Los Alamos NATIONAL LABORATORY

October 10, 2021

Towards the use of 2D materials as unique protection layer for bialkali photocathodes

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YouTube scientific videos on our findings:

https://www.youtube.com/watch?v=S4krKYGUopg&feature=youtu.be

https://www.youtube.com/watch?v=rkusTI_45o0

Addressing decadal R&D priority for cathodes

[1] Hemminger, J.C., *Next Generation Photon Sources for Grand Challenges in Science and Energy*. Office of Science (*http://science.energy.gov/~/media/bes/pdf/reports/files/ngps_rpt.pdf*), *2009*.

[2] Barletta, W.A. et al, *Compact Light Sources*. Department of Energy's Office of Science (*http://science.energy.gov/~/media/bes/pdf/reports/files/CLS.pdf*), *2010*.

[3] Henning, W. and C. Shank, *Accelerators for America's future. Department of Energy's Office of Science* (*www.acceleratorsamerica.org/files/Report.pdf*), *2010*.

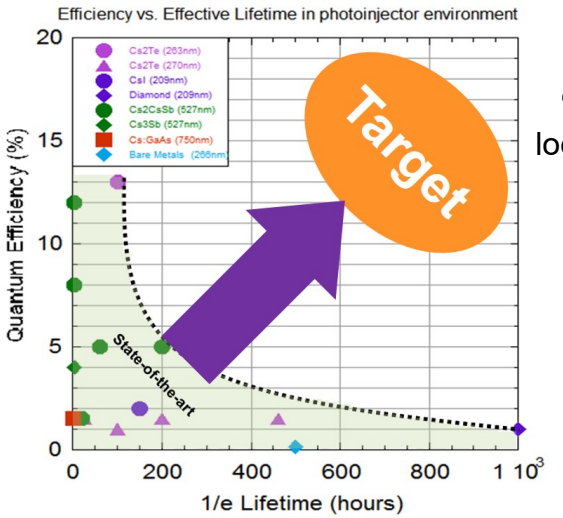
Our project aims to address nationally articulated need (DOE commissioned studies) which call for transformative advances in electron source development: ***long lifetime at high efficiency and high brightness***

- "Singular risk area[1]"
- "One of the highest accelerator R&D priorities for the next decade[2]"

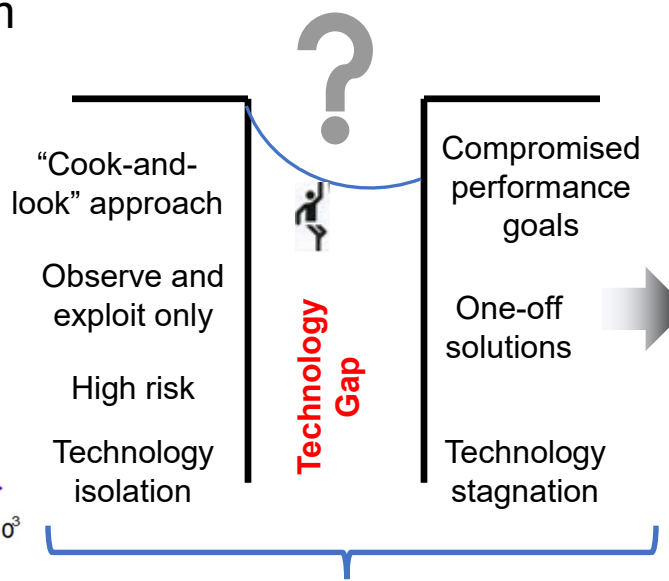
Transformative: enabling discovery science, national security missions

The problem: Performance-Lifetime limitation
Our innovation: Decouple the limitation by 2D materials

Current status & problem



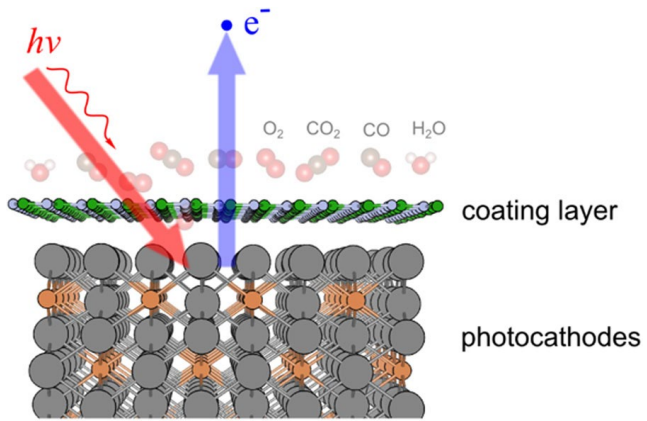
Bridging the technology gap



Present approaches do not depart from historical methods

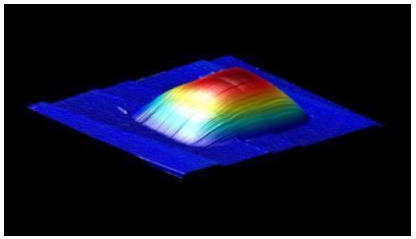
Our idea

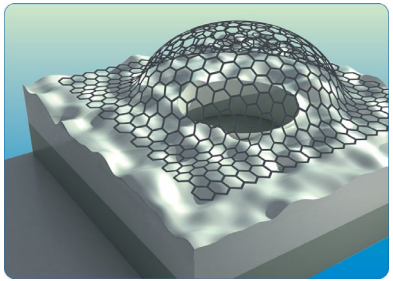
N.A.Moody *US patent 8,823,259* (2014)



