

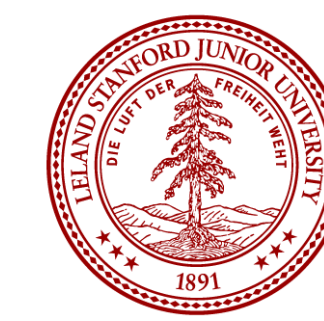
Photo-electronic Enhancement of Thermionic Emission

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Existing Solar Technology

Photovoltaics use the quantum nature of light to generate electron/hole pairs in a semiconductor. Photons with energy less than the bandgap are not absorbed (absorptive losses). A fixed amount of energy from each photon can be harvested, so excess energy from the photon is lost as heat (thermalization losses).
Solar Thermal systems convert concentrated high grade 5800° C sunlight into low grade 600° C heat.

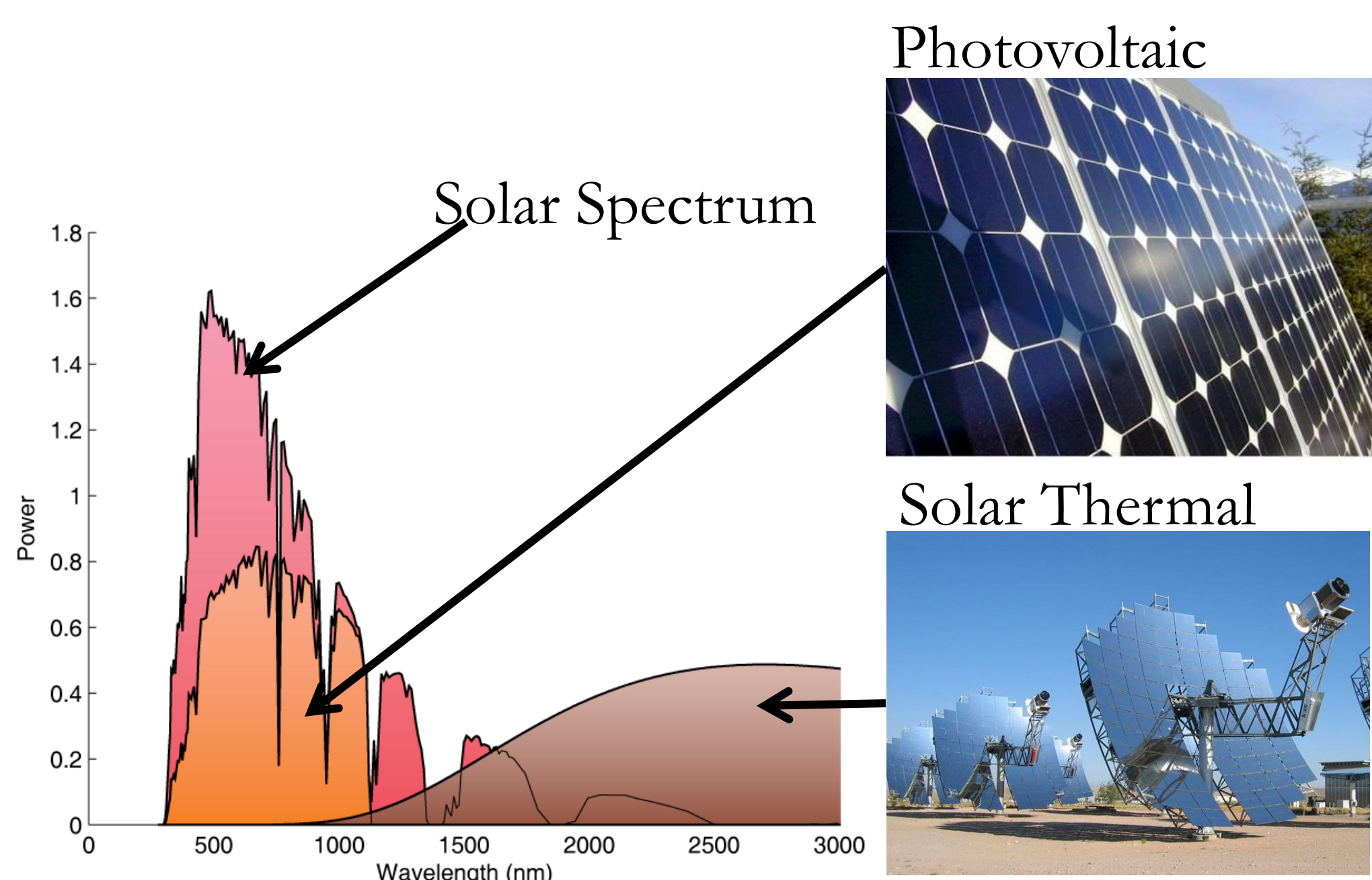
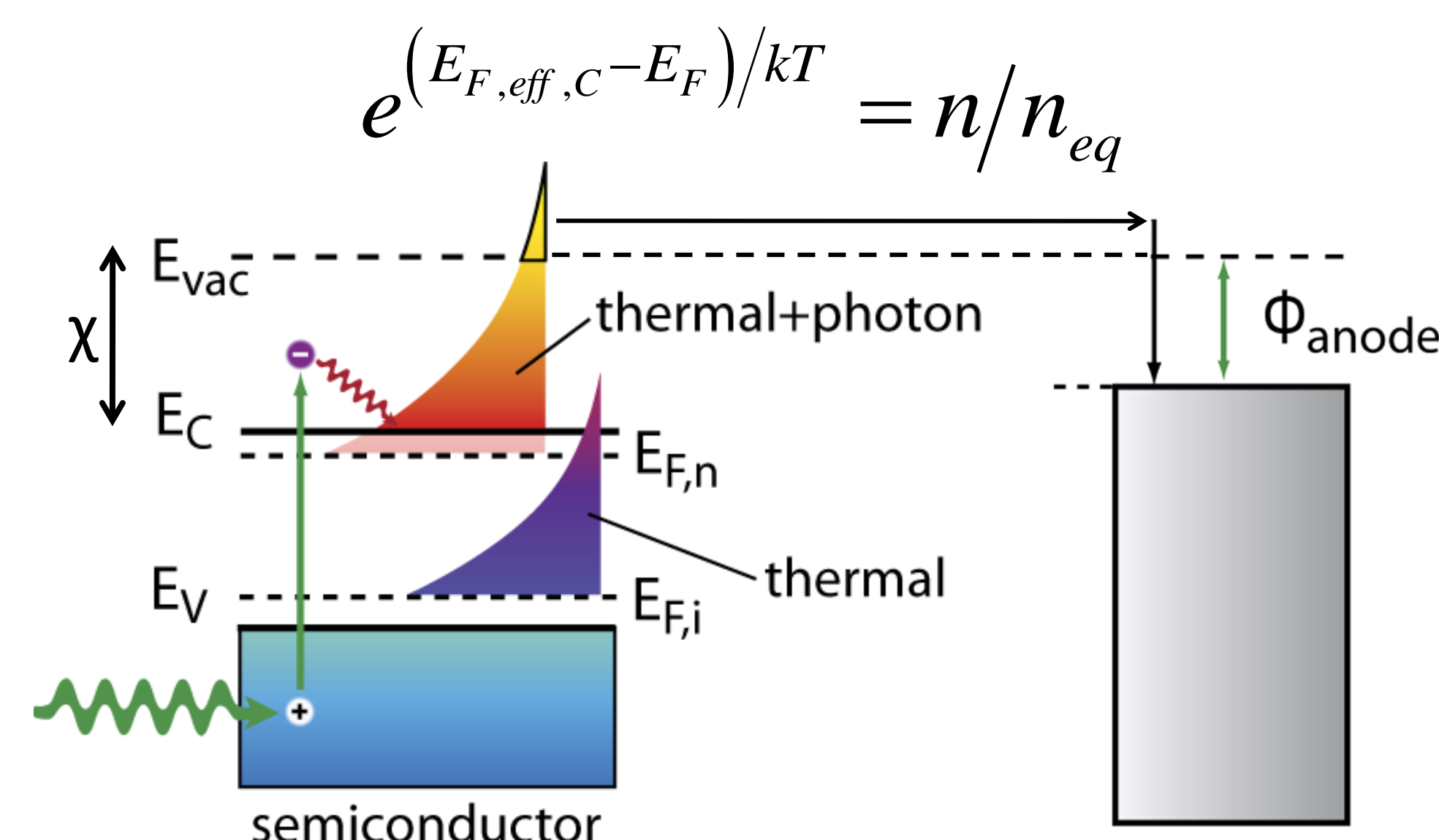


