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Surface photovoltage study of perovskite materials and structures for solar cell applications

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Background:

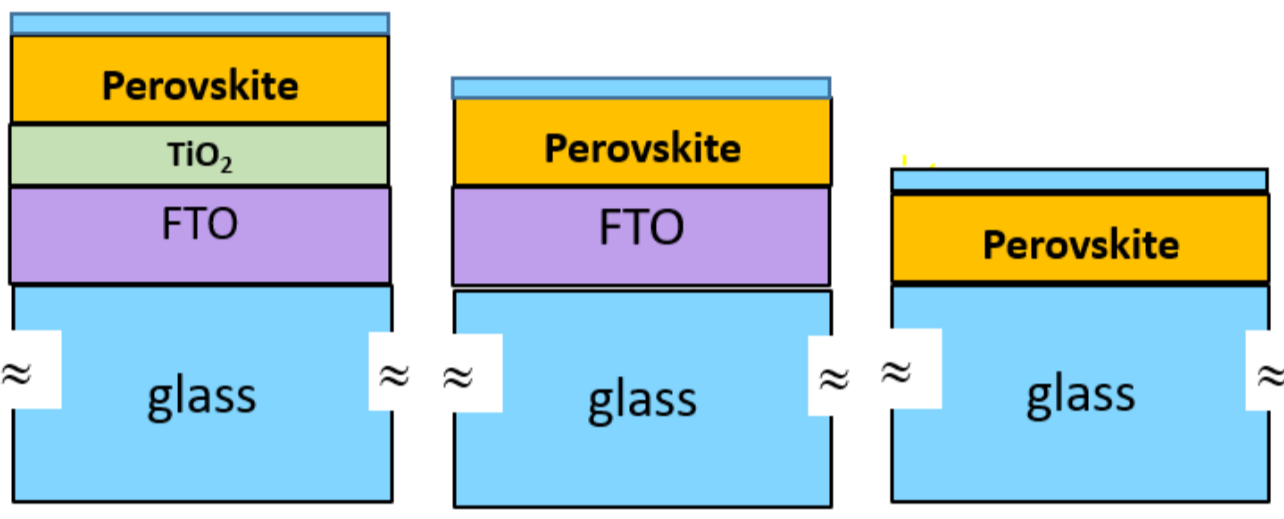
- Perovskites (PSK) are considered as a perspective material for the 4th generation solar cells because of their tunable bandgap around 1.6 eV via compositional engineering, high absorption coefficient and steep absorption edge.
- The power conversion efficiency of PSK solar cells has grown from 14.1% to 26.1% during the last 10 years (2013-2023)
- However, their stability is still a problem due to the degradation of the optoelectronic properties of the PSK light absorber, as well as of the selective carrier transport layers (SCTL) used to selectively extract photogenerated carriers.

A challenge: Understand the carrier generation, transport and recombination in the PSK and at the PSK/SCTL interface and surface.

Experimental samples:

