Innovations for a Sustainable Tomorrow

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Green-Light-Driven Multi-Alkali Photocathodes For Sustainable Electron Accelerators

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Photoinjector-based accelerators depend on photocathodes to convert laser photons into high-quality electron beams. Conventional metal cathodes typically require ultraviolet drive lasers and operate at low quantum efficiency, increasing laser-system complexity and electrical demand. Green-light-sensitive alkali and multi-alkali photocathodes offer an alternative by enabling efficient photoemission at visible wavelengths, where compact Yb-fibre laser systems can operate with fewer frequency-conversion stages. Their high quantum efficiency reduce the photon flux required for a given beam charge, while low intrinsic emittance delivers high beam brightness at the source. However, sustainable operation depends not only on initial QE but also on charge lifetime under realistic operatinal vacuum and extraction conditions. Improving both efficiency and durability could establish green photocathodes as a key technology for lower-energy, high-brightness electron injectors.

Introduction

Photocathodes are transducers that converts light into electrons with some quantum efficiency (QE , $\eta < 1$) [1]. These have multiple applications with in industry for light sensing and are a crucial technology in particle accelerators to generate ultra-short electron pulses. Conventional metal cathodes often require UV lasers and have low QE, increasing laser complexity and power demand. Green-sensitive alkali and multi-alkali photocathodes offer high-QE visible-light emission, improving optical efficiency, beam brightness, and overall injector design [1,2]. Integrated with optimised laser, RF-gun, and beam-transport systems, they could support more energy-efficient accelerators for scientific, medical, and industrial use.

Drive Laser : From Wall Plug to Electron Beam

- Drive laser delivers photons to cathode for required bunch charge.
- The UV route is technically demanding; Cu and Cs_2Te operation near 266 nm requires lossy harmonic conversion from Ti:sapphire or Nd:YAG/Nd:YVO_4 laser systems [3].
- The green route is preferable; Yb-fibre lasers operate near 1030 nm and reaches 515 nm with a single frequency-doubling stage [3, 4].
- A 1030 nm Yb-fibre laser can be doubled to 515 nm, where NaK_2Sb-based cathodes can reach QE values up to ~20% [5].
- The main advantage is system-level simplification; visible-light photocathodes allow efficient Yb-fibre laser technology to replace more complex UV conversion chains [6-8].

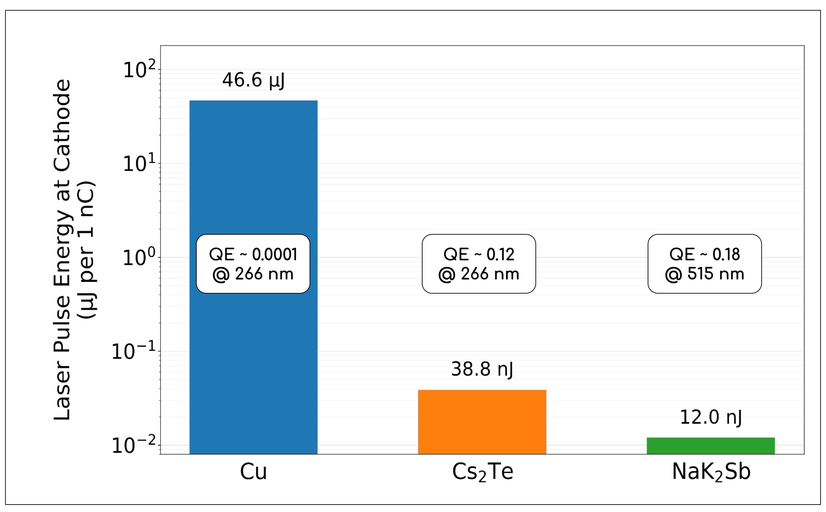

Fig 1: Optical pulse energy needed to extract 1 nC at the photocathode is discussed. High-QE alkali-antimonide cathodes use less energy than UV-driven copper.