Photo-electronic Enhancement of Thermionic Emission

In the PETE scheme carriers are excited into the conduction band of a semiconductor and thermionically emitted. The emission current can be described in terms of an effective fermi level or in terms of the carrier population.

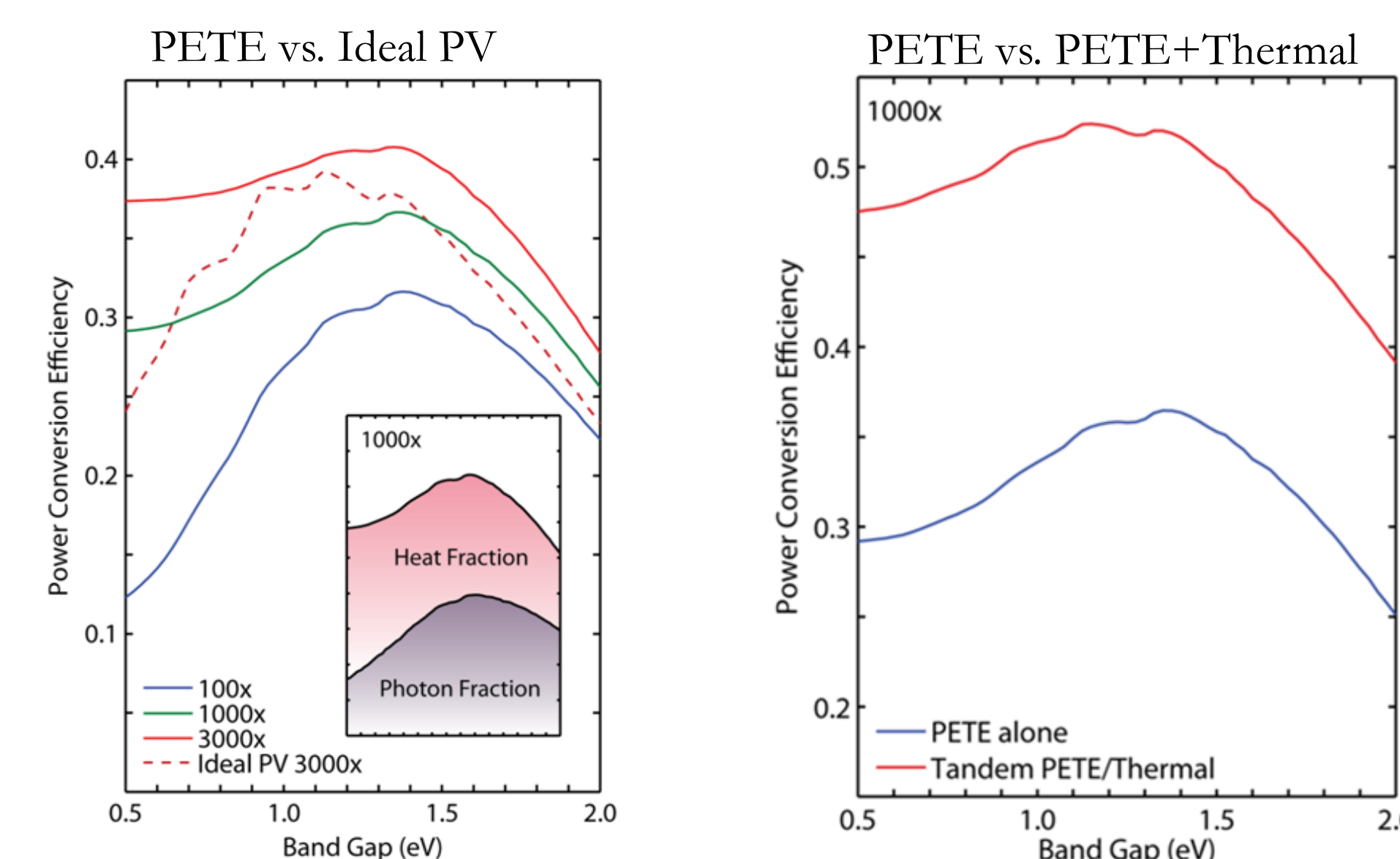
$$J_{PETE} = A * T^2 e^{-\phi_{eff}/kT} = \frac{1}{4} q_e n \langle v \rangle e^{-\chi/kT}$$

