State-of-the-art photocathodes grown on atomically thin layers of graphene

October 11, 2018

Future coherent x-ray sources and advanced colliders could provide insight into improved access and control of matter on the timescale of electronic motion and the spatial scale of atomic bonds. Such capabilities require increasingly high-performance electron beams that far exceed present state-of-the-art technologies. DOE-commissioned studies have pointed to electron sources as one of the highest accelerator R&D priorities for the next decade, requiring a transformational advance in cold cathode performance.

Los Alamos researchers and their collaborators have developed a unique approach that decouples two competing physical mechanisms that have prevented scientists from improving cold cathode efficiency and lifetime. The team integrated atomically thin materials with high-performing existing photocathode technologies for better environmental protection. The journal *Advanced Materials Interfaces* reported the research.

Significance of the work

Photocathodes generate large quantities of free electrons when they are exposed to photons of light. The success of a photocathode material hinges on its longevity and quantum efficiency (ratio of emitted electrons to incoming photons). Materials with higher quantum efficiency generate more electrons. Exposure of photocathode material to air degrades the material and decreases its longevity.

The study used the potassium cesium antimonide semiconductor (K_2CsSb), which has one of the highest quantum efficiencies of any photocathode in the visible region of the spectrum. The team examined the use of thin layers of graphene, a two-dimensional form of carbon, to protect the photocathode. Graphene possesses an exceptionally high gas barrier property, ultrahigh electrical and thermal conductivity, optical transparency, high charge mobility and the ability to sustain extreme current densities. The investigators discovered that atomically thin layer of graphene provide insulation from air without decreasing charge mobility or quantum efficiency of the photocathode.

The research demonstrates the ability to grow state-of-the-art photocathodes (traditionally grown on thick substrates) on extremely thin, transparent graphene substrates that have a quantum efficiency comparable to those deposited on rigid substrates. This configuration marks progress toward encapsulating high performance, environmentally susceptible photocathodes using graphene as a passivating barrier. It is a promising step toward fabricating photocathodes with enhanced lifetimes and on the optically transparent yet electrically conductive substrates needed for new light sources. The graphene-wrapping method could be used for any photocathode whose performance suffers when exposed to air.

The progress provides several advances to MaRIE, the Laboratory's proposed matter-radiation interactions in extremes capability, including the option to switch from metal cathodes to higher performance semiconductor cathodes that reduce emittance by 50 percent. This development reduces risk by creating "headroom" throughout the design and could decrease system complexity and beam energy for immediate cost savings.

Achievements

Los Alamos capabilities that were critical to the project's success included chemical vapor deposition to synthesize high quality graphene and nanomaterial processing to transfer graphene onto challenging substrates. The team obtained quantum efficiency maps by rastering a 405 nm light emitting diode (LED) over the sample. The researchers characterized the samples in reflection mode, i.e. illuminated from the photocathode side with photoemission current collected from the same side. They observed high quantum efficiency approaching 17 percent over a large area from the photocathode on graphene substrates. The team deposited the photocathode on a pure nickel foil for comparison. The quantum efficiency is lower and less uniform on nickel than on the graphene samples.

The research team

Reference: "Free-standing Bialkali Photocathodes using Atomically-thin Substrates," *Advanced Materials Interfaces 5,* 1800249 (2018); DOI: 10.1002/admi.201800249.

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N.A. Moody owns the patent US 8,823,259 on a concept of graphene protection of chemically reactive films.

The Laboratory Directed Research and Development (LDRD) program funded the Los Alamos work, which was partially conducted at the Center for Integrated Nanotechnologies, a DOE Office of Science User Facility operated by Los Alamos and Sandia national laboratories. The research supports the Lab's Energy Security mission area and its Materials for the Future science pillar by developing materials with controlled functionality and predictive performance.

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