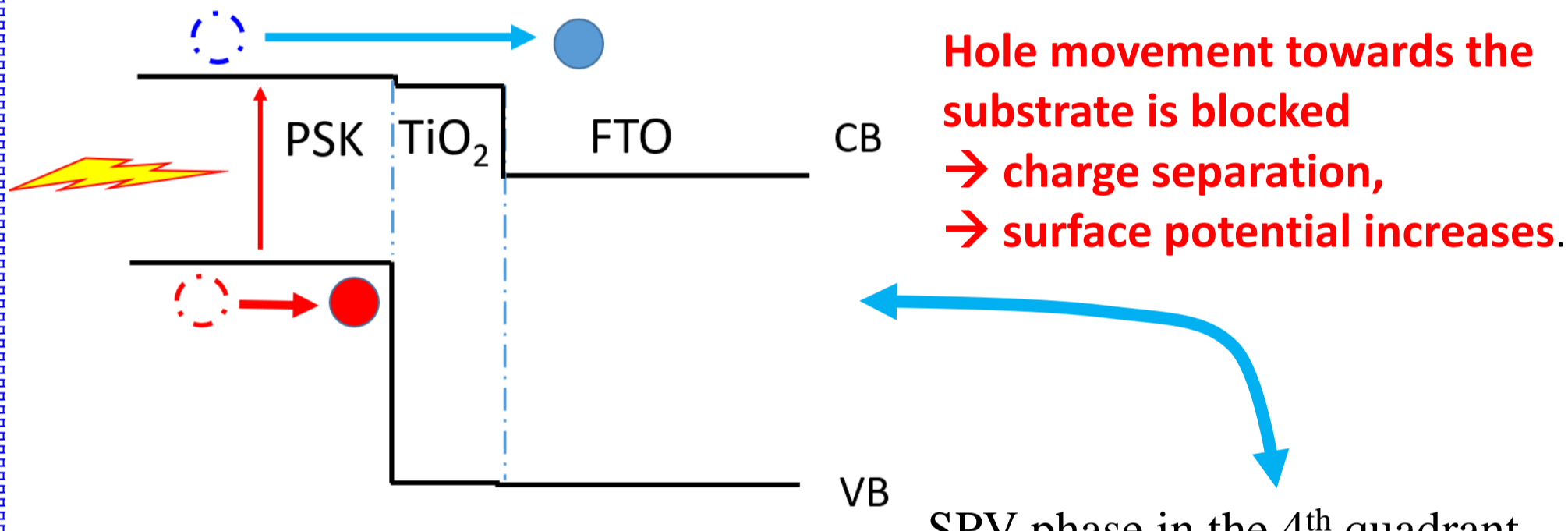
Fully inorganic lead halide PSK thin films CsPbI₃ and partial solar cell structures

- electron transport layer TiO₂ deposited on FTO/glass substrates by spray pyrolysis (FTO=fluorine-doped tin oxide)
- Perovskite - deposited via spin-coating
- glass sheet a few μm thick to protect the perovskite