Photoexcitation boosts the thermionic emission current over the equilibrium level by a factor of the exponential of the difference of the equilibrium and effective fermi levels.



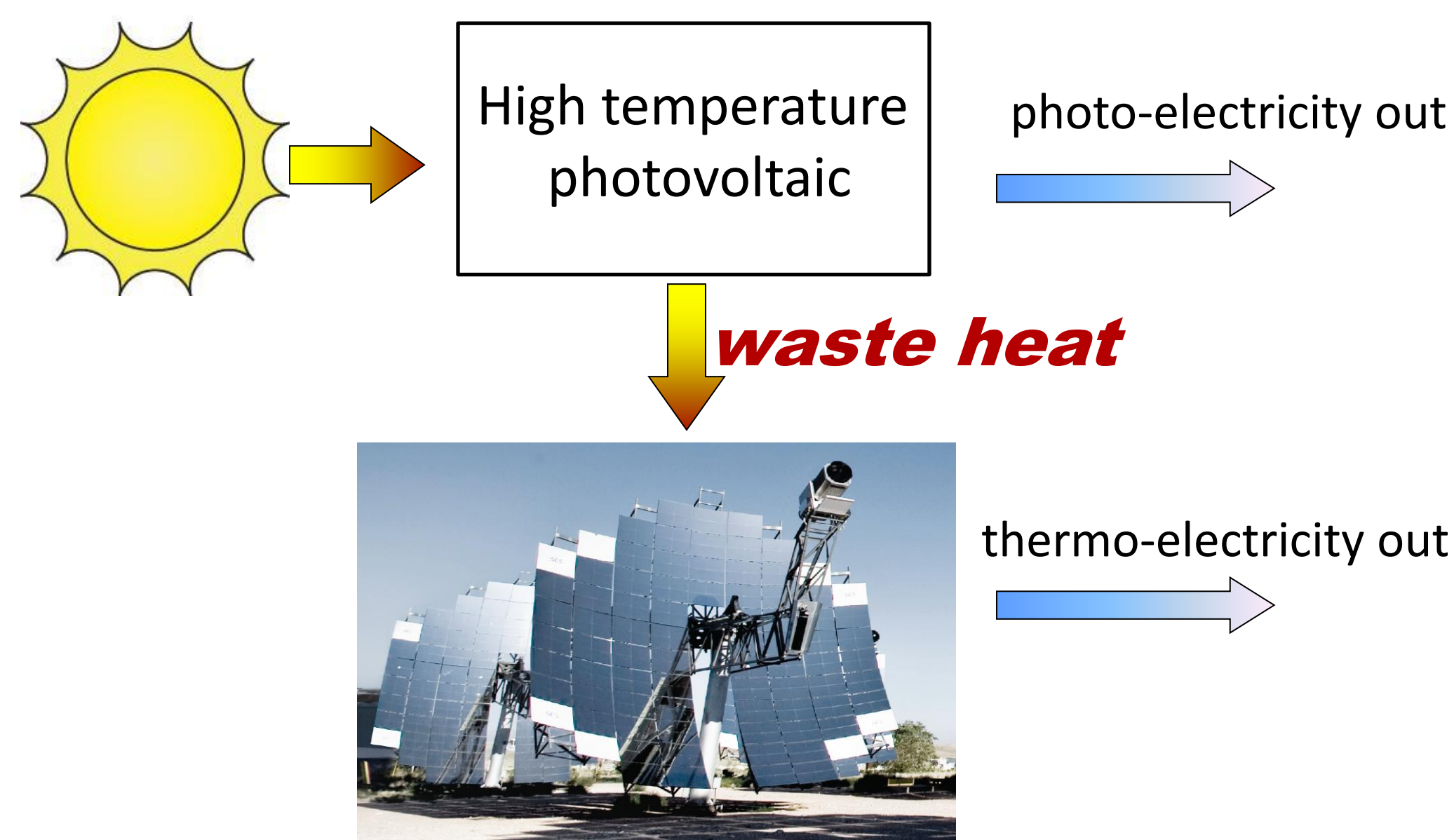
Theoretical Device Performance

Simulations have been created to model the performance of a PETE device. Every photon with energy greater than the bandgap is absorbed and creates one electron/hole pair, while sub-bandgap