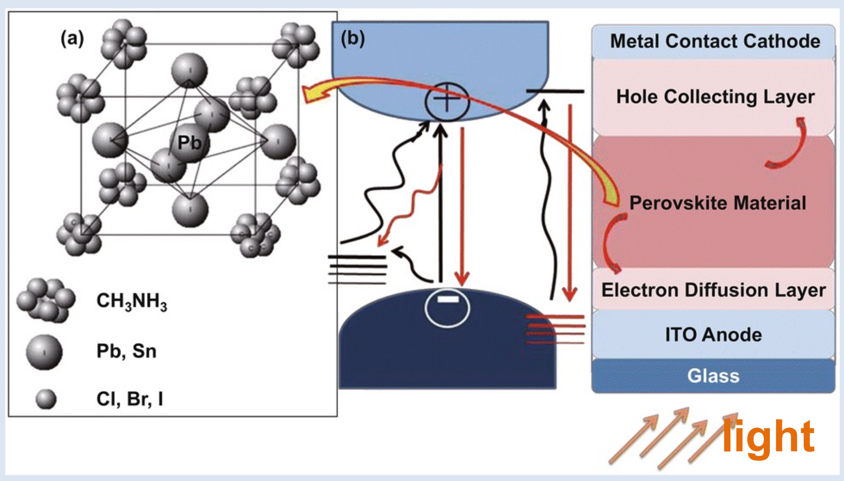
PM2022 - 15th Pisa Meeting on Advanced Detectors

R&D on organometal halide perovskites for photodetectors

The organometal halide perovskites (OMHP) semiconductors are promising candidates for fast, sensitive and large area photodetectors. A gain in OMHP based detectors has been observed in several architectures, but usually in association with a slow time response. A model describing the underlying mechanics is still missing or at least incomplete. In this talk the state of art of the photo-detectors based on OMHP perovskites will be presented, and the activities carried on within the PEROV experiment as well. One goal of the PEROV project is to find out whether OMHPs exhibit an internal avalanche multiplication. Several $CH_3NH_3PbBr_3$ perovskite based devices have been developed, fabricated and characterized: film-based devices with 300 nm thickness and devices based on high quality single crystals with seeding techniques or with unconventional lithographic techniques, with thickness from microns to mm.

Organo Metal-Halide Perovskites (OHMP)

- **OHMP** are a class of hybrid organic-inorganic semiconductor materials with a perovskite unit-cell structure **ABX_3** with
  - A = $CH_3NH_3^+$, B = metallic cation (Pb^{2+})
  - X= halide anions (Cl^-, Br^-, I^-)



- OMHP are emerging as new generation photovoltaic material
- **promising candidate as <u>large area and flexible</u> sensitive photodetectors**
  - → **interest for HEP detectors !**

- OHMP band gap tunable changing halide (I,Br,Cl) 🙂
- OMHP contain highly mobile defects and have instabilities issues 🙁

OHMP combine **advantages from organic and inorganic semiconductors**

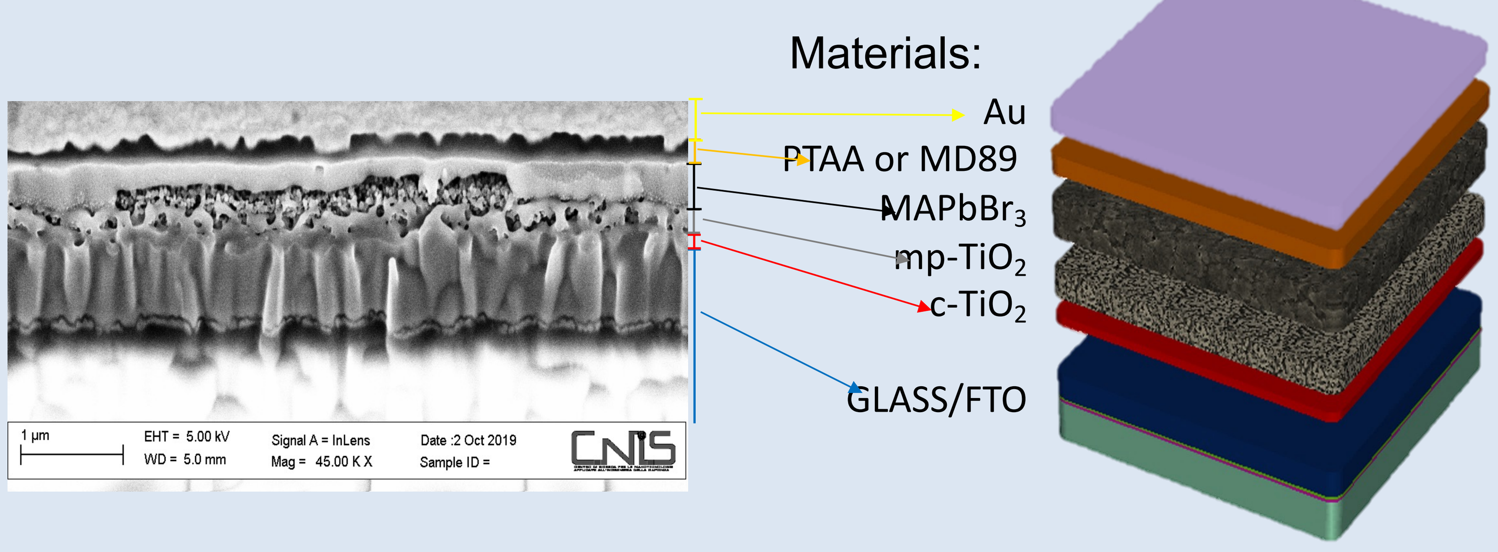
Organic semiconductors:
- Disordered system
- Localized electronic states
- Hopping transport ⇒ low mobility
- **Low cost, low temperature processing**
- **Can be solution processed**
- **Scalable to large area**

