Characterization of highly coherent photocathodes for integration in ultrafast electron diffraction guns

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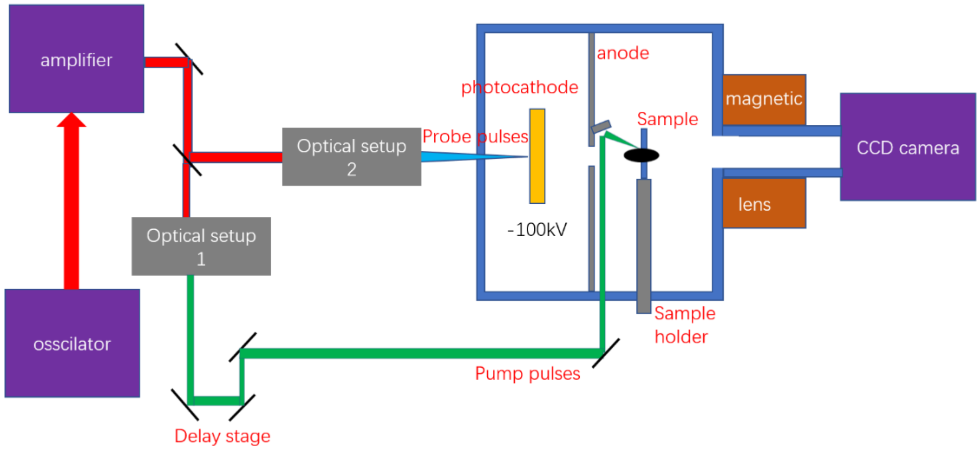
Project description: Electrons can diffract from thin crystalline samples, just like X-rays, thanks to their quantum mechanical nature. In fact, electron beams are superior in numerous respects for the sake of probing atomic-scale phenomena. For instance, unlike electromagnetic waves, electron beams are not restricted by the diffraction limit at their focus which is why electron microscopes can achieve sub-nanometer resolution – more than two orders of magnitude better than with optical microscopes. While in transmission electron microscopes specific charged-particle lenses are incorporated to produce images of the specimens, a different configuration is used to record diffraction patterns to gain insight into crystalline structures. Ultrafast electron diffraction (UED) is the art and science of producing atomically resolved molecular movies in femtosecond to nanosecond time scales – as opposed to still images lacking any temporal information. Changes in the crystalline structure of quantum materials following processes such as excitation by fs laser pulses can therefore be probed in real-time thereby providing invaluable insights into a host of atomic and molecular phenomena.

Investigating suitable photoemission electron guns that can be driven with UV fs laser pulses in ultrahigh vacuum chambers has been one of the technological backbones of electron microscopy and diffraction. The first goal of this project is to develop beam characterization protocols to study a number of photocathode candidates that are expected to desirably procure high coherence (low emittance) together with high brightness. The second goal is to incorporate these in our existing UED high-vacuum chambers which involves designing a pathway to guide the driving fs laser pulses into the chamber and controlling the electron pulse duration.

Required knowledge: E&M (e.g. current density, Maxwell's equations), QM (e.g. potential wells, quantum tunneling), Optics (e.g. basic reflection and refraction phenomena), Programming language (basic MATLAB or Python). The student is expected to be willing to learn to work with software for mechanical design (e.g. Solid Edge) and charged particles simulation (e.g. General Particle Tracer or ASTRA).

Learning outcomes: The curious student dedicated to this project for the duration of the program is anticipated to learn and gain insight on various experimental and computational aspects of the physics of charged particle beams, electron photoemission, ultrafast lasers, non-linear optics, and high-vacuum systems designed for UED experiments.



A pump/probe UED setup. UV fs laser pulses drive the photocathode through the photoemission effect. A pulse of electrons (black ellipse) undertakes diffraction a short time (fs-ns range) after a fs pulse produced at the desired wavelength by non-linear optical methods excites the sample. An atomic movie is reconstructed using the various frames formed by each diffraction event. Ever brighter and more coherent photocathodes are highly desired in these experiments.

References:

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[3] Ch. J. Knill, *et al.*, *"Near-threshold photoemission from graphene-coated Cu(110)"*, Phys. Rev. Appl. 19, 014015 (2023).
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