photons are absorbed as heat. Black body radiation losses and transfer, as well as radiative and Auger recombination losses are included. The device efficiency for a given bandgap is maximized for the cathode temperature and electron affinity. **A PETE device combined with solar thermal could have efficiencies >50%!**



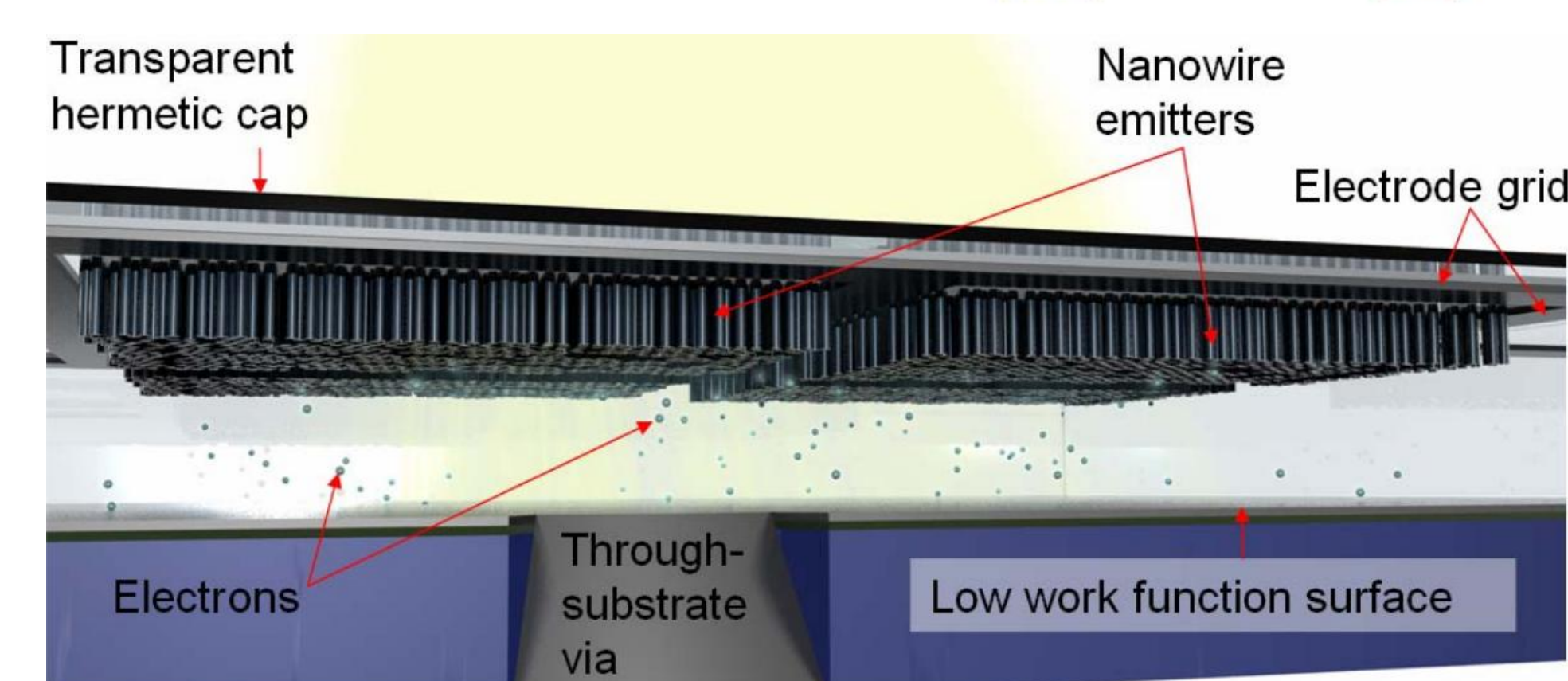
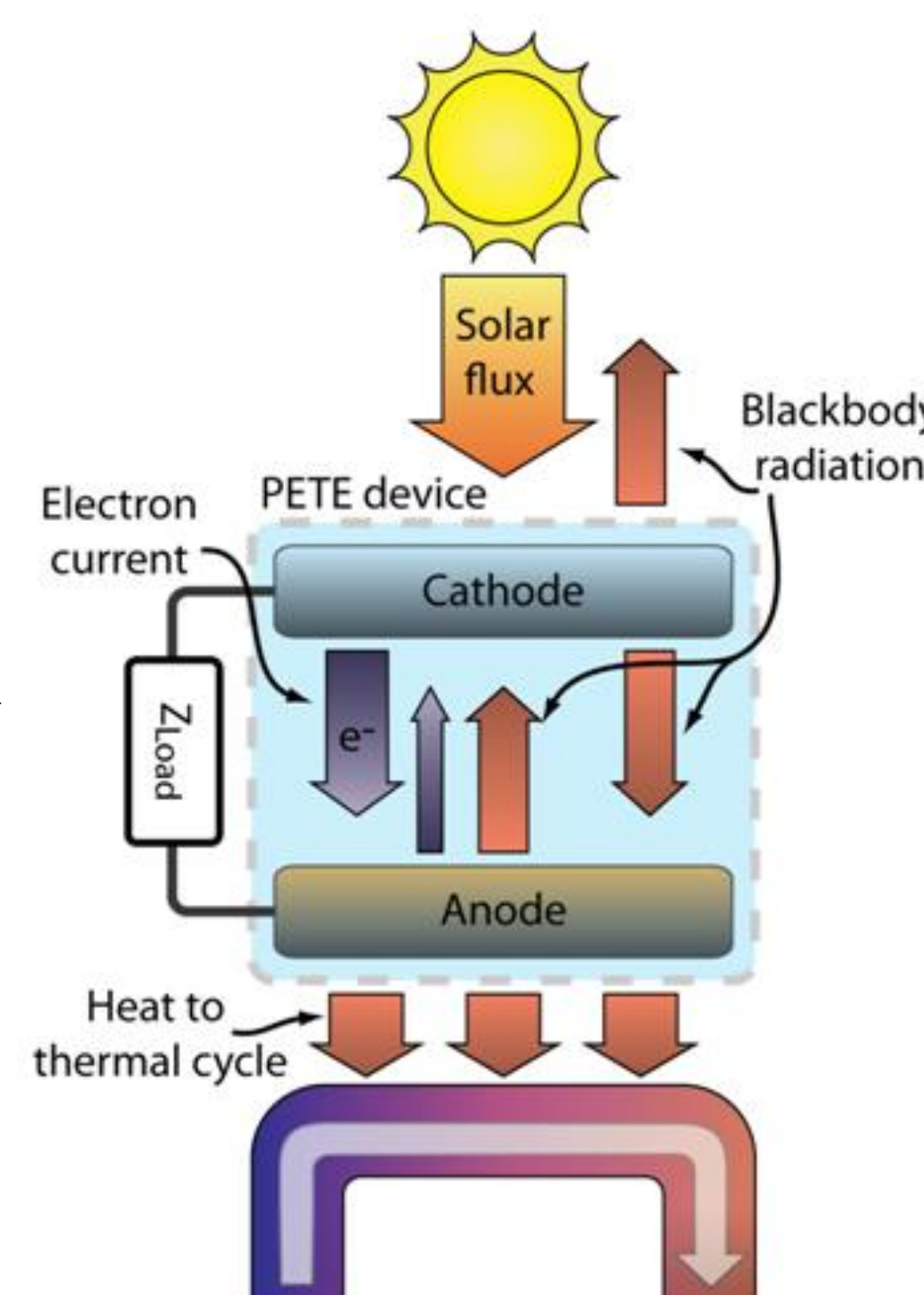
Major Opportunity: Combined Cycles

