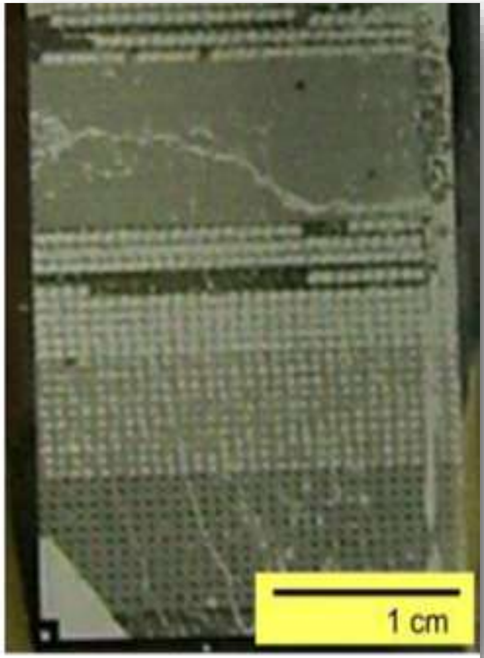
Single-shot experiment

- Melting, Ablation and irreversible reactions

- Single or highly-oriented crystal sample
- Homogenous and large area sample



Julian Hirscht

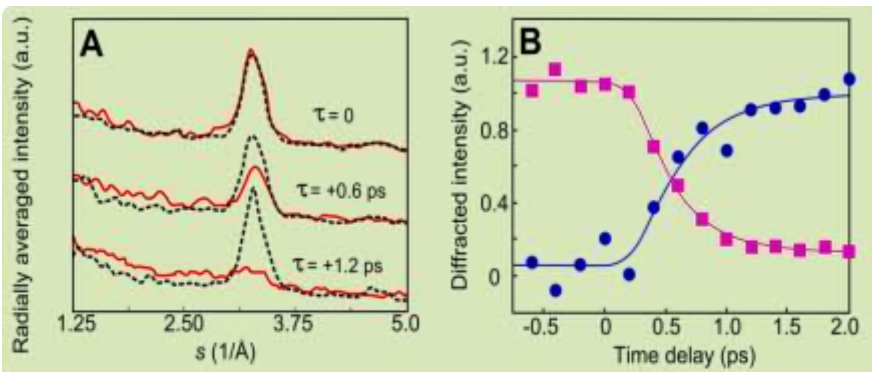
Dongfang Zhang

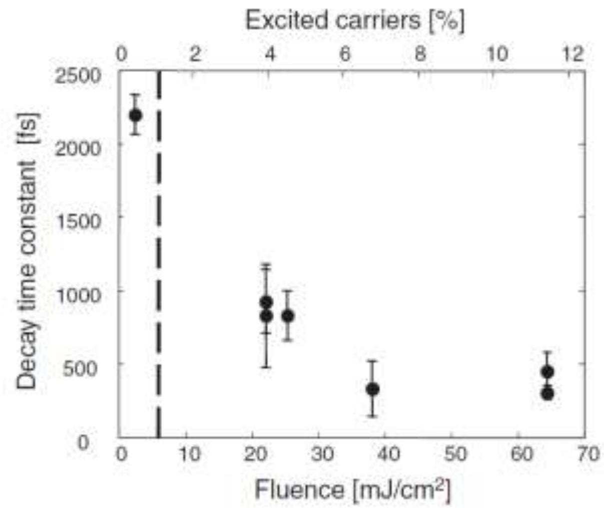
Si nonthermal melting

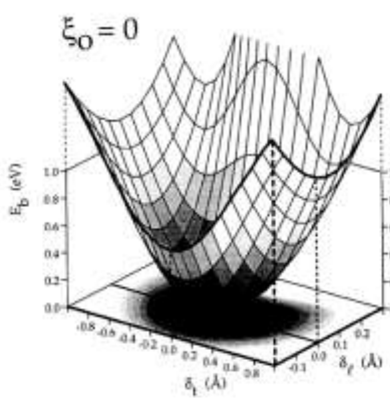
PRL **100,** 155504 (2008) PHYSICAL REVIEW LETTERS week ending 18 APRIL 2008

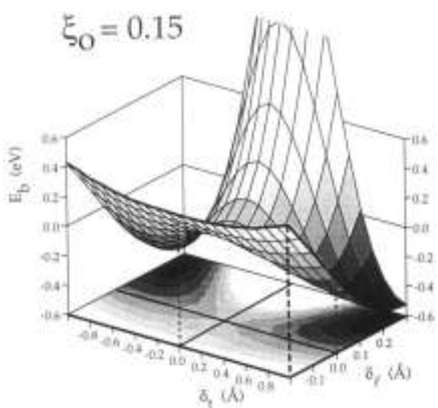
Electronically Driven Structure Changes of Si Captured by Femtosecond Electron Diffraction

Maher Harb,[1] Ralph Ernstorfer,[1] Christoph T. Hebeisen,[1] Germán Sciaini,[1] Weina Peng,[2] Thibault Dartigalongue,[1] Mark A. Eriksson,[2] Max G. Lagally,[2] Sergei G. Kruglik,[1] and R. J. Dwayne Miller[1,*]