Inorganic semiconductors:
- **Ordered periodic crystal ⇒ band structure**
- **Delocalized Bloch states**
- **band transport ⇒ high mobility**
- Usually wafer based technology
- Costly, high temperature processes

		Silicon	$CH_3NH_3Pb(I,Br)_3$
Density		2.33 g/cm³	4.15 g/cm³
Band gap (eV)		1.12 (indirect)	1.5-1.6 / 2.24 (direct)
Mobility (cm²/Vs)	electrons	1400	< 70/190
	holes	450	< 160/220
Absorption (cm⁻¹)		< 10⁴	> 4x10⁴
Threshold energy for impact ionization (eV)		1.2	~2 / 2.5 (estimated)
Mean free path (nm)		≤ 100	~100 (theory)

Film Based device

Thin film deposition of MAPbBr3 perovskite (300nm)



Ready devices with different Optical Band-Gap

Pro:	Contra:
• **Scalable to large area** • **small transit time due to low thickness** • **flexible substrate**	• **polycrystalline** • **grain boundaries** • **large variability between samples**

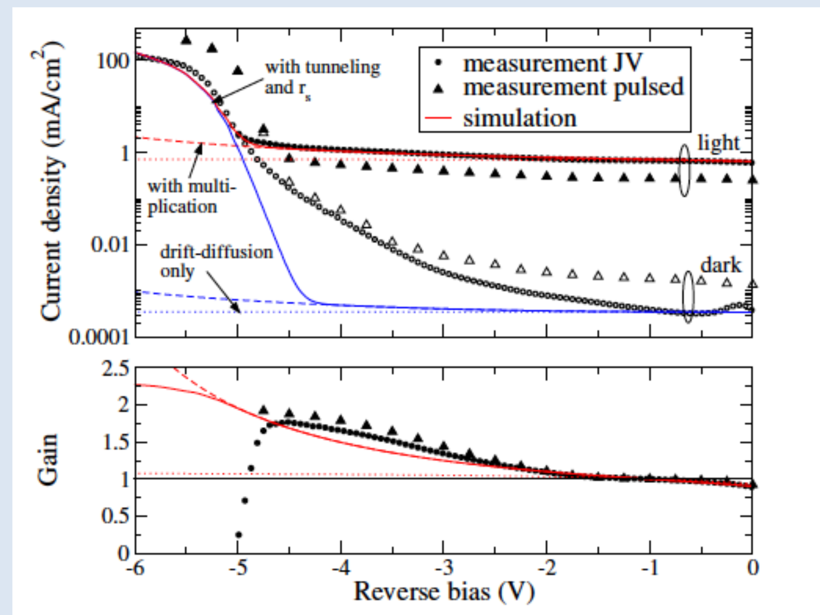
- Breakdown-like behavior at around -4–5 V
- Small amount of photocurrent gain Incident photon to current efficiency IPCE = J_{ph} hc / (P_{in} e λ) ~ 2