A PV topping cycle could take advantage of the quantum nature of light, while the solar thermal system could generate power from the waste heat. This has not been done because high temperatures significantly decrease PV performance. A 20% efficient topping cycle could increase the performance of a solar thermal system by 60%.



PETE Device

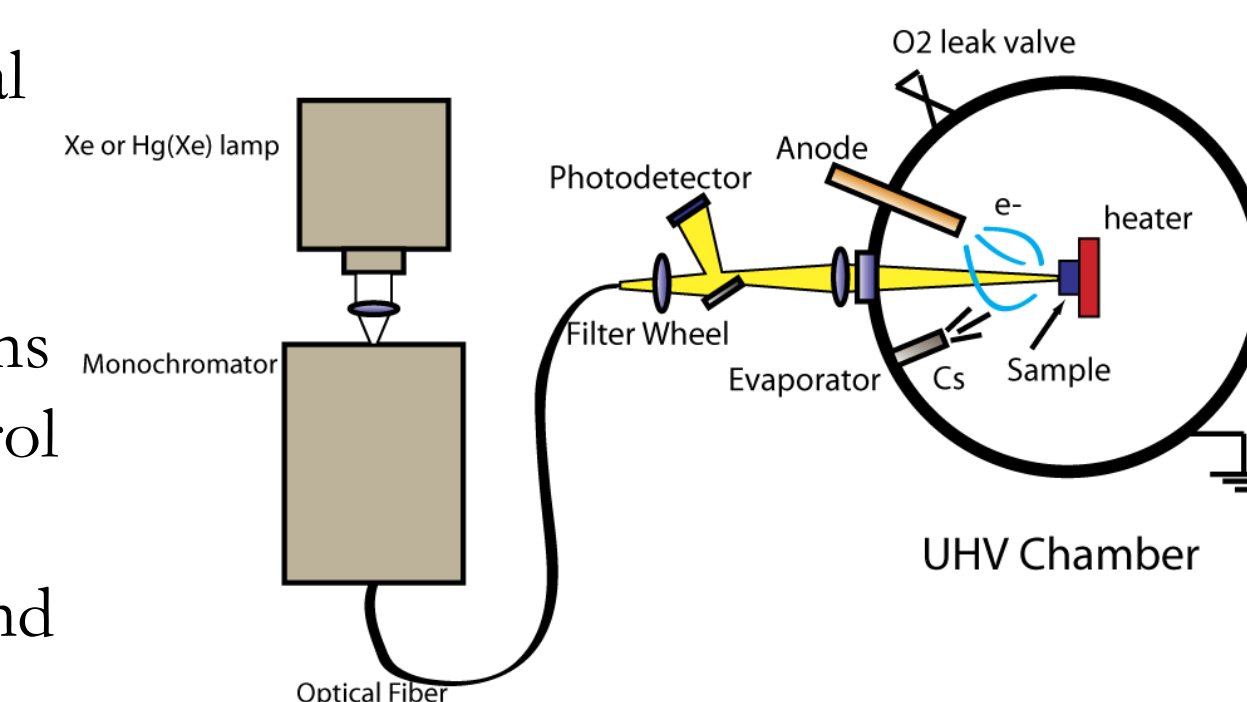
A PETE device would consist of a semiconducting cathode and a metal anode separated by a small vacuum gap, both having low work functions to allow significant emission from the cathode and to minimize thermalization losses in the anode. Heat from thermalization and absorptive losses is used to thermionically emit carriers, and is also used by a thermal cycle attached to the anode. The cathode surface may be textured, or coated with nanowires or nanocones to enhance emission.