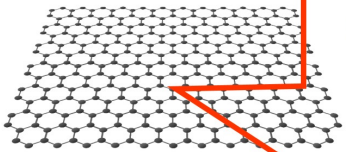
G.Wang and N.Moody et al.
npj 2D Materials and Applications 17 (2018)

Why 2D materials & our team expertise

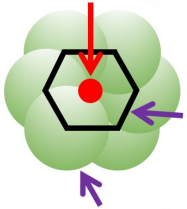




Discovered in *2004*



Geometric pore 0.64 Å

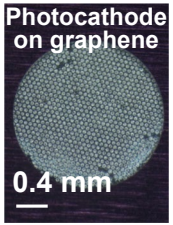


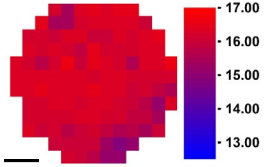
Bond length (C-C) 1.42 Å

van der Waals radius of carbon atom 1.10 Å

- **Impermeable to gases**
- **High material stability**
- **Allows electron transmission**

2D materials (U.S.)

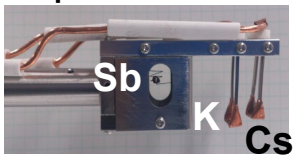


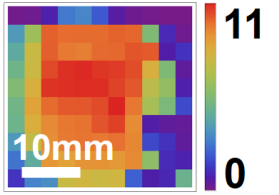


K_2CsSb/Gr in vacuum tube

Bialkali (Japan)

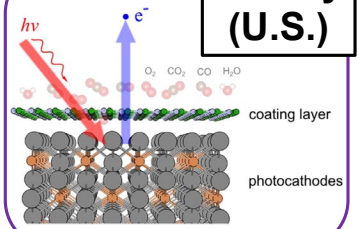
Evaporation sources



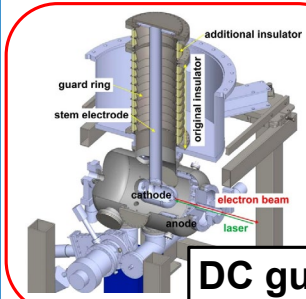


K_2CsSb/Mo in vacuum chamber

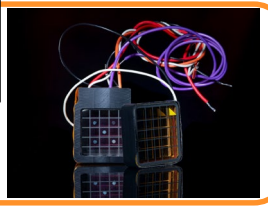
Theory (U.S.)



DC gun (Japan)

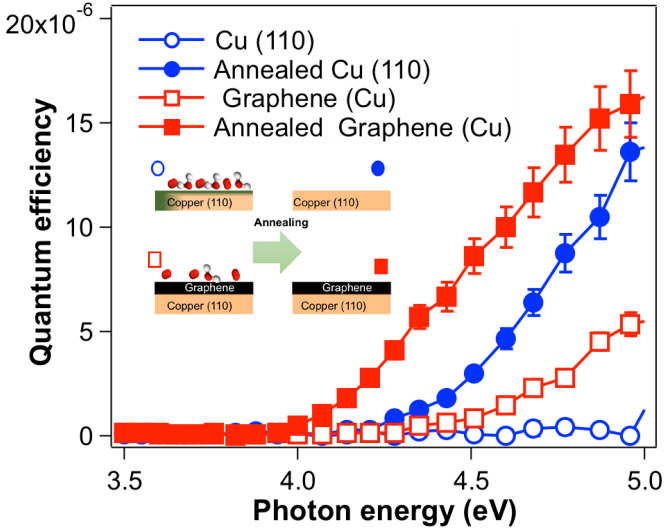


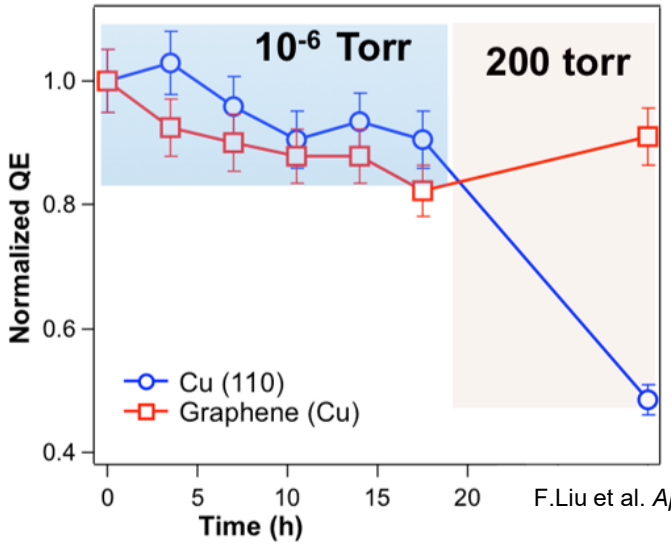
Bialkali in vacuum tubes (U.S.)



