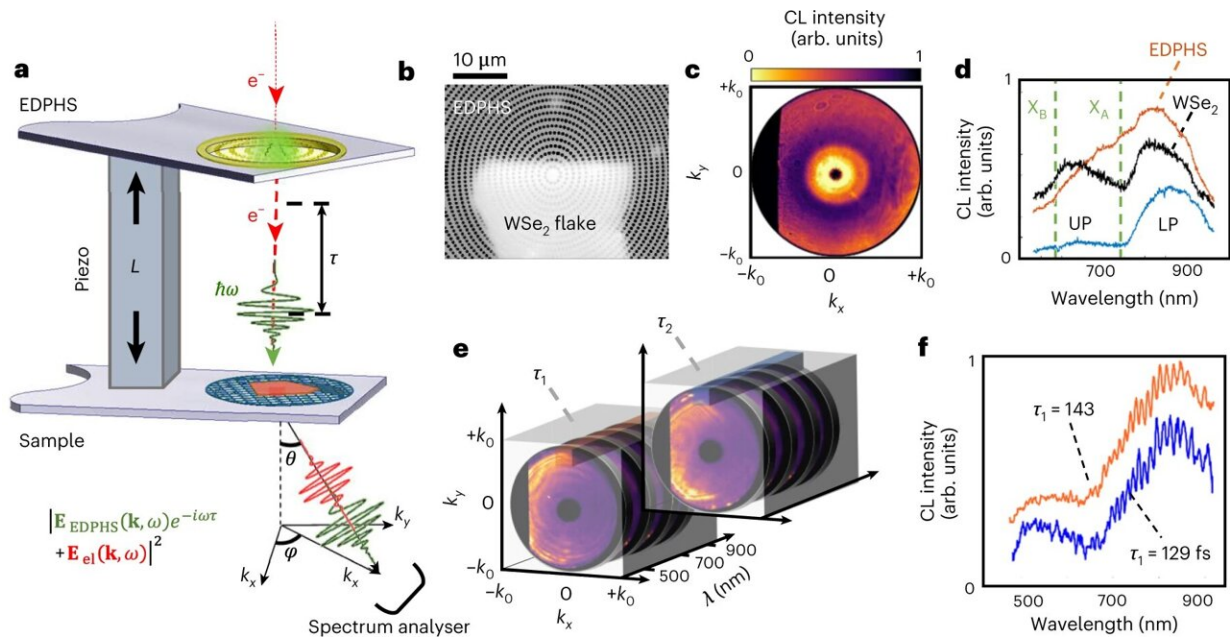


# New analysis method developed for nano and quantum materials

February 23 2023, by Eva Sittig



Spectral interferometry with an electron beam. **a**, An electron ( $e^-$ ) moving at a kinetic energy of 30 keV interacts with an EDPHS that generates photons with a collimated Gaussian spatial profile. The delay  $\tau$  between the photon and electron beams arriving at the sample is controlled by distance  $L$  between the sample and EDPHS. The energy–momentum distribution of the total scattered field from the sample is detected and analyzed to specify the mutual correlation between the EDPHS and sample radiation, as specified in the main text. Due to the excitation of exciton–polaritons with a large lateral wavenumber  $k_{\parallel}$ , both EDPHS-induced and electron-induced radiation from the sample are scattered to larger polar angles  $\theta$ . **b**, SEM image of the combination of EDPHS and sample at a distance of  $L = 2 \mu\text{m}$ . **c**, Angle-resolved CL pattern of the EDPHS structure. Here,  $k_x = k_0 \sin\theta \cos\varphi$  and  $k_y = k_0 \sin\theta \sin\varphi$ , where  $\theta$  and  $\varphi$  are the polar and azimuthal angles

with respect to the sample plane. **d**, CL spectra of the EDPHS (red line) and WSe<sub>2</sub> flake (black line), as well as the superposition of both at a distance of  $L = 24 \mu\text{m}$  between the EDPHS and sample (blue line), integrated over the entire momentum space. **e**, Schematic of the three-dimensional data cubes (CL intensities versus wavenumbers ( $k_x, k_y$ ) and wavelength ( $\lambda$ )) at selected delays between the EDPHS and sample. The data shown at the forefront are angle-resolved CL maps of the total field at a filtered wavelength of  $800 \pm 10 \text{ nm}$ . **f**, CL spectra of the total field at  $\theta = 45^\circ \pm 2^\circ$  and  $\varphi = 100^\circ \pm 2^\circ$ . The maps in **e** and **f** are acquired at the indicated delay values of  $\tau_1 = 129 \text{ fs}$  ( $L = 19 \mu\text{m}$ ) and  $\tau_2 = 143 \text{ fs}$  ( $L = 21 \mu\text{m}$ ). Credit: *Nature Physics* (2023). DOI: 10.1038/s41567-023-01954-3

A slow-motion movie on sports television channels shows processes in hundredths of a second. By contrast, processes on the nanoscale take place in the so-called femtosecond range: For example, an electron needs only billionths of a second to orbit a hydrogen atom.