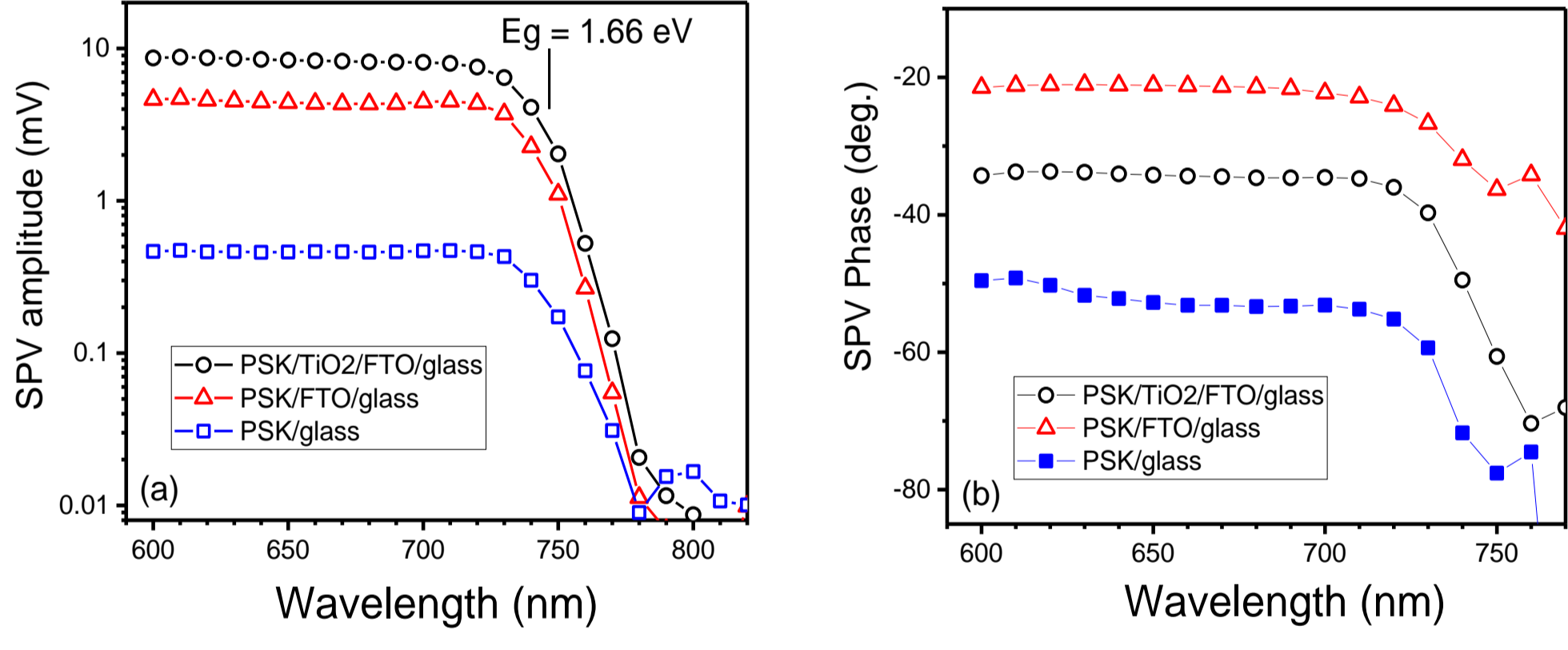


Results and discussion:

Generation mechanisms of the SPV signal



SPV phase in the 4th quadrant

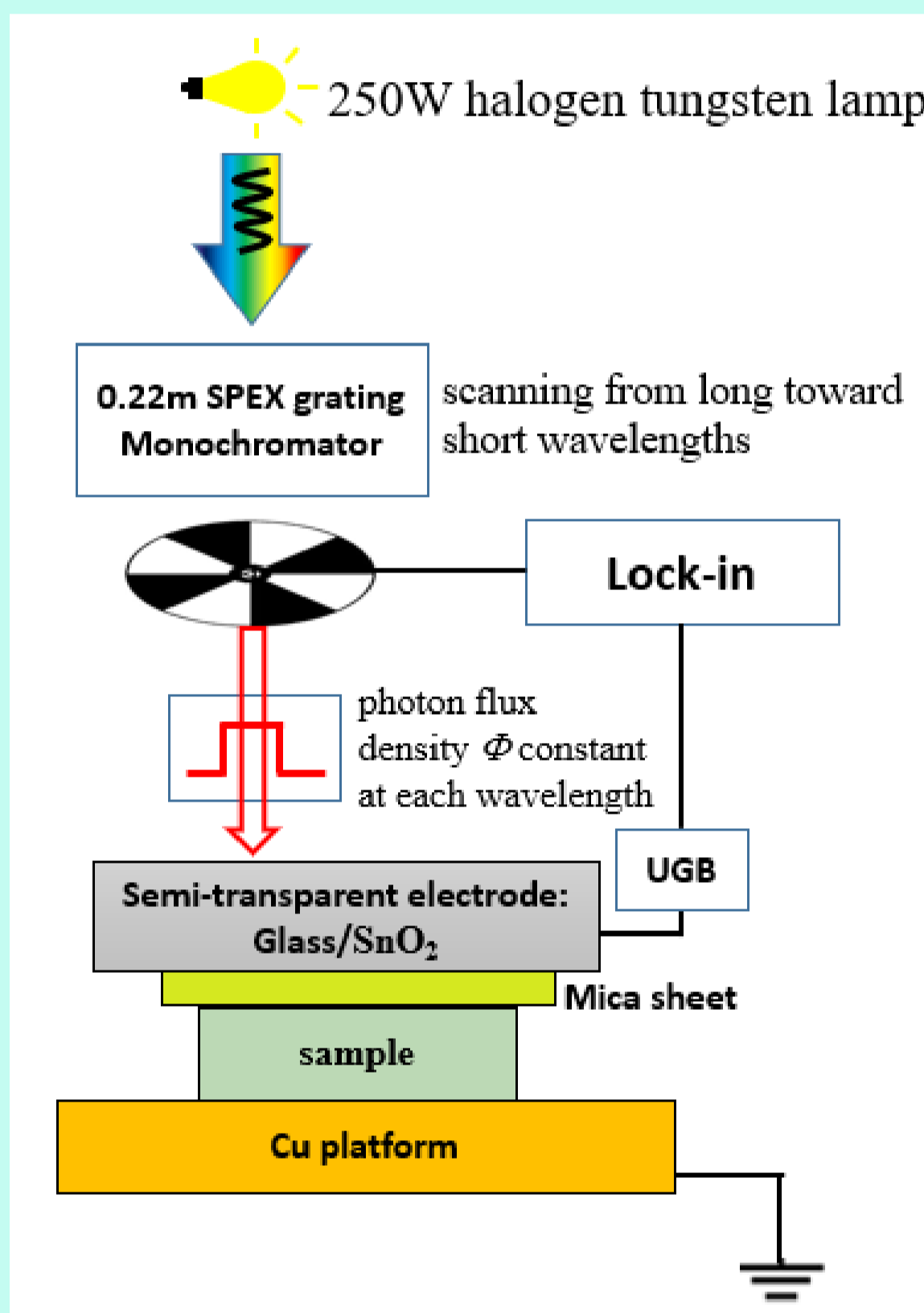


MIS-SPV amplitude (a) and phase (b) spectra of the three structures measured at 94 Hz.

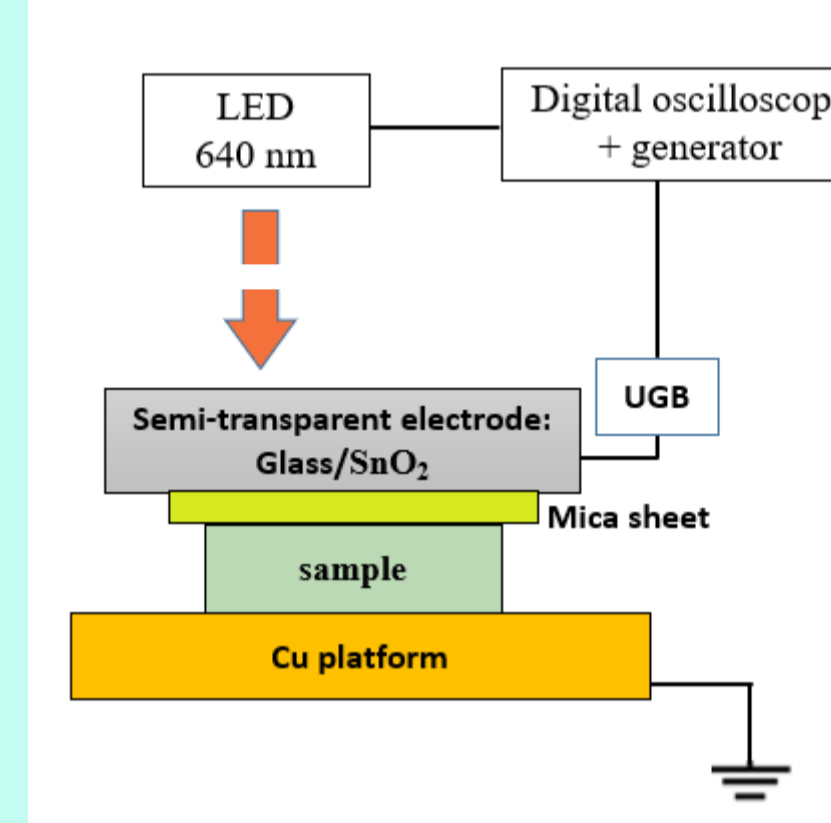
Surface Photovoltage (SPV) method: The Metal-insulator-semiconductor (MIS) SPV operation mode

- chopped light, flux density $\sim 10^{13} \text{ cm}^{-2}\text{s}^{-1}$
- $\text{SPV} = V_s^{\text{light}} - V_s^{\text{dark}}$

