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Pulsed Electron Gun for Ultrafast Time-Resolved Electron Diffraction at Surfaces with Femtosecond Temporal Resolution and High Coherence Length

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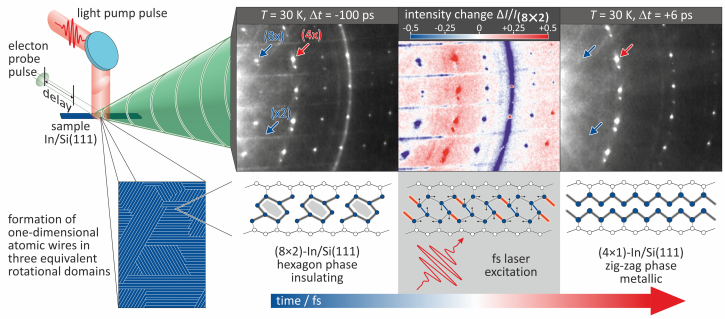
Time-Resolved Electron Diffraction



Pump-Probe Setup

- Pump: fs laser pulse
- Probe: fs electron pulse
- High electron energies (30 - 100 keV)

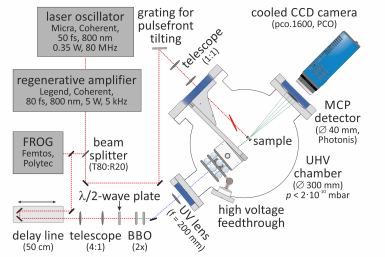
Surface Sensitivity

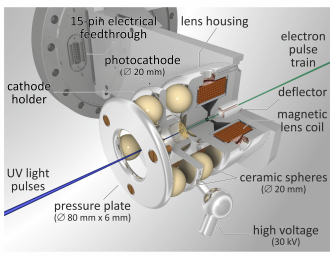
- Grazing angle of incidence 1° - 6°
- Small momentum transfer, comparable to low energy electron diffraction

Accessible Transient Parameters

- Surface structure: spot positions
- Near surface bulk structure: Kikuchi line pattern
- Correlations: spot profiles
- Surface temperature: Debye-Waller effect

Experimental Setup and Gun Design





Laser Pulse

- Initial pulse: λ = 800 nm, E = 1.55 eV, τ = 80 fs, 5 kHz repetition rate
- Beam splitting: 80% sample excitation, up to 10% electron generation via BBOs, 10% pulse characterization (FROG)

Pulsefront Tilting

- First order back diffraction at blazed grating in Littrow geometry (tilt angle 71°)
- Pump pulse width at sample: $\tau_{pump} \approx 100$ fs

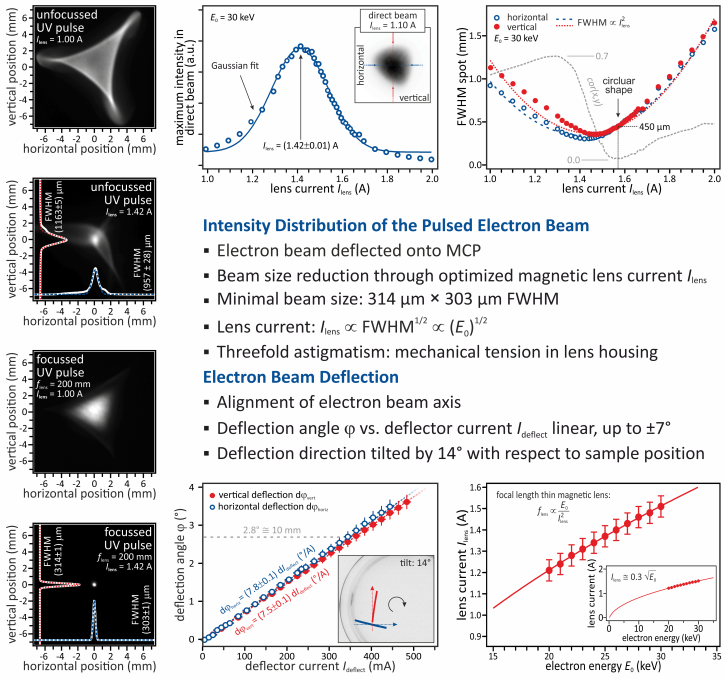
Photocathode

- Focused third harmonic UV light pulses (λ = 267 nm, E = 4.65 eV, τ = 80 fs, ∅ 25 µm)
- One-photon-photo-emission
- 10 nm Au / 2 nm W / sapphire
- Optimized work function of Au film → Initial electron energy spread ΔE = 0.1 eV
- E_e: 30 keV, E_{acc}: 7.5 keV/mm