Physicists around the world are using special instruments to capture such ultrafast nano-processes in films. Researchers at Kiel University (CAU) have developed a new method for such films that is based on a different physical concept and thus allows further and more precise options for investigation.

To do this, they combined an [electron microscope](#) with nanostructured metallic thin films that generate very short light pulses. In a first experiment, they were thus able to document the coherent interactions of light and electrons in a semiconductor on film. Their results are published in *Nature Physics*.

## **New method is simpler and more cost-effective**

Until now, movies showing ultrafast nano-processes have typically been

produced using high-power lasers combined with [electron microscopes](#). But only a few research groups can afford the large and complex setups. "Our concept does not require expensive and complicated lasers and can be easily replicated," says Nahid Talebi, Professor of Experimental Physics at the CAU.

Electron microscopes bundle electrons into a beam, accelerate it and direct it at a material sample. How the electrons pass through the sample or are reflected allows conclusions about the properties of the materials and the processes inside.

"Electron microscopes have a significantly better spatial resolution than optical microscopes and make investigations in the nanometer range possible in the first place," says Talebi. The special components she has developed make it relatively easy to improve also the temporal resolution of electron microscopes and convert them to their ultrafast versions. By this nanoscale processes can now also be captured in ultrafast films on the femtosecond time scale without lasers.

With her new publication, Talebi not only demonstrates that her method works. Together with her research associate Dr. Masoud Taleb, she also provides experimental evidence for coherent interactions of photons and electrons in a semiconductor, which had previously only been described theoretically. The quantum material tungsten diselenide, WSe<sub>2</sub>, used for this purpose originates from a collaboration with Professor Kai Rossnagel within the priority research area KiNSIS (Kiel Nano, Surface and Interface Science) at Kiel University.

### **Nano-structured metal generates short light pulses**

A central component of Talebi's concept is a special nanostructure looking similar to a kitchen sieve. It can be inserted into an electron microscope, where it functions like a light source, called "EDPHS"

(electron-driven photon source). When an [electron beam](#) hits this metal structure, the hole pattern generates targeted, short light pulses that can be used to make fast films.

To create the special structure the researchers drilled tiny holes of 25 to 200 nanometers into a thin gold foil. Talebi had precisely calculated the size and distances, because the light pulses only occur with a certain hole pattern. The "nanosieves" were produced in close collaboration with Dr. Mario Hentschel from the research group of Prof. Harald Giessen, University of Stuttgart.

Together with colleagues from Amsterdam, Talebi had previously modified the electron microscope so that it can detect cathodoluminescence. These light signals are generated when fast electrons hit metal.

## **Interactions between electrons and photons documented in films**

In the experiment described in the current publication, the short light pulses from the sieve-like nanostructures hit the semiconductor sample at the speed of light. Here they excite excitons, so-called quasiparticles.

These are electrons that have detached themselves from an atom and are still coupled to the hole they created ("electron-hole pairs"). "If a short time later the slower electron beam also hits the semiconductor sample, we can see from the reaction of the electrons how the excitons have behaved in the meantime," explains Talebi.

The resulting cathodoluminescence signals from the superposition of the electron beam and the light pulses show a coherent interaction between electrons and photons.

To be able to capture these processes in a film, the researchers also integrated a piezoelectric crystal into the microscope setup. This allows them to precisely change the spatial distance between the [light source](#) and the sample, and by this also the temporal distance between the incident light pulses and the electrons. "In this way, images can be taken at different stages of the process and assembled into a film," Talebi summarizes.

**More information:** Nahid Talebi, Phase-locked photon–electron interaction without a laser, *Nature Physics* (2023). [DOI: 10.1038/s41567-023-01954-3](#).  
[www.nature.com/articles/s41567-023-01954-3](http://www.nature.com/articles/s41567-023-01954-3)

Provided by Kiel University

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