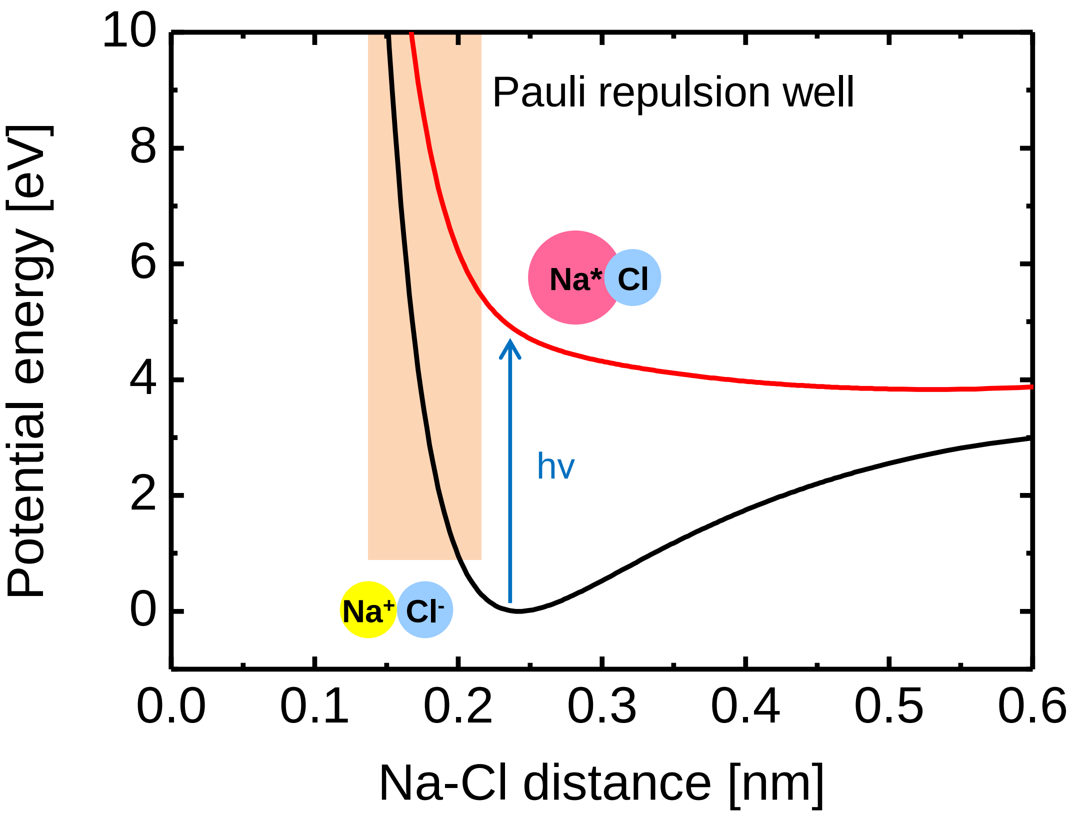


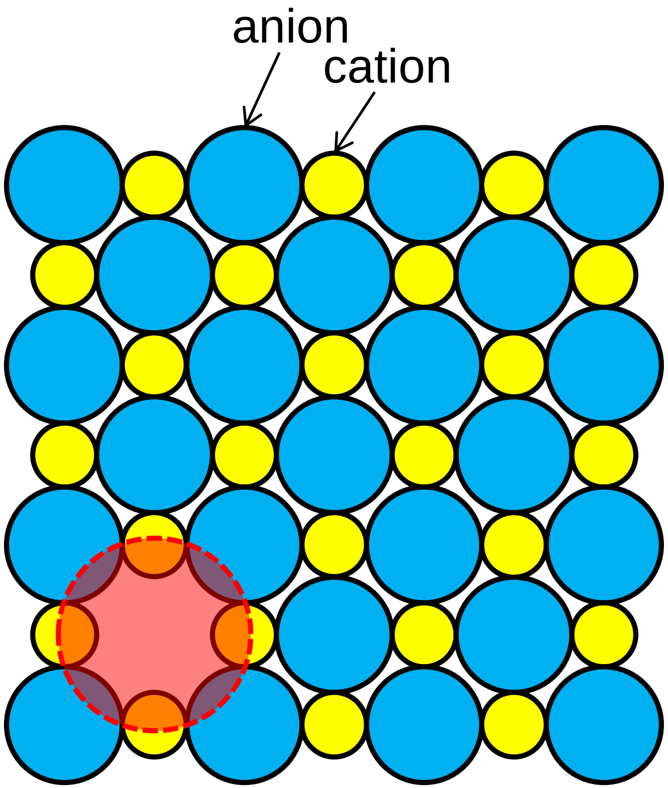


Nonthermal melting in Si !