US-Japan team working together under DOE-KEK funding

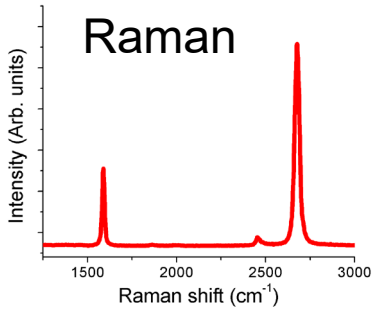
Experimental demonstration of our concept on metal photocathodes

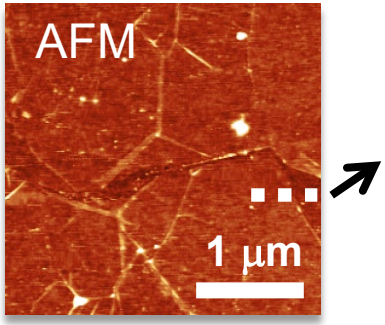


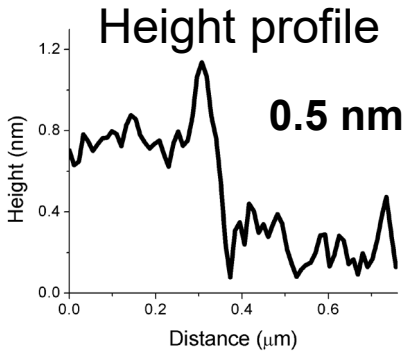


F.Liu et al. *Appl. Phys. Lett.* (2017)

- Successful **electron transmission** through graphene
- **8 orders of magnitude** improvement in operating pressure

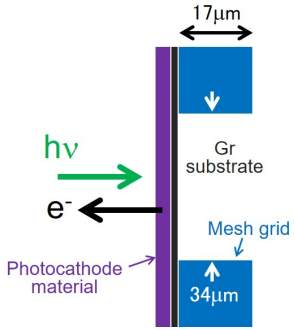




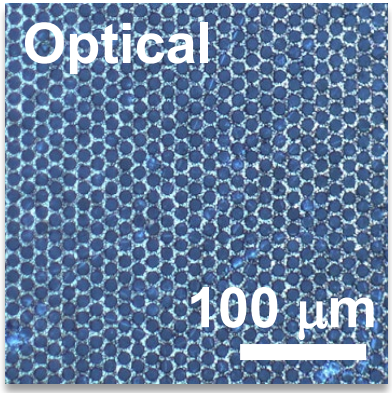


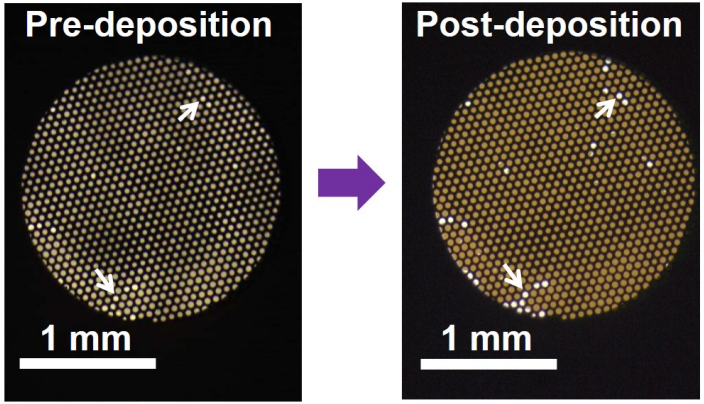
- High crystal quality graphene
- Uniform & atomically thin graphene

Milestone #1: Demonstration of material compatibility between 2D materials and bialkali photocathodes

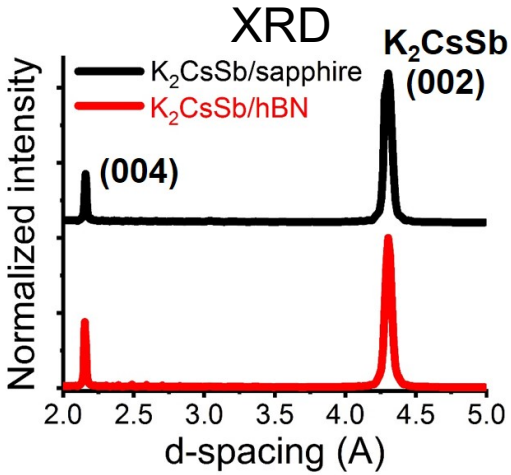


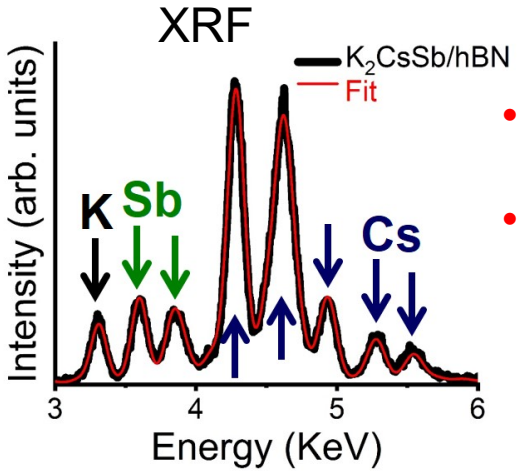
N.A.Moody, H.Yamaguchi et al.
US Patent 10,535,486 (2020)





