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Time-Resolved X-ray Diffraction Investigation of Ultrafast Structural Changes in Fe

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We have studied the rapid structural transformations in thin Fe films after pulsed laser annealing. Time resolved x-ray diffraction with femtosecond X-ray pulses at the EuXFEL facility was used to characterize the kinetics of the crystallization from the melted phase. Pulsed laser induced melting on the picosecond time was studied for various metals (e.g. Au, Pd)[1, 2]. However, the subsequent ultrafast cooling processes remain poorly studied.

Analysis of the changes in the integrated intensities of the Bragg peaks and liquid "halo" scattering peak allow to describe the kinetics of crystallization in Fe thin films during ultrafast cooling. The isothermal crystallization of the Fe layers in the partial melting regime for various pump laser energies is investigated. The high temperature bcc δ-Fe phase is crystallized from liquid within 1 nanosecond time scale. Independent of the deposited energy density, the constant nucleation rate is observed following JMAK (Avrami) analysis.

These first experimental findings offer insights into the crystallization process of monoatomic Fe metal during ultrafast cooling.

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References

1. J. Antonowicz et al., Acta Materialia 276 (2024) 120043.
2. M. Z. Mo et al., Science 360 (2018) 1451-1455.