P. Stampfli et al. Phys. Rev. B **49,** 7299 (1994)

Strong localized force in alkali halides





Self-trapped exciton, color center formation

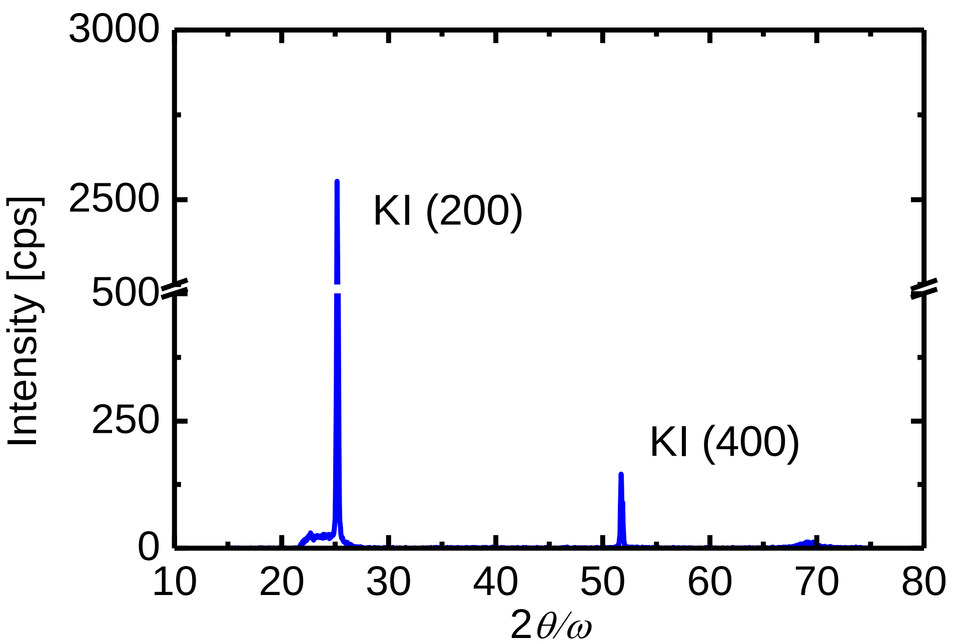
Sample preparation – KI thin crystals

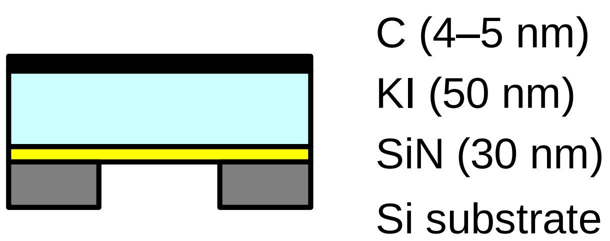
Self standing SiN (30 nm) mesh by chemical etching process

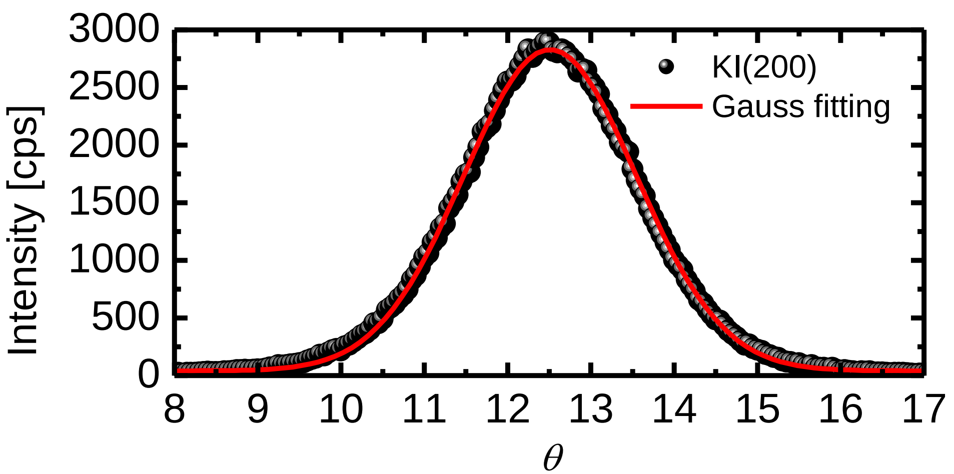
Pre-annealed (400 degrees)

Thermal deposition of KI (50 nm)

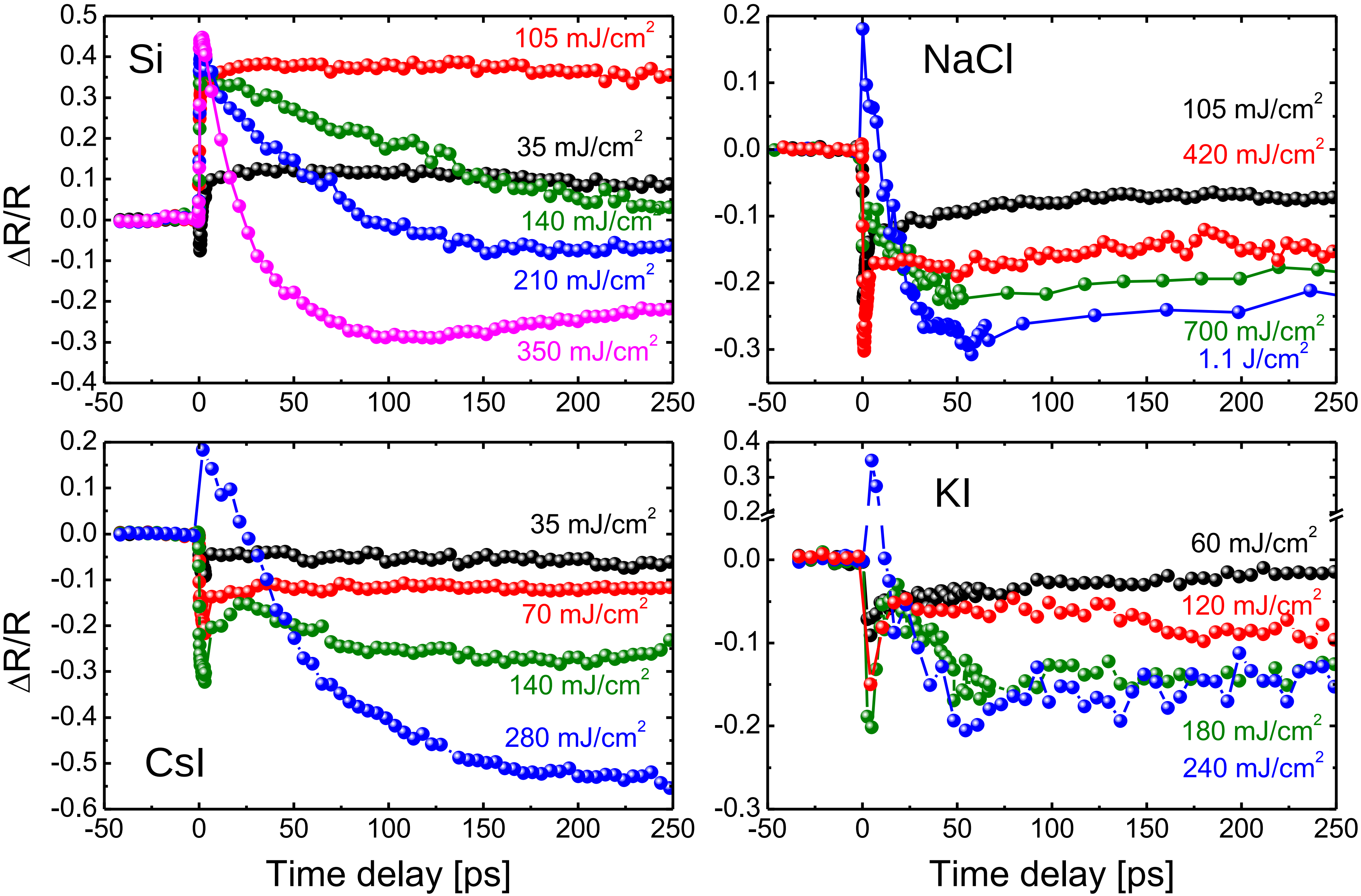
Coating with Carbon (4–5 nm)