H.Yamaguchi et al. *npj 2D Materials and Applications* (2017)

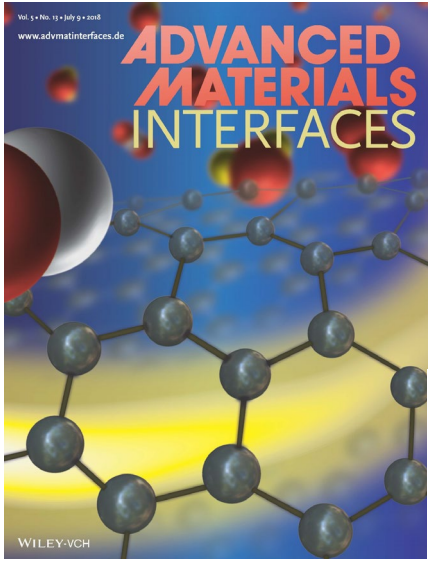


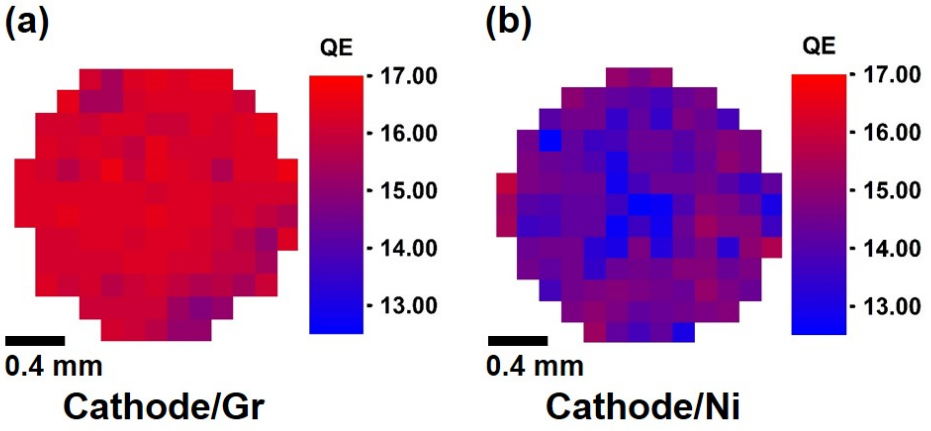


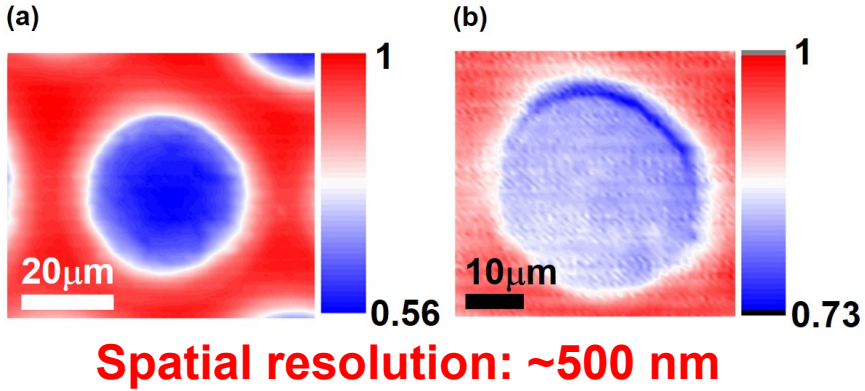
- **High crystallinity** achieved on 2D material (XRD)
- **Nearly ideal stoichiometry** of $K_{1.85}Cs_{1.08}Sb$ achieved on 2D material (XRF)

H.Yamaguchi et al. *phys. stat. solidi (a)* (2019)