SPV spectra, 900 – 600 nm Chopped light @ 94 & 492 Hz

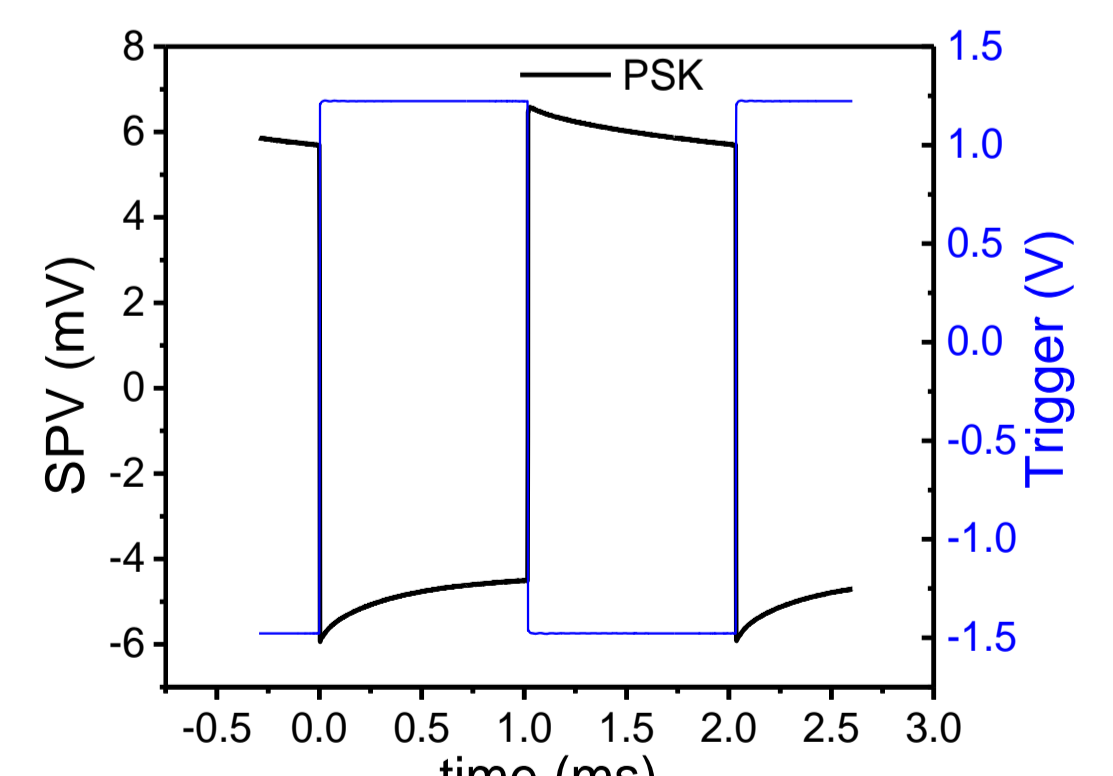
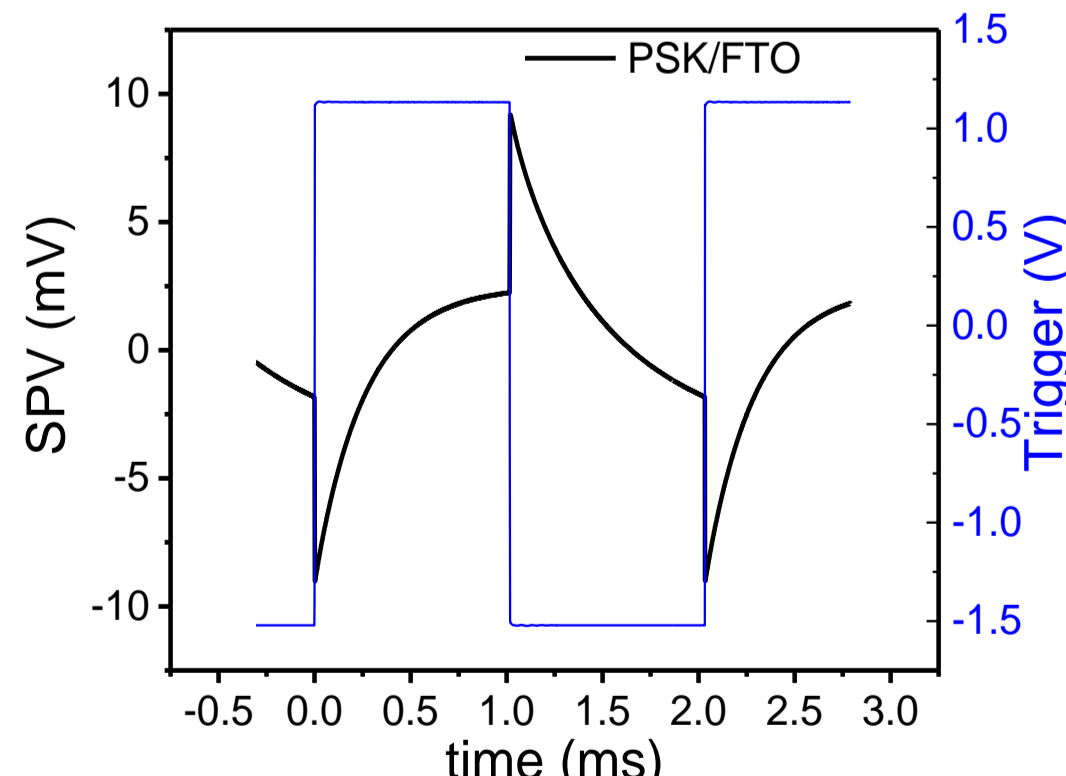
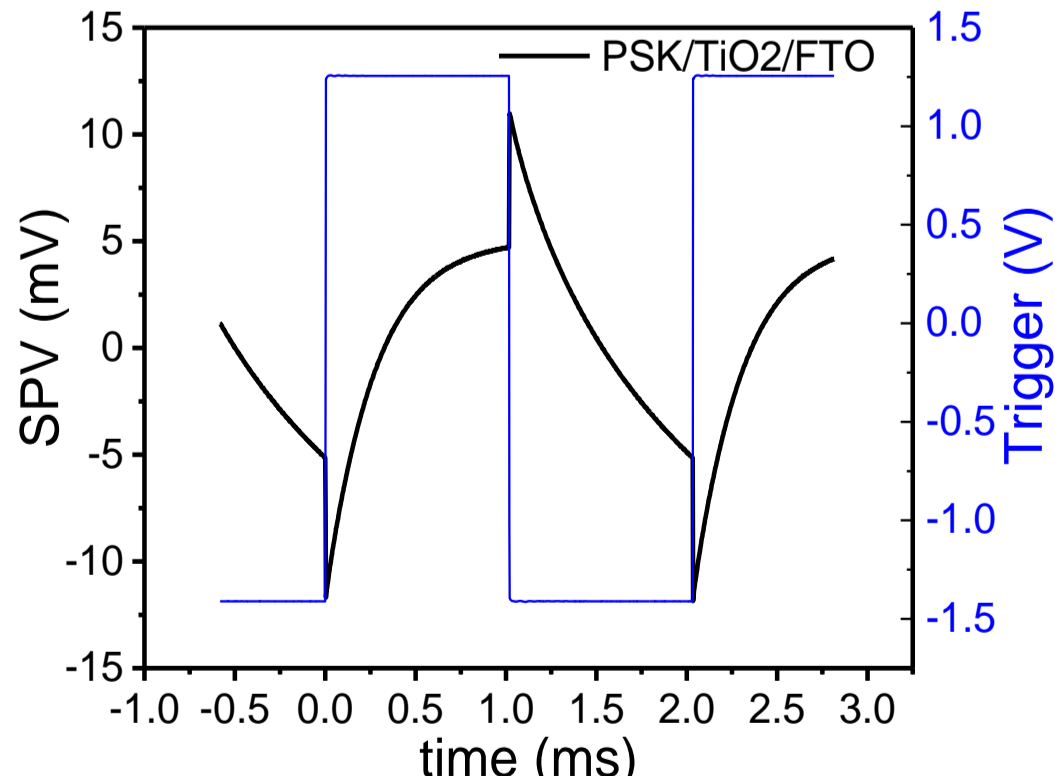


SPV transients @ 640 nm, 12.5 μW 9.9, 21, 94 & 492 Hz, duty cycle 50%



The SPV spectra

- Reveal the PSK optical absorption edge of 1.66 eV (assessed from Tauc plot)
- Show the role of the electron transport layer (TiO₂) in obtaining a good photoresponse.
- SPV phase in the 4th quadrant \leftrightarrow increased surface potential \leftrightarrow positive SPV



SPV transients of the three PSK structures measured with 640 nm excitation at 12.5 μW and 492 Hz.

- Positive SPV develops in the light semi-period in line with the SPV spectra.
- Strange signal jumps in negative (positive) direction when the excitation is turned on (off). Tentatively explained as the contribution of a negative SPV component (SPV phase in the 2nd quadrant), which increases with the excitation and rotates the SPV phase clockwise.

Conclusions:

- The PSK bandgap is determined.
- The ETL (TiO₂) has a paramount role for the charge separation and photovoltage generation.
- The mechanism of charge separation is confirmed.
- An unknown SPV negative process is identified that could be related to trapping/recombination of carriers at the PSK interfaces and/or Dember effect.