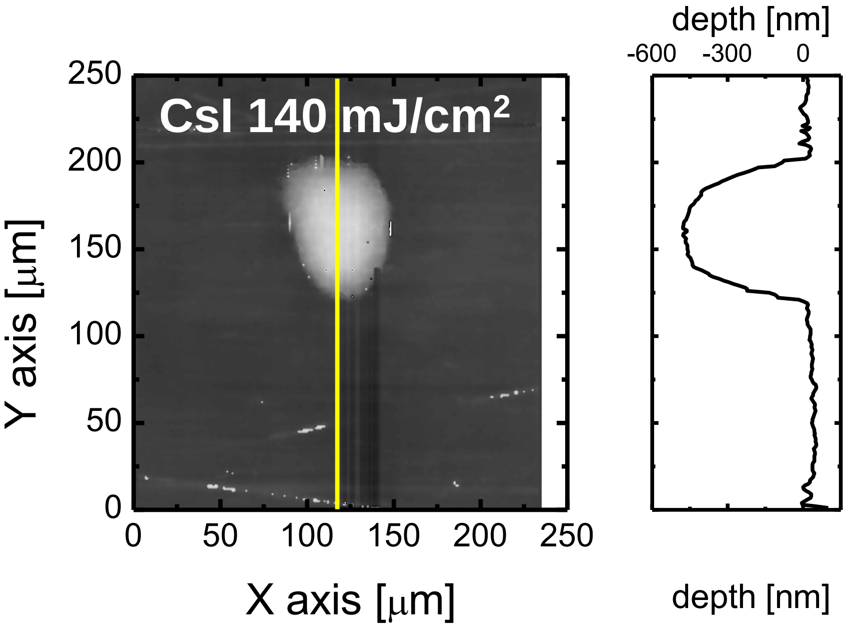


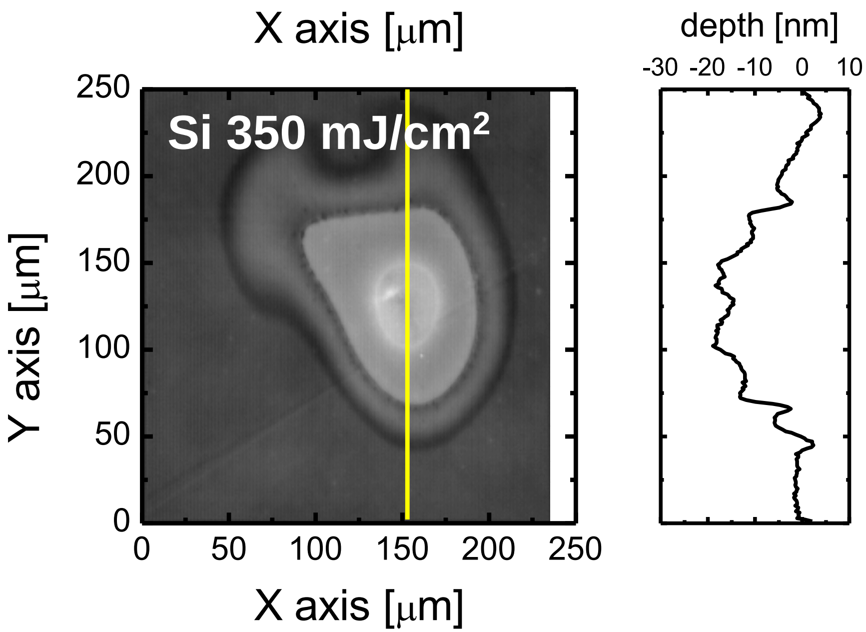


Optical studies

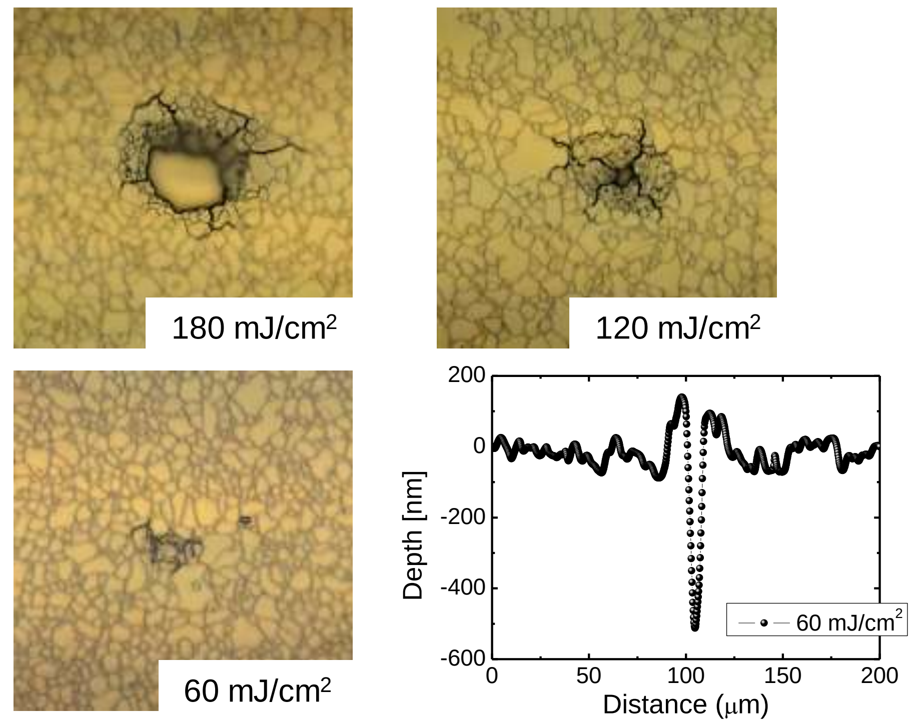


Sample surface after irradiation





KI



Micron deep crater formation in alkali halides with low laser fluence