High spatial resolution maps with high QE and uniformity



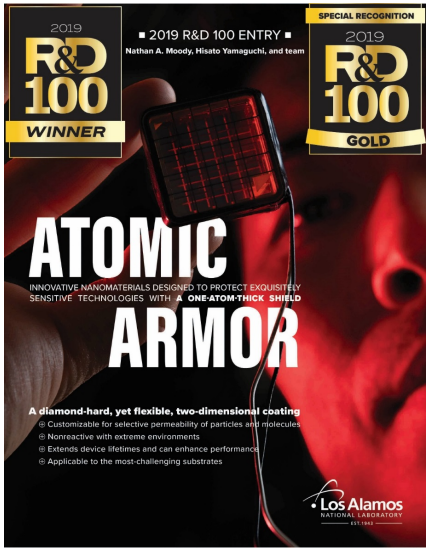


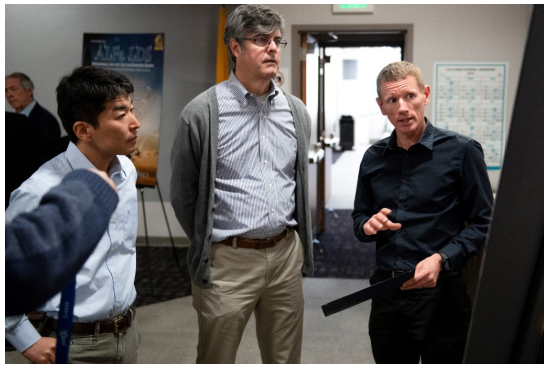


Spatial resolution: ~500 nm

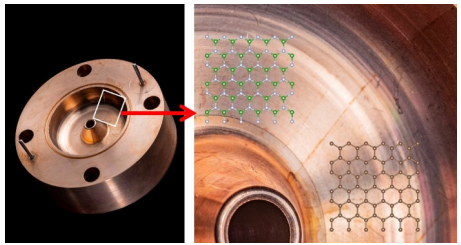
H.Yamaguchi et al. *Advanced Materials Interfaces* (2018)

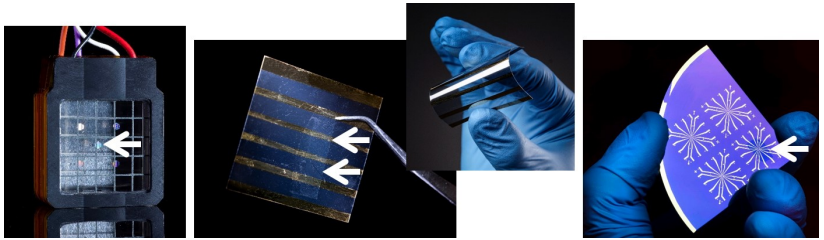
Recognition of our work: R&D 100 Award in 2019

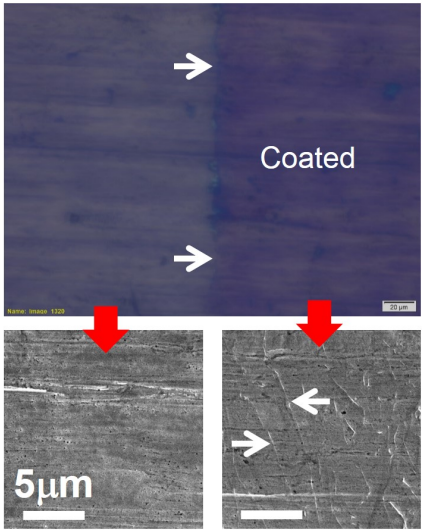




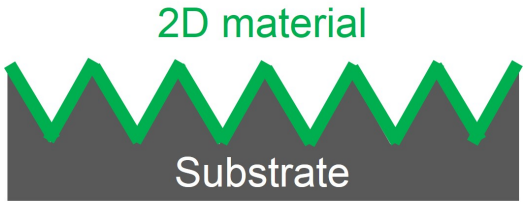
Coating of surfaces with ***macro-scale roughness***





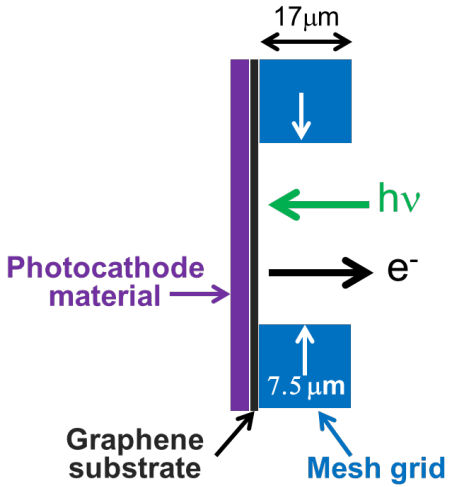


Coating of surfaces with ***micro-scale roughness*** (e.g. rolled stainless steel)



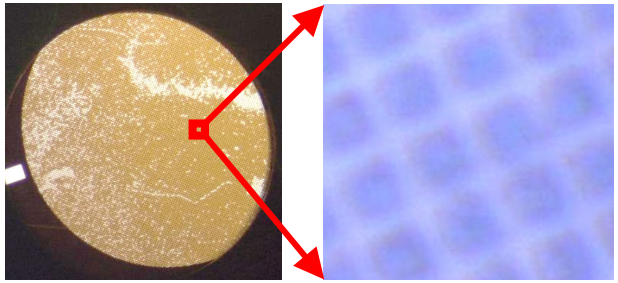
Special recognition Market Disruptor - Products