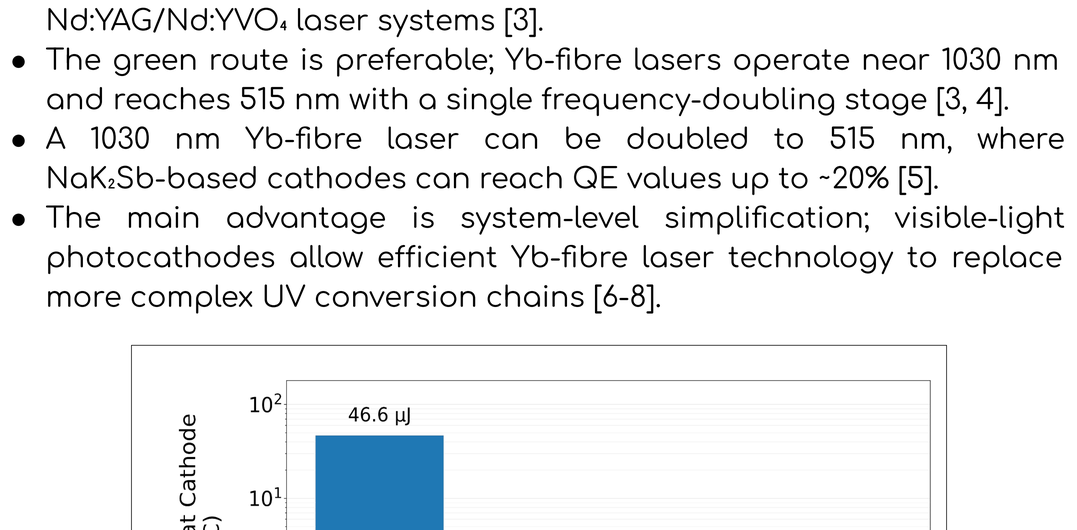

Fig 2: Top: UV Ti:Sapphire route to 266 nm with multiple conversion stages. **Bottom:** green Yb-fibre route to 515 nm with a simpler single-doubling scheme [12,13].

Operational Lifetime: Beyond Initial QE

- Stable QE is preferable for sustainable and efficient accelerator operation.
- QE degrades due to several reasons such residual gas, laser heating, ion back-bombardment, and charge extraction reduce performance over time [10].
- As the QE degrades more photons are needed to deliver the target bunch charge.
- Charge lifetime, $Q_{1/e}$, is the total extracted charge at which the photocathode QE has fallen to QE_0/e, or 36.8% of its initial value [9].
- Extending the lifetime of NaK_2Sb and K_2CsSb could make green multi-alkali cathodes standout sustainable electron sources [5,9,11].

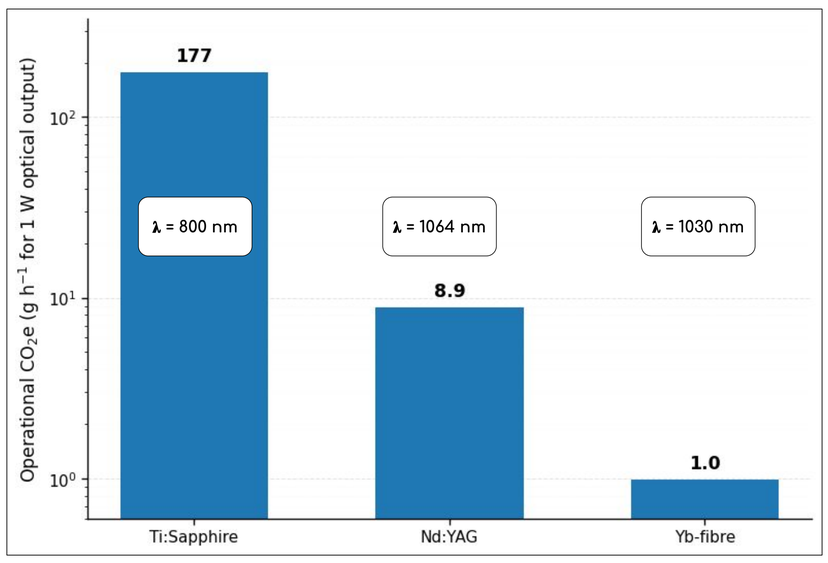

Fig 3: Yb-fibre lasers show the lowest operational CO_2e per watt of optical output, reflecting their much higher wall-plug efficiency [6-8].

Conclusion

Green multi-alkali photocathodes offer a promising route towards more sustainable electron accelerators by enabling high-QE photoemission with visible green light. When paired with efficient Yb-fibre laser systems, they can reduce photon demand at the cathode and simplify wavelength conversion compared with conventional UV-driven routes. However, their practical value depends not only on high initial QE, but also on maintaining performance during operation. Extending the charge lifetime, $Q_{1/e}$, of materials such as NaK_2Sb and K_2CsSb could make them standout photocathodes for sustainable, high-brightness electron sources in future accelerator facilities.

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