Micron deep crater in alkali halides

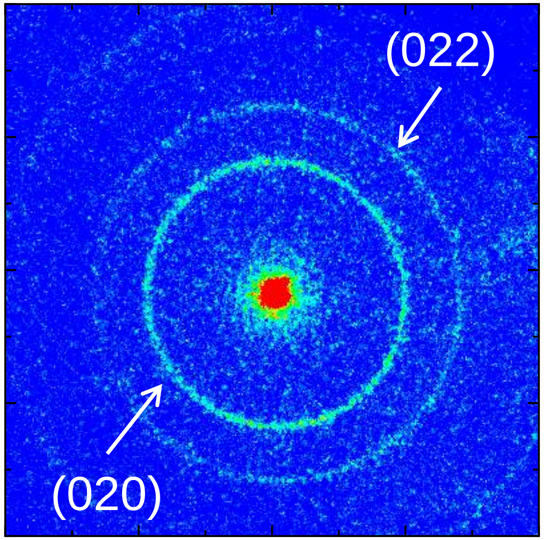
F	Depth (Si)
350 mJ/cm^2	26 nm
210 mJ/cm^2	16 nm
70 mJ/cm^2	9 nm

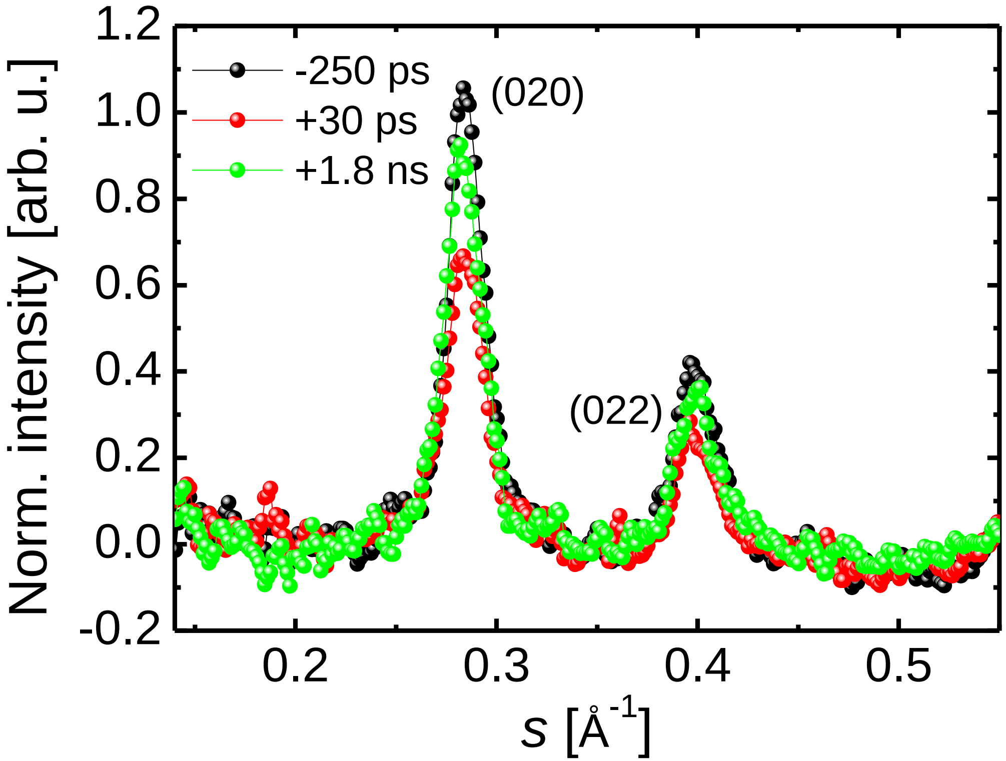
F	Depth (NaCl)
420 mJ/cm^2	970 nm
350 mJ/cm^2	950 nm

