# 2D Layered Metal Monochalcogenides for Photoelectrochemical (PEC)-Type Photodetectors and Water Splitting Applications

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Aqueous-based photoelectrochemical (PEC) devices, such as self-powered photodetectors and water splitting cells, represent powerful tools to convert the electromagnetic radiation into chemical fuels and electricity.[1] To achieve efficient PEC systems, it is mandatory to develop photocatalytic materials that efficiently absorb light in the desired spectral range (UV/visible for energy conversion systems), creating free charge carriers with suitable energies to carry out the oxidation-reduction (redox) reactions before they recombine.[2] In order to progress in these tasks, two-dimensional (2D) materials, including either single- and few-layer flake forms, are attracting huge interest as potential advanced photo(electro)catalysts.[3] Recently, 2D group-IIIA and group-IVA metal monochalcogenides (MCs), with chemical formula MX (M = Al, Ga, In, Tl and M = Si, Ge, Sn, Pb respectively; X = S, Se, Te), have been theoretically predicted to be low-cost and environmentally friendly water splitting photocatalysts. Among them, layered germanium selenide (GeSe) and indium selenide (InSe), are promising material candidates for optoelectronic devices due to their tuneable electronic structure, strong visible-light absorbance, photoresponse and environmental stability. However, the evaluation of their photo(electro)catalytic properties was still incomplete until last years, pointing out the need of experimental trials and validation. Here, we report the first experimental characterization of the PEC water splitting activity of single-/few-layer flakes of GeSe and InSe produced in inks form by scalable liquid-phase exfoliation (LPE) approach in non-toxic solvent (*i.e.*, 2-propanol).[4] The PEC behaviour of MCs-based photoelectrodes, obtained by spray coating approach,[5] were evaluated in different aqueous media, ranging from acidic to alkaline solutions and under different illumination wavelengths in the visible spectral range, namely 455, 505 and 625 nm. The obtained performances (responsivity and external quantum efficiency -EQE- up to 0.32 A/W and 86.3%) are superior to those of several self-powered and low-voltage solution-processed photodetectors, approaching the ones of their commercial UV–Vis counterparts. Finally, we demonstrate the use of MCs-based photoelectrodes as photoanodes or photocathodes for water splitting reactions under simulated sunlight, inspiring the use of 2D MCs in innovative PEC systems.

## REFERENCES

[1] J. Zhou, L. Chen, Y. Wang, Y. He, X. Pan, and E. Xie, Nanoscale, 8 (2016), 50–73.
[2] S. Bellani, M.R. Antognazza, F. Bonaccorso, Adv.Mater., 9, 31 (2019), 1801446.
[3] M. I. Zappia, G. Bianca, S. Bellani, M. Serri, L. Najafi, R. Oropesa-Nuñez, B. Martín-García, D. Bouša, D. Sedmidubský, V. Pellegrini, Z. Sofer, A. Cupolillo, F. Bonaccorso, Adv. Funct. Mater., (2020), 1909572.
[4] G. Bianca, M. I. Zappia, S. Bellani, M. Serri, L. Najafi, B. Martín-García, R. Oropesa-Nuñez , T. Hartman, D. Sedmidubský, V. Pellegrini, Z. Sofer, A. Cupolillo and F. Bonaccorso, ACS Appl. Mater. Interfaces, 12, 43, (2020), 48598–48613.
[5] F. Bonaccorso, A. Bartolotta, J. N. Coleman, C. Backes, Adv. Mater., 29, 28 (2016), 6136-6166.

## FIGURE

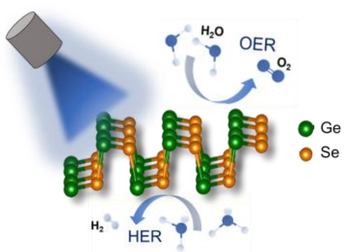


**Figure 1:** Schematic processes of photoelectrochemical water splitting on transition metal monochalcogenide nanoflakes.

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