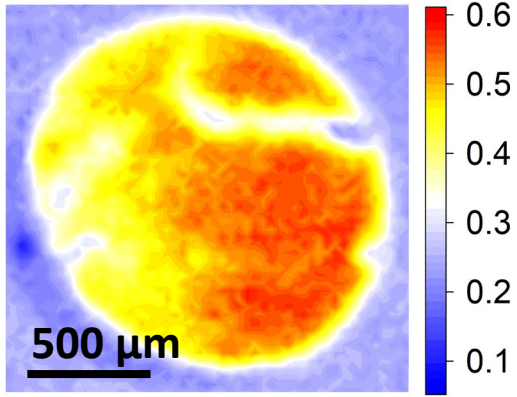
Milestone #2 (achieved recently): QE maps of K_2CsSb through graphene coating

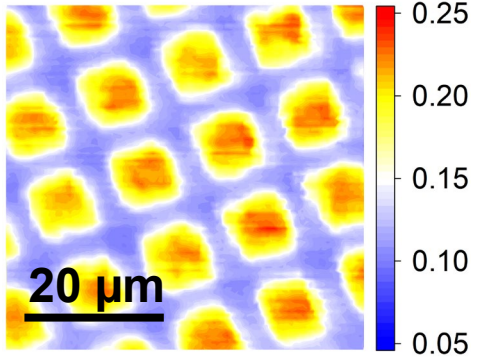


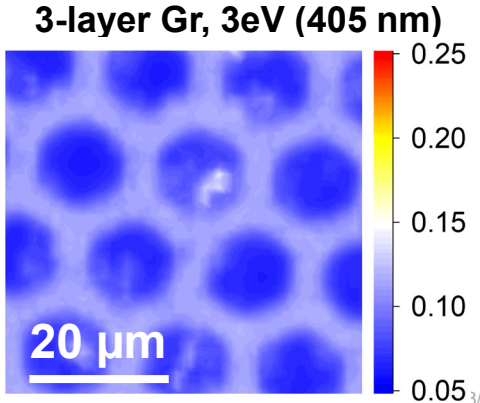
First ever **QE of bialkali photocathodes through graphene coating** demonstrated