F	Depth (CsI)
280 mJ/cm^2	704 nm
140 mJ/cm^2	472 nm
105 mJ/cm^2	418 nm

F	Depth (KI)
180 mJ/cm^2	>2500 nm
120 mJ/cm^2	1400 nm
60 mJ/cm^2	500 nm

Electron diffraction

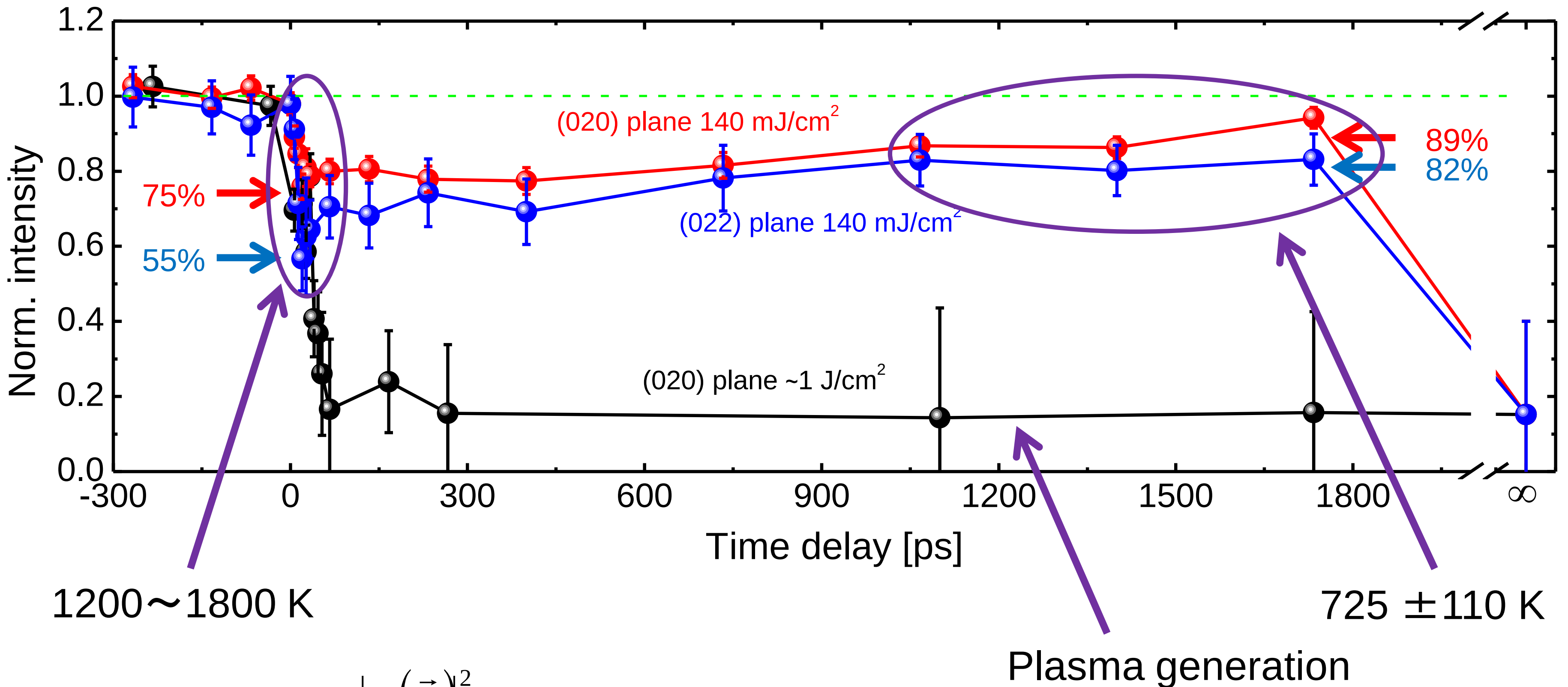




F = 140 mJ/cm^2
Absorption = ~2%
Film thickness: 50 nm
2-photon absorption

Temperature raise	~780 K (melting point 954 K)
Excited halide center	~4%

Thermal? Plasma?

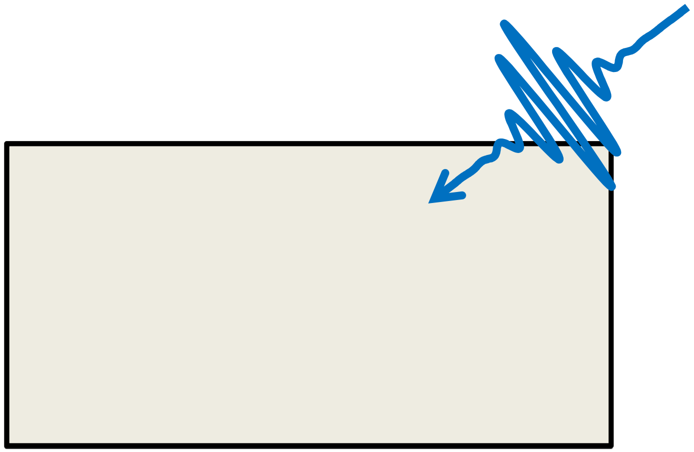


$$I = \left| F\left(\vec{K}\right) \right|^2$$

$$F\left(\vec{K}\right) = G\left(\vec{K}\right) \sum_{j=1}^{M} f_j\left(\vec{K}\right) D_j\left(\vec{K}\right) \exp\left(2\pi i \vec{K} \cdot \left\langle \bar{r}_j \right\rangle\right)$$