Magnetic Lens and XY Deflector

- Electron beam optimization

Electron Beam Optimization



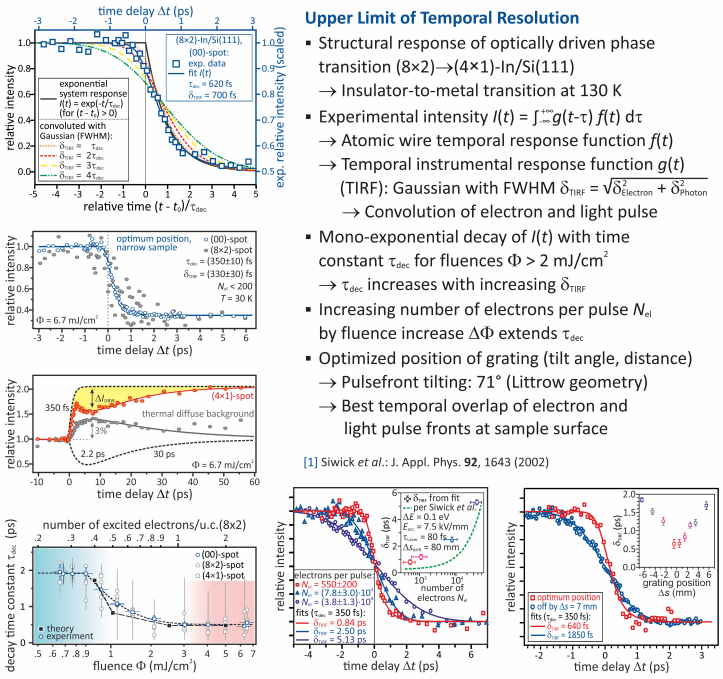
Intensity Distribution of the Pulsed Electron Beam

- Electron beam deflected onto MCP
- Beam size reduction through optimized magnetic lens current I_{lens}
- Minimal beam size: 314 µm × 303 µm FWHM
- Lens current: $I_{lens} \propto \mathrm{FWHM}^{1/2} \propto (E_0)^{1/2}$
- Threefold astigmatism: mechanical tension in lens housing

Electron Beam Deflection

- Alignment of electron beam axis
- Deflection angle φ vs. deflector current $I_{deflect}$ linear, up to ±7°
- Deflection direction tilted by 14° with respect to sample position

Temporal Resolution

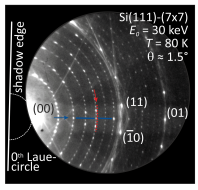


Upper Limit of Temporal Resolution

- Structural response of optically driven phase transition (8×2)→(4×1)-In/Si(111) → Insulator-to-metal transition at 130 K
- Experimental intensity $I(t) = \int_{-\infty}^{+\infty} g(t-\tau)\, f(t)\, \mathrm{d}\tau$ → Atomic wire temporal response function $f(t)$ → Temporal instrumental response function $g(t)$ (TIRF): Gaussian with FWHM $\delta_{TIRF} = \sqrt{\delta^2_{Electron} + \delta^2_{Photon}}$ → Convolution of electron and light pulse
- Mono-exponential decay of $I(t)$ with time constant τ_{dec} for fluences Φ > 2 mJ/cm² → τ_{dec} increases with increasing δ_{TIRF}
- Increasing number of electrons per pulse N_{el} by fluence increase ΔΦ extends τ_{dec}
- Optimized position of grating (tilt angle, distance) → Pulsefront tilting: 71° (Littrow geometry) → Best temporal overlap of electron and light pulse fronts at sample surface

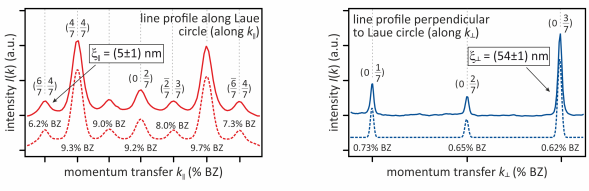
[1] Siwick *et al.*: J. Appl. Phys. **92**, 1643 (2002)

k-Resolution and Coherence Length

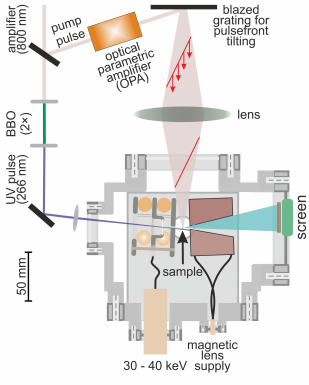


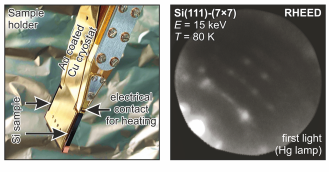
Determination of Coherence Length ξ

- Si(111)-(7x7): huge domains with ∅ > 100 nm → Instrumental response not limited by surface morphology
- Gaussian diffraction spots on Laue circles: FWHM = 1/ξ
- Along Laue circle: FWHM = 9% BZ → $\xi_{\parallel}$ = 5 nm
- Perpendicular to Laue circle: FWHM = 0.65% BZ → $\xi_{\perp}$ = 54 nm
- Optimization: small electron emission area, magnetic lens design



Outlook: Sub-100 fs Electron Diffraction





fs-Pulsed Light Excitation at λ = 800 nm

- Modification of accessible excited electronic states by different photons (0.5-1.5 eV) by OPA
- Optical grating parallel to sample

fs-Pulsed Probing with Electrons

- Back-illuminated Au photocathode
- Lens behind sample: drift region < 5mm
- E_e = 30-40 keV, $\mathscr{E}_{ext}$ = 20 kV/mm,

Single Electron Counting with Direct Detection