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Dedicated X-ray diffraction setup for diamond anvil cell studies at the European X-ray free electron laser

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Scientific advances are often enabled by either new emerging techniques or a previously unconsidered combination of existing methods. Particularly synchrotron X-ray diffraction (XRD) has led to large advances in our understanding of materials under high pressure and temperature conditions. Especially its combination with diamond anvil cells (DAC) has been very fruitful and, therefore, almost every 3rd generation synchrotron source in the world has now one or several beamlines dedicated to high pressure DAC research.
On the other hand, in the regime of X-ray free-electron lasers (XFEL), which provide previously unprecedented brightness in a single X-ray pulse, high-pressure and temperature XRD experiments as of today are mainly conducted with a combination of laser driven shock. The absence of DAC research at these facilities is mainly due to a combination of two factors: either the XFEL sources provide only a relatively low photon energy (<11 keV) leading to strong absorption of the X-rays in the diamond anvils as well as a small angular XRD coverage; or if the pulse energy is high enough (e.g. SACLA up to 25 keV on the fundamental) repetition rate on the order of only 10 to 120 Hz is not fast enough to provide significant advantage over 3rd generation synchrotron sources for time-resolved studies, such as the dynamic piezo-driven DAC.
The European XFEL (EuXFEL) in Schenefeld, Germany, is now capable of providing X-ray photons with energies up to 25 keV and a repetition rate of 4.5 Mhz and thus, facilitates the opportunity of combining DAC-XRD experiments with the unique properties of XFEL radiation sources.
Here we want to present the new DAC setup dedicated to XRD studies at the high energy density (HED) instrument of the EuXFEL. This setup has been provided through the Helmholtz International Beamline for Extreme Fields (HiBEF) user consortium and is situated in the interaction chamber 2 of the HED instrument. Currently, two sample platforms are available in the vacuum chamber: the first is a combination of standard or membrane DACs, for use with time resolved optical spectroscopy as well as pulsed laser heating, and the second provides capabilities and space for dynamic DACs with ultrafast piezo driven compression drivers.
The primary goal of both setups is to utilize the high brightness of the EuXFEL source, which permits good quality XRD images, comparable to several seconds of exposure in a 3rd generation synchrotron, even from a single X-ray pulse. The EuXFEL provides bursts of X-ray pulses within a so-called pulse-train with a frequency of 4.5 MHz, equating to 220 ns between each pulse. In combination with an AGIPD detector currently commissioned at the instrument, images will be collected with 4.5 MHz, facilitating the study of physical phenomena by XRD with a unique time resolution.
In the standard DAC setup, the thermal response due to single laser heating pulses or heating by intense X-ray pulses can be investigated by a combination of spectroradiometric measurements (utilizing a streak camera) and XRD on a submicrosecond timescale without the need of collecting multiple iterations in a pump-probe experiment, as performed previously at 3rd generation synchrotron facilities. The dynamic DAC setup enables the study of materials under fast compression and closes the strain rate gap between these type of experiments at synchrotron facilities and shock compression experiments further.
First experiments utilizing the standard DAC setup have been conducted during a community assisted commissioning beamtime in October 2019 (Proposal number 2292, PI R.S. McWilliams). Many exciting new results have been obtained, but also challenges arising from the nature of an XFEL source have been identified.
We will present the setup, its capabilities and some of the first interesting results in this contribution.

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