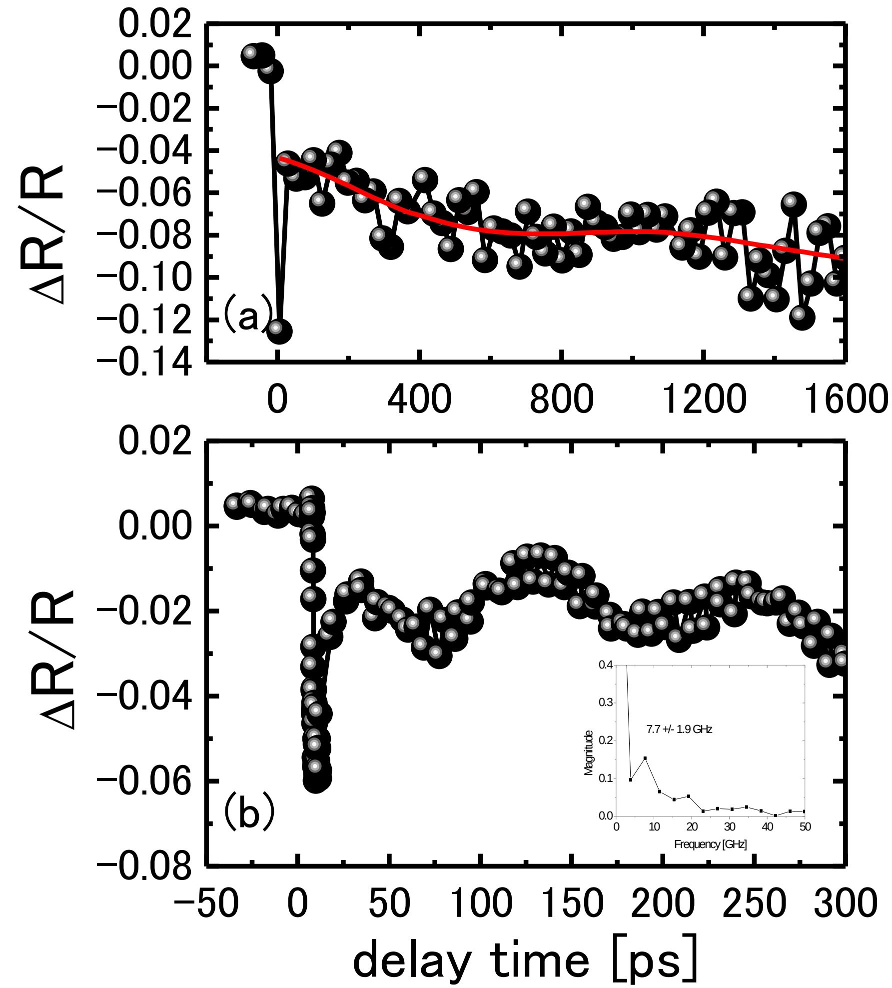
$$D_j = \exp\left(-K^2 B_j\right) = \exp\left(-8\pi^2 K^2 U_j\right) = \exp\left(\frac{8\pi^2 U_j \sin^2\theta}{\lambda^2}\right)$$

Localized force in alkali halides



KI crystal
photoexciation

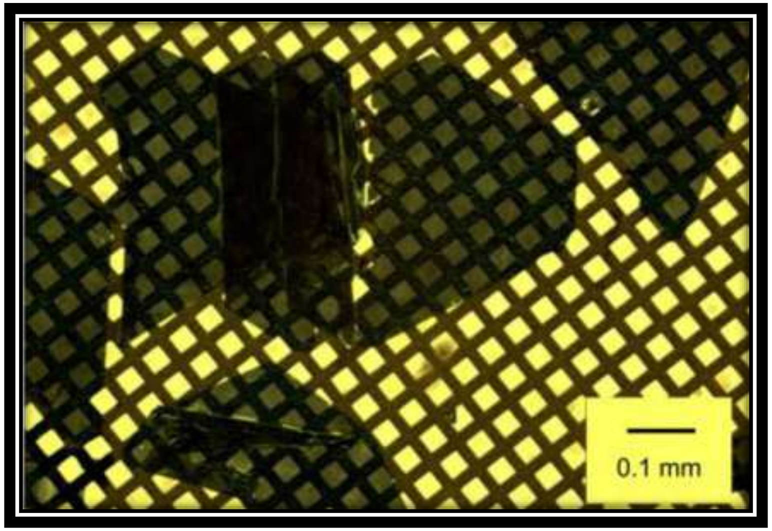
These defects and disordered regions introduce strong electronic stress that leads to the expulsion of material.