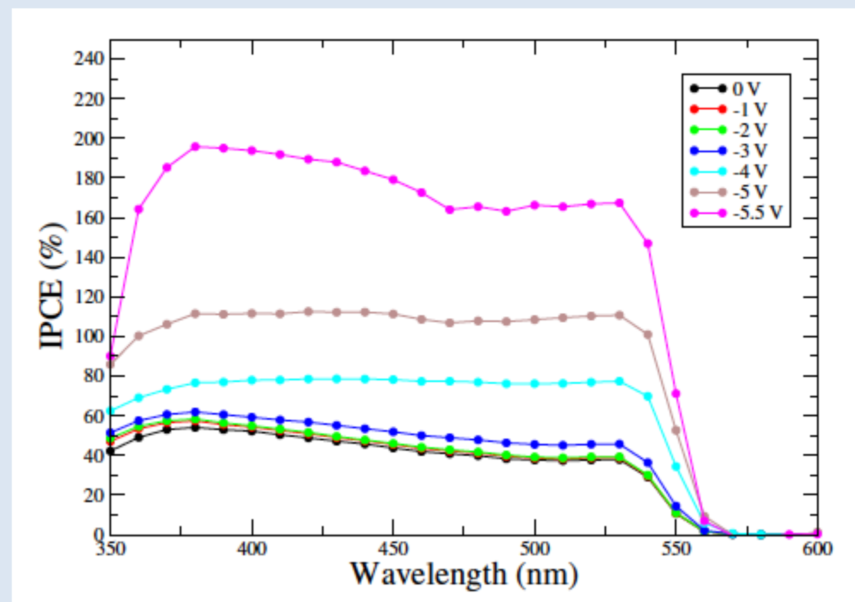
- Developed phenomenological model to explain the observed reverse bias behavior and gain though
  - *tunneling-assisted electron extraction at the TiO 2 /MAPbBr 3 interface*
  - *carrier multiplication*

- Both processes mediated by the electric field due to *mobile ions Br-*

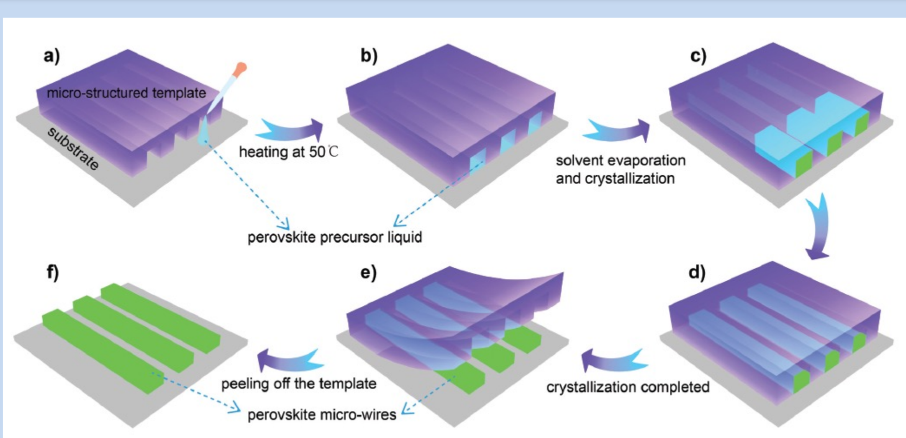
- Mobile ionic species in halide play an important role in photodetector and solar cell performance and stability
  - Not fully understood but critical

Appl. Phys. Lett. ***120****, 113505 (2022)*



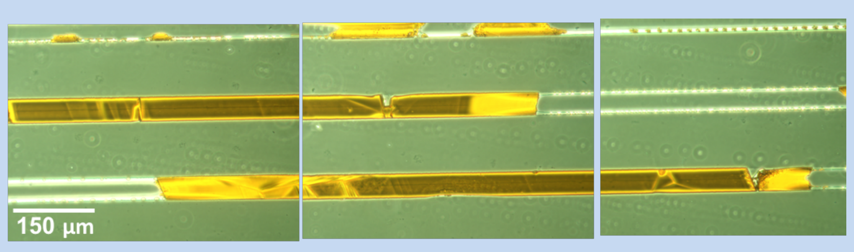


Micro-channels

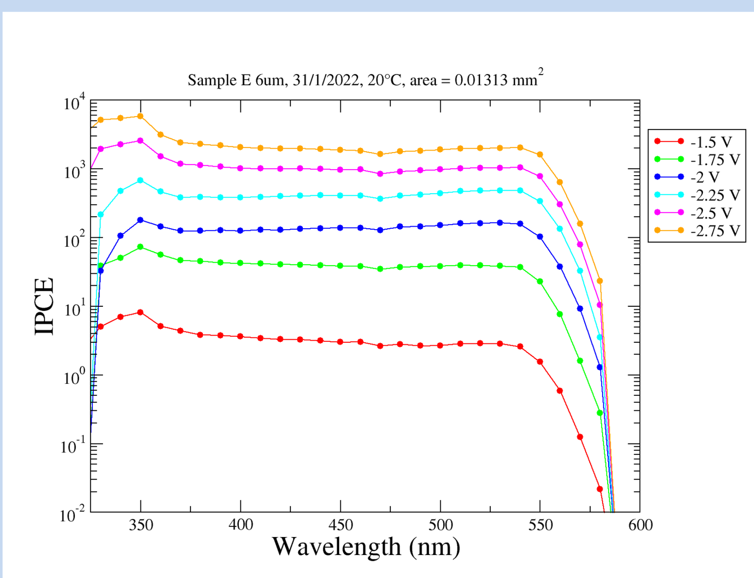


Pro:
• **large flexibility in dimension** • **moderate area** • **pixelization** • **flexible substrate** • **Deposited directly on substrate**
Contra:
• **need high optimization of parameters (pressure, temperature,..)**