Quantum efficiency (%) map through graphene





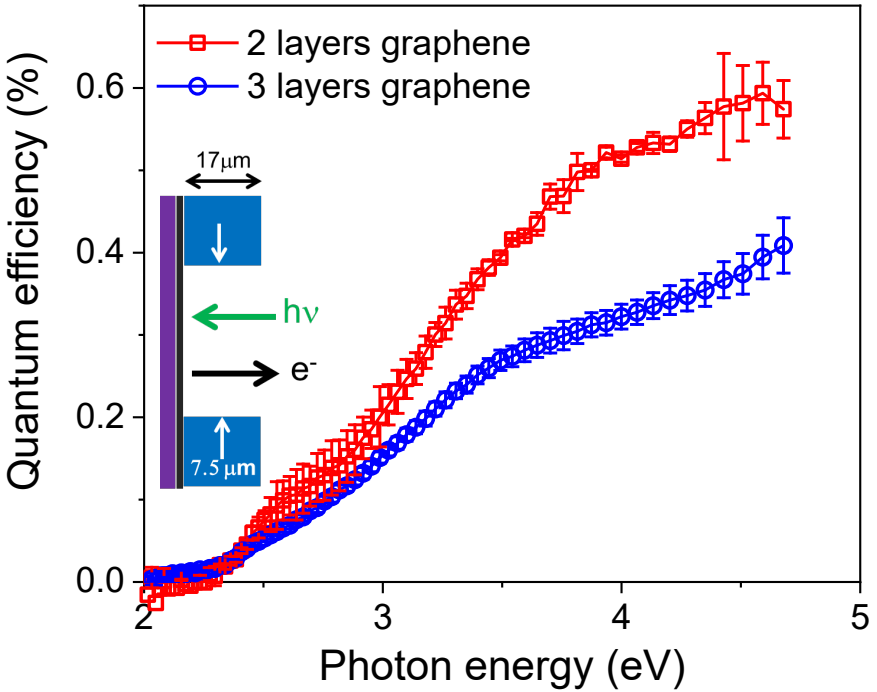




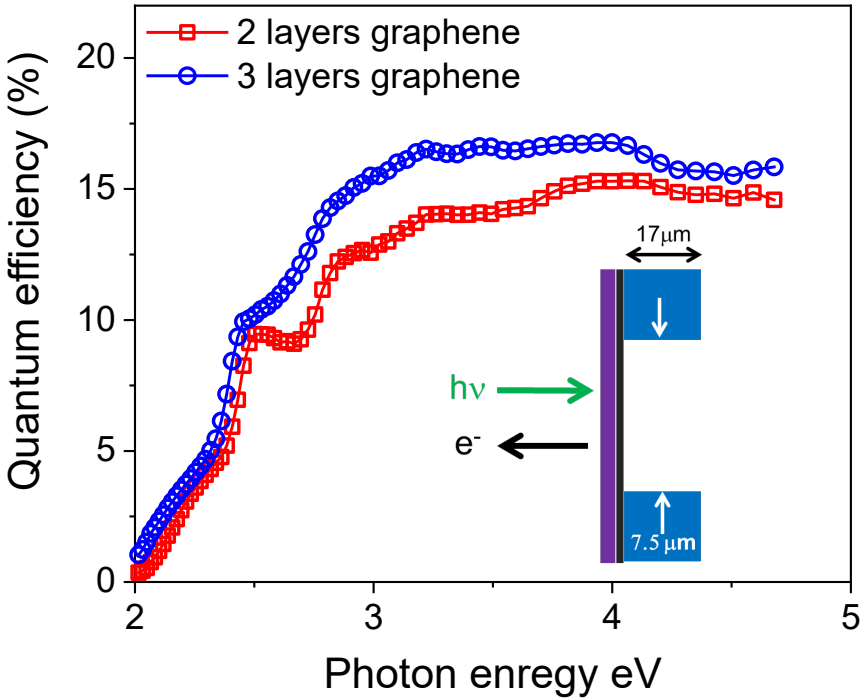
Submitted

Spectral QE of K_2CsSb photocathodes through graphene coating

QE through graphene coating

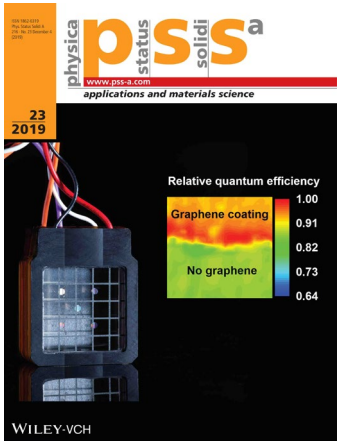


QE without graphene coating

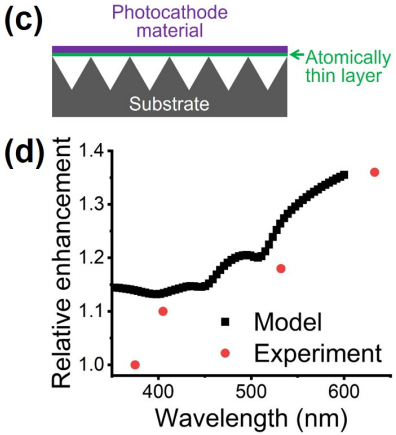


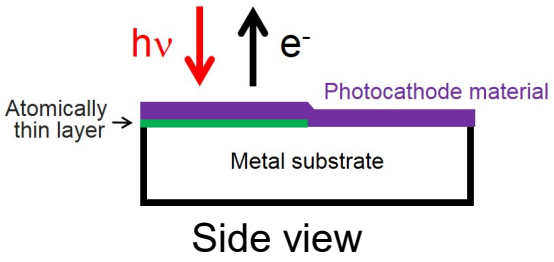
Submitted

Unexpected finding #1: QE enhancement of bialkali photocathodes by coating metal substrates with graphene