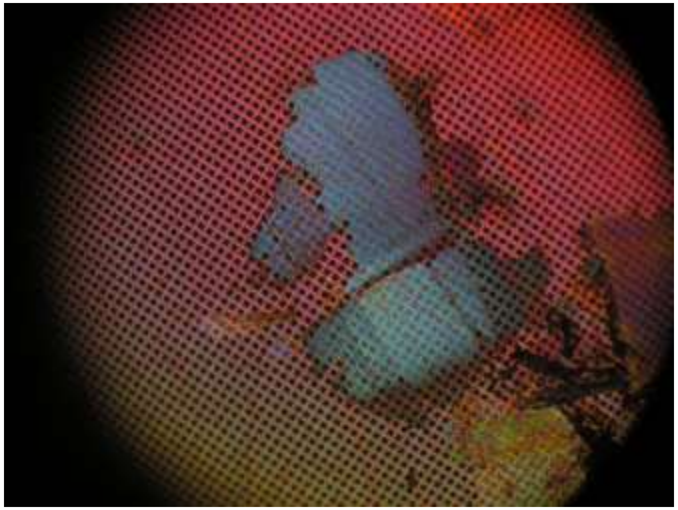


Multiple shot experiments

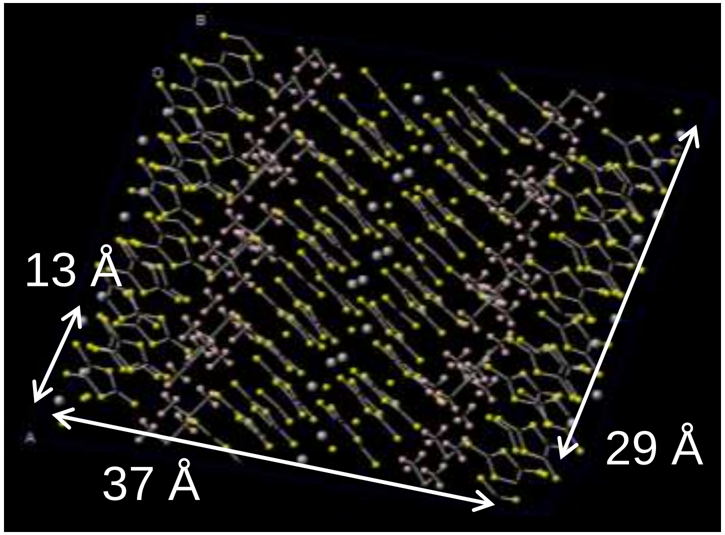
- Photoinduced repetitive reactions

- Single crystal
- Large structural modification
- Find a proper material





$Me_4P(Pt(dmit)_2)_2$

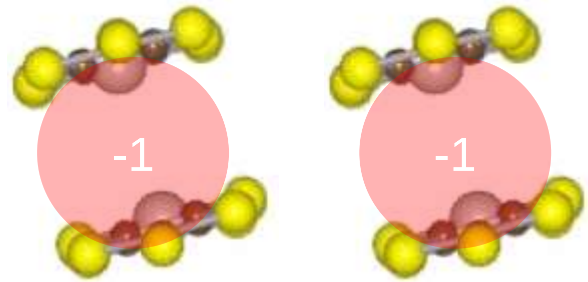


Stuart Hayes

Tadahiko Ishikawa

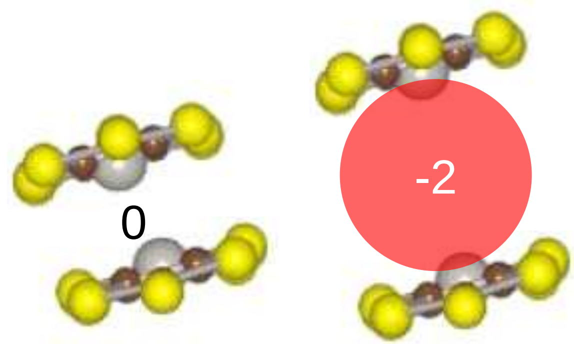
Collaboration work
Miller Group, Max Planck Institute
Koshihara Group, Tokyo Institute of Technology
Kato Group, RIKEN

HT phase (>215 K)



Paramagnetic metal

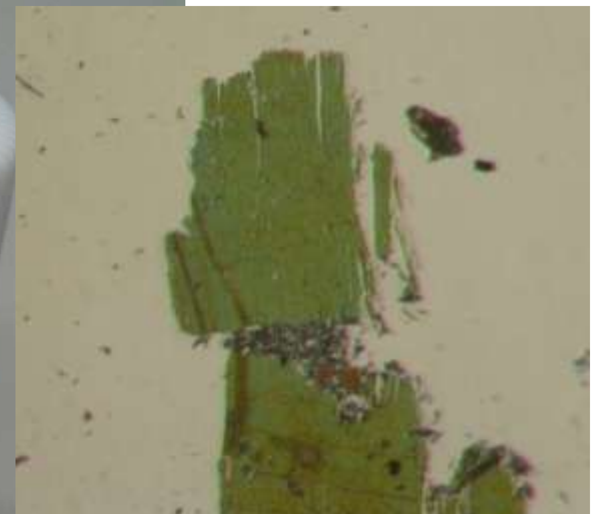
LT phase (>215 K)



Charge-ordered state
Non magnetic insulator

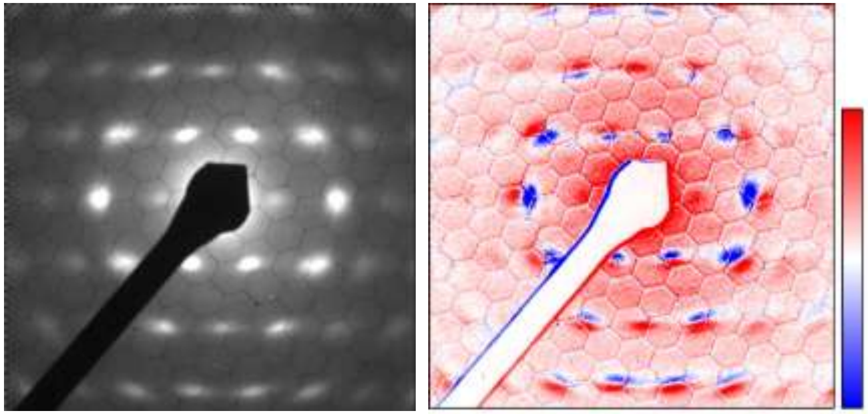
Sample preparation

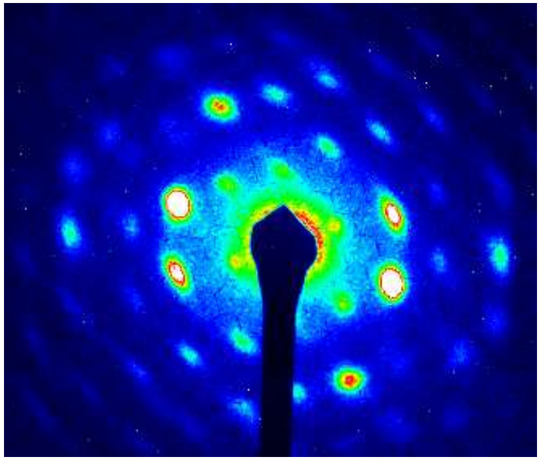
Microtome the sample down to 150 nm



Sercan Keskin

Coherent phonon oscillation





Crystal with large lattice parameters
→ We can go for protein crystals!?

We observed the coherent phonon oscillation…
We have not put the index yet…

Thank you for your attention!

Max-Planck-Institut für Struktur und Dynamik der Materie

CFEL SCIENCE

UHH

CUI THE HAMBURG CENTRE FOR ULTRAFAST IMAGING