Typical dimension: W x L x H = 150 μm x 500 μm x 6(2) μm

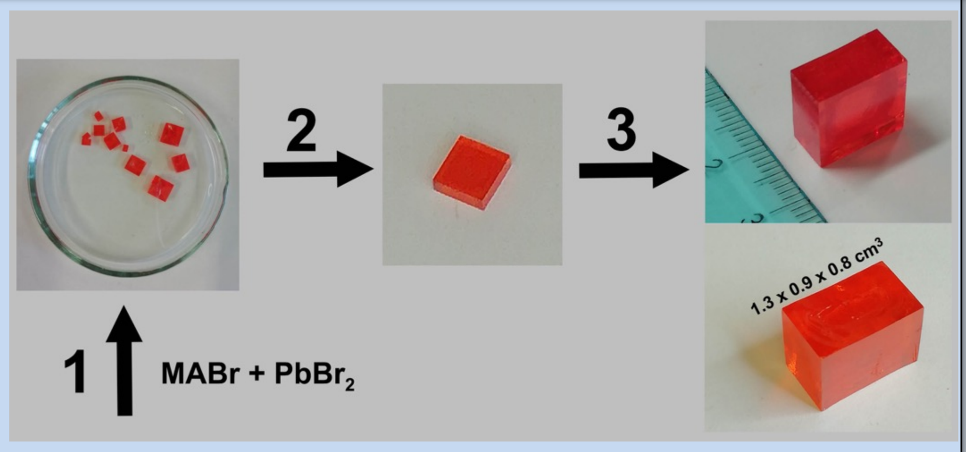


- Device realized with CH_3NH_3PbBr deposition on **patterned** Indium Tin Oxide/ $CH_3NH_3PbBr_3$ and Au evaporation
- *Deposited patent*: 102022000010469
- Gain observed at larger bias for thickness of 2 and 6 um

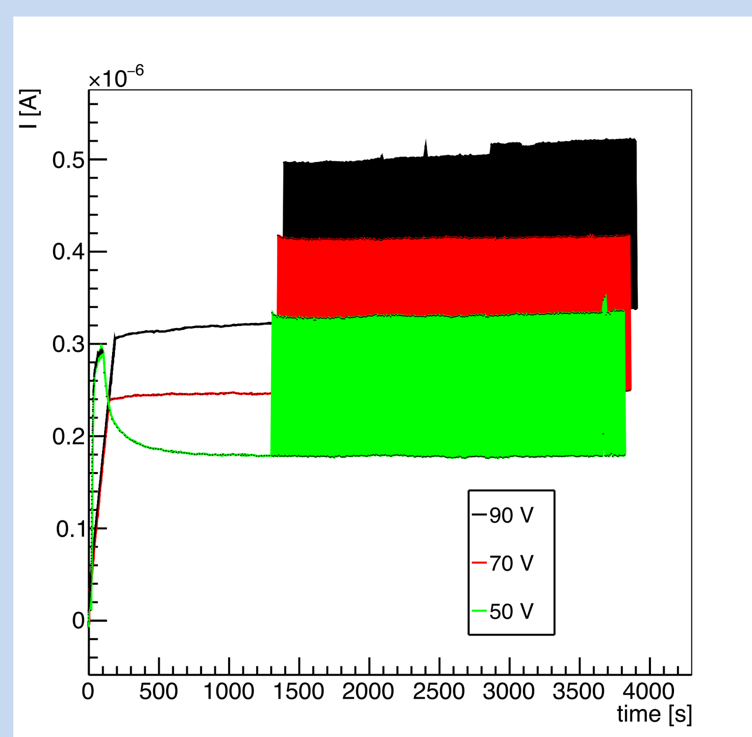


Large Bulk crystals

Pro:
• **ideal for single crystal large dimension, up to O(1) cm³** • **low defects**
Contra:
• **No scalability to large area** • **Need to be cut mechanically for low thickness**



- Dimensions up to 1.0 x 1.5 cm² and up to 0.5 cm thick down to 300 μm by cutting the crystals along one of the {100}cubic planes
- Device realized with Indium Tin Oxide / $CH_3NH_3PbBr_3$ / Au
- Stability response measured under 500 nm pulsed light illumination



Marianna Testa for the PEROV collaboration