Experimental Tests

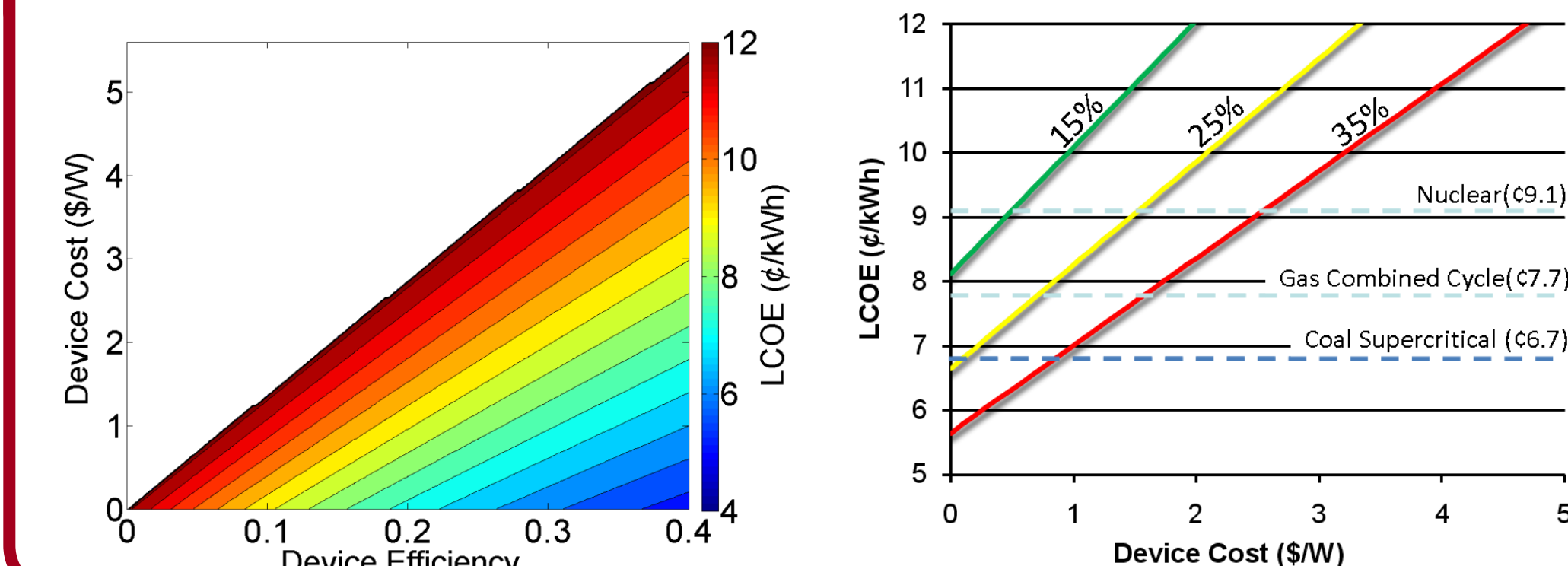
Capabilities:

- Frequency resolved optical excitation (solar)
- Collection and energy analysis of emitted electrons
- Sample temperature control
- Coating deposition of materials such as Cs, Ba, and SR
- LEED
- Reflectivity measurements