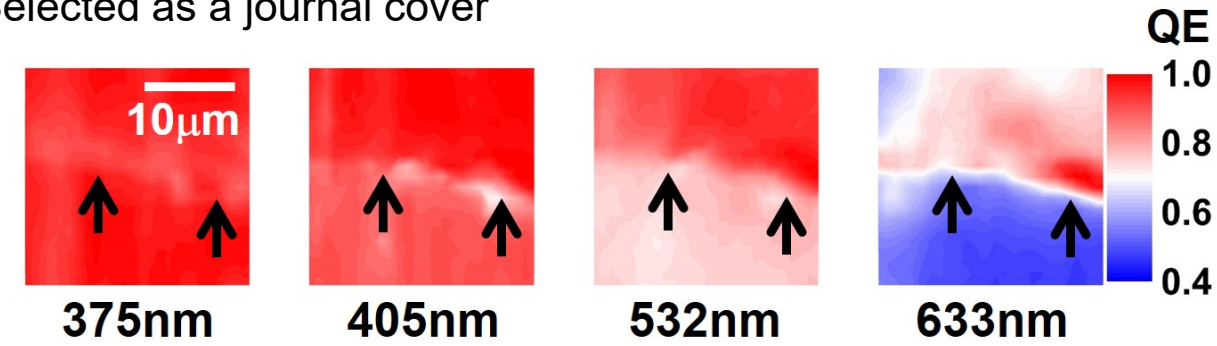


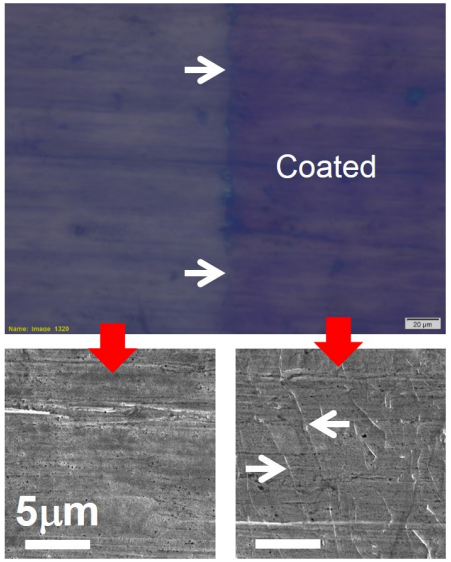
Enhanced mirroring effect





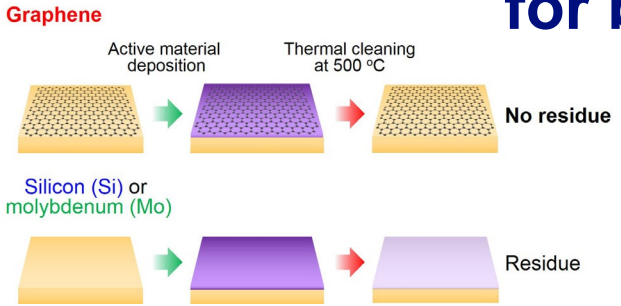
Selected as a journal cover





H. Yamaguchi et al. *phys. stat. solidi (a)* (2019)

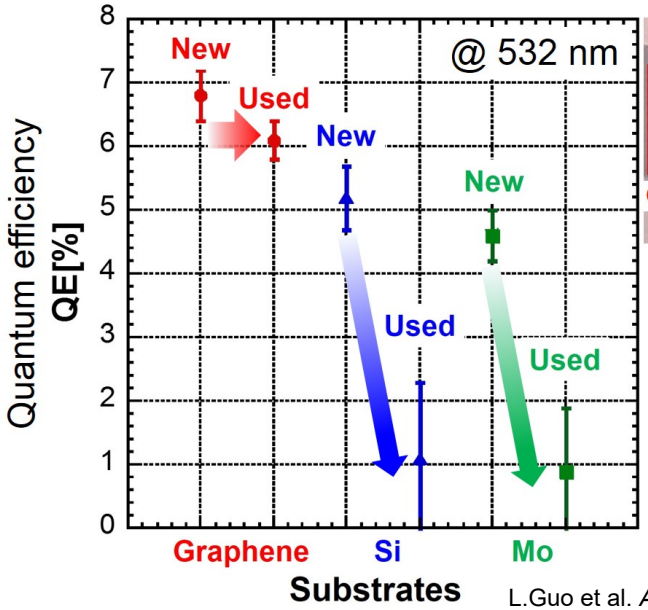
Unexpected finding #2: Graphene as reusable substrate for bialkli photocathodes

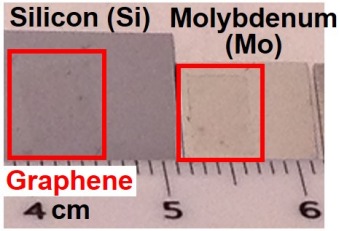


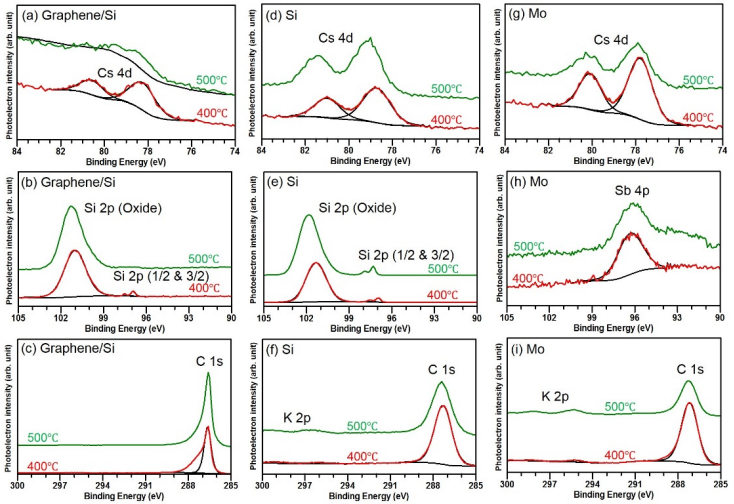
On other substrates

On graphene

News released







No detectable photocathode residue on graphene by X-ray photoelectron spectroscopy

L.Guo et al. *Appl. Phys. Lett.* (2020)

Summary

- Patent granted for our concept in the U.S. (2014)
- Successful demonstration of our concept on metal photocathodes published in *Applied Physics Letters* (2017)
- Successful demonstration of material compatibility between bialkali photocathodes and 2D materials published in *nature partner journals 2D Materials and Applications* (2017)
- Successful demonstration of high QE (17 % at its peak) from bialkali photocathodes deposited on 2D materials published in *Advanced Materials Interfaces* (2018)
- Our technology won R&D 100 Award (2019)
- Successful demonstration of 2D materials as QE enhancer for bialkali photocathodes published in *physica status solidi (a)* (2019)
- Successful demonstration of 2D materials as reusable substrates for bilalkali photocathodes published in *Applied Physics Letters* (2020)
- Successful demonstration of QE from bialkali photocathodes through graphene protection layers submitted (2021)

Collaborators

External

Jeff DeFazio (Photonis)
Kevin Jensen (NRL)
Mengjia Gaowei (BNL)
Lei Guo (Nagoya Univ., Japan)
Masahiro Yamamoto (KEK, Japan)

Internal

Nathan Moody
Fangze Liu (now in China)
Vitaly Pavlenko
John Smedley
Gaoxue Wang
Enrique Batista
Ping Yang
John Lewellen (now at SLAC)

Funding

External

Internal