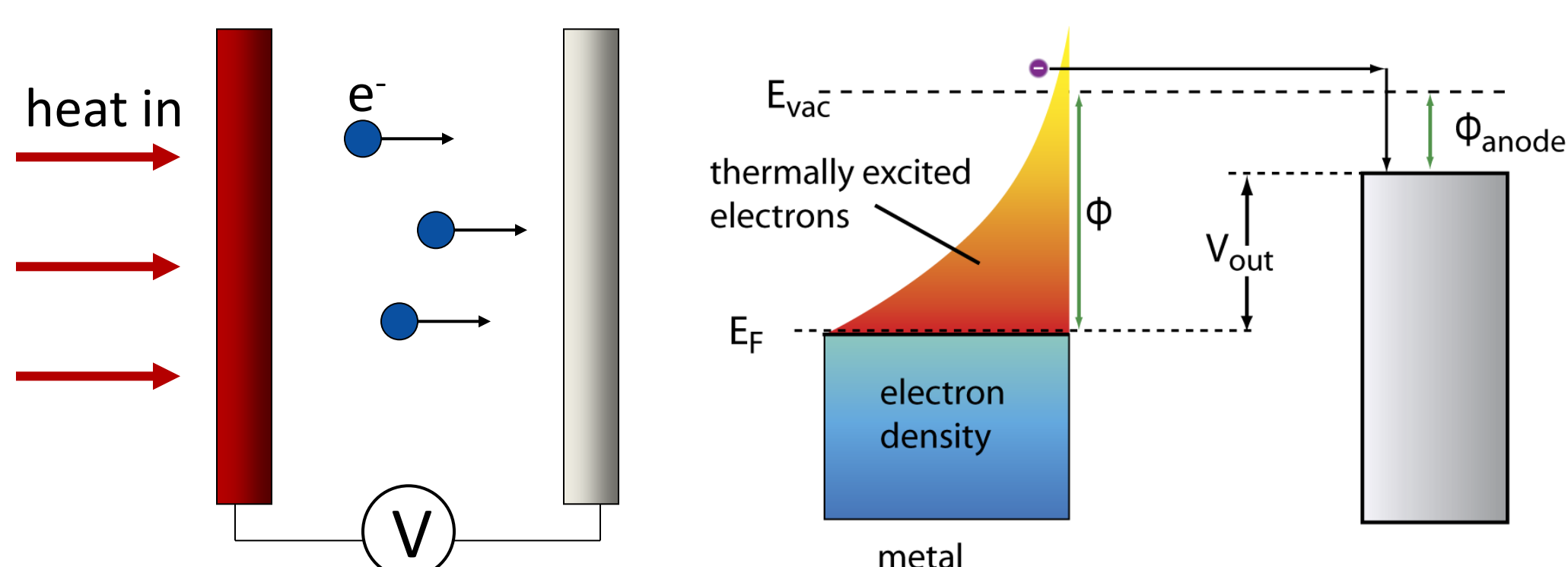
Real World Impact

We modeled the LCOE of a 100 MW SunCatcher parabolic dish array equipped with PETE using the Solar Advisor Module developed at NREL. A PETE equipped solar thermal plant has the potential to produce electricity more cheaply than nuclear, gas, or potentially even coal.

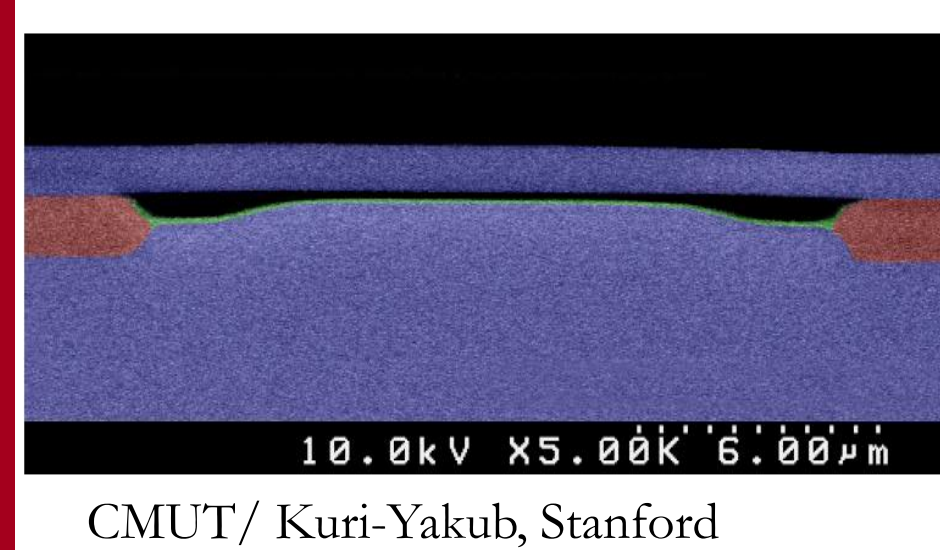


Thermionic Emission

When a material is heated, electrons with high kinetic energy can escape into vacuum, a process called thermionic emission. This process has been explored in the past to generate electricity. Electrons emit from a high temperature cathode and are collected by a lower temperature anode, ideally yielding a voltage of the difference in electrode work functions. Because of achievable material work functions, thermionic emission for energy conversion faces challenges such as very high operating temperatures, low output voltages, and space charge due to high current densities.



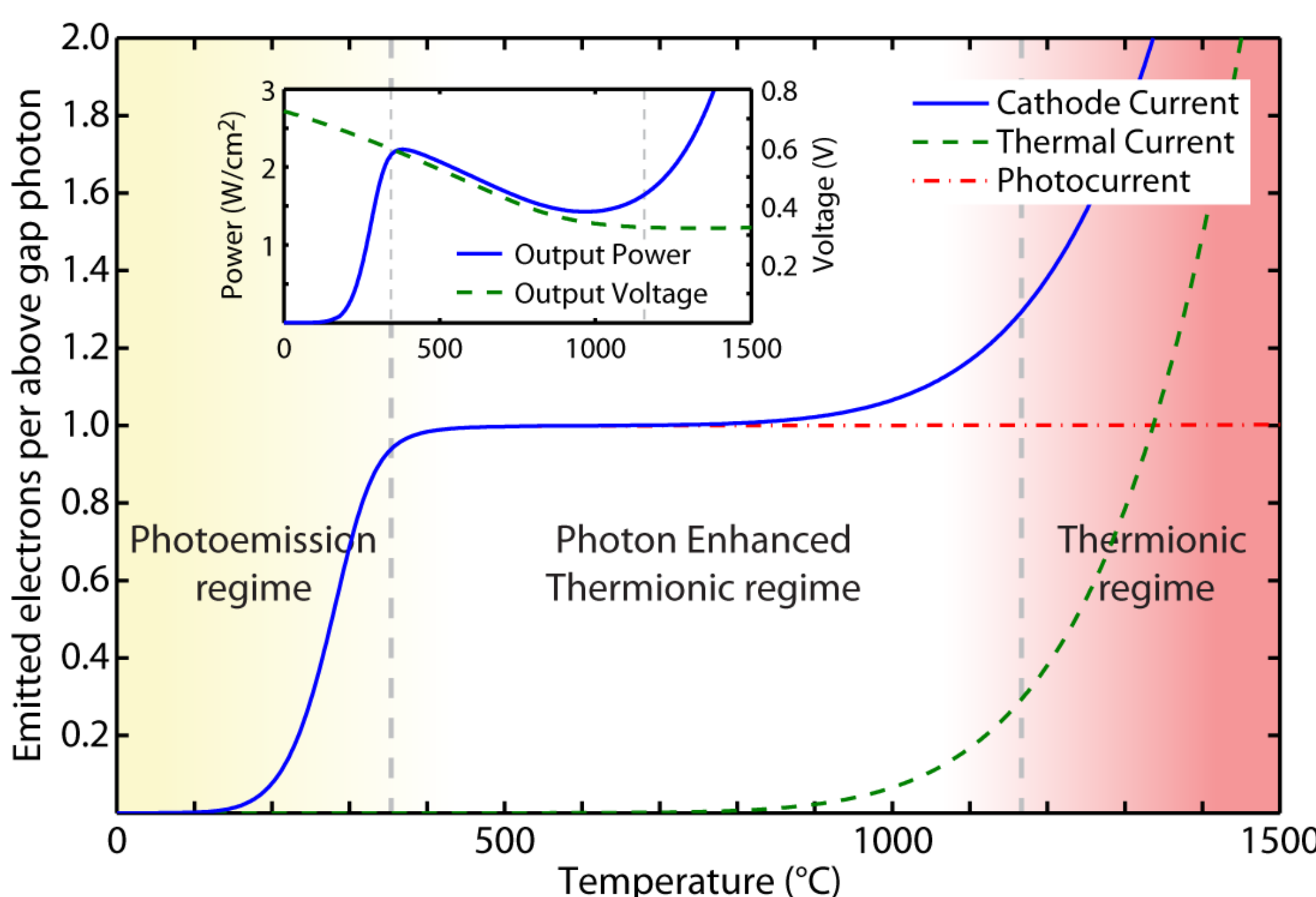
Thermionic emission warrants a revisit with new tools and techniques enabled by advances in nanofabrication and refractory semiconductor processes, including nanomaterials to enhance photon absorption and electron emission and nanogap MEMS devices to reduce space-charge with wafer-bonded vacuum encapsulation.



We believe that combining thermionic emission with photoexcitation will allow the creation of a highly efficient device that can act as a solar thermal topping cycle. → PETE

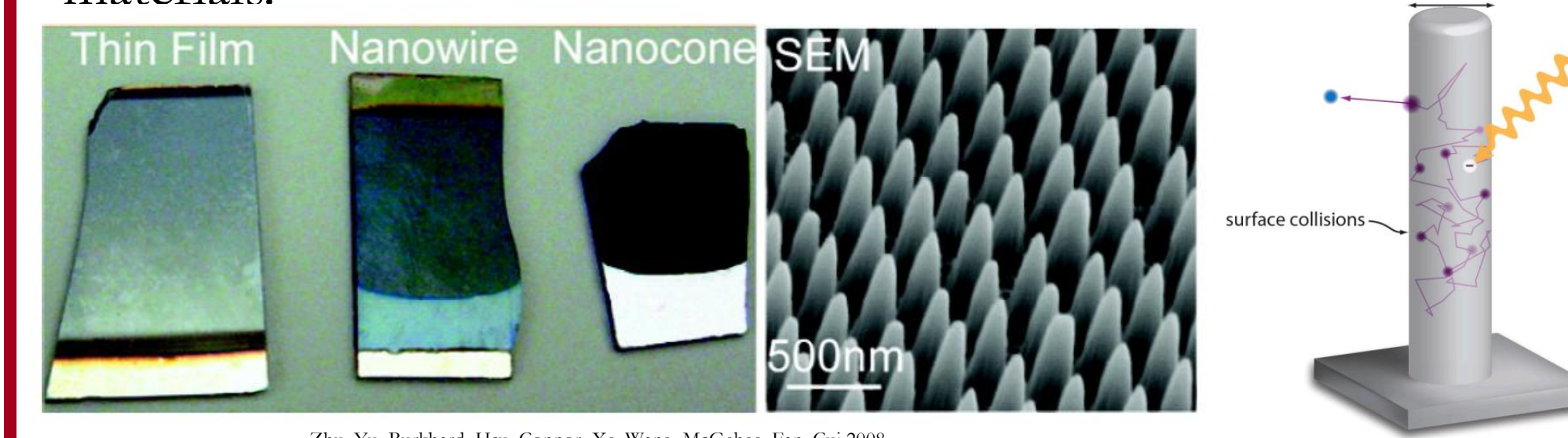
Regimes of Electron Emission

- **Photoemission regime** - electrons must escape prior to thermalization.
- **PETE regime** - electrons must escape prior to recombination. This regime has not been explored, because of lack of necessity.
- **Thermionic regime** - Little benefit from photoexcitation due to the high thermal carrier concentrations.



Future Research Directions

- Demonstrate enhanced emission at elevated temperatures, i.e. the PETE effect.
- Achieve high photoemission yield through nanoengineering. Nanomaterials can increase absorption and are predicted to decouple the electron escape length from the absorption length.
- Identify temperature stable surface coatings and excellent cathode materials.



Acknowledgements

