Photovoltaic Cells from 2D Germanane

James T. McLeskey Jr.
Randolph-Macon College
Ashland, Virginia USA

The 2D Germanium (Ge) analog to graphene is known as germanene. Hydrogenated-germanene (germanane or Ge-H) has an inherently tunable direct[1] bandgap of approximately 1.6 eV and a high electron mobility. It is relatively stable giving it great potential for application in photovoltaics, photodetectors, and thermoelectrics. The author has previously synthesized germanane and demonstrated a Schottky diode,[2] and as of 2023, some thirty-four different electronic device applications, including photodetectors had been reported.[3] However, a working photovoltaic device has yet to be realized. In this presentation, the author will report on previous work done using germanane and efforts underway to prepare a germanane-based PV.

Material Synthesis

Wet Chemistry Synthesis

Ge-H was first synthesized by Goldberger et al in 2013 via the deintercalation of Ca ions from $CaGe_2$ crystals using concentrated acid.[4] By substituting the acid with other alkylating agents, different functional groups can replace the hydrogen. The method is cost-effective and stable and allows for the exfoliation of Ge-H sheets.

Epitaxial Growth Methods

Germanene has been produced by via high-vacuum methods such as molecular beam epitaxy (MBE) and surface segregation. In 2014, Dávila et al grew a germanene film via MBE of germanium on gold.[5] In 2018, Yuhara et al grew a germanene via segregation through Ag(111) thin films on Ge(111).[6] Unfortunately, unlike germanane, germanene films oxidize very quickly.[7] To overcome this issue, Suzuki et al added a layer of graphene or hexagonal boron nitride on top of the silver before growing germanene. With this protective van der Waals material layer, stable germanene can be grown at ambient pressure.[8]

Device Fabrication

Despite the promise of germanane as an optoelectronic building block, only a small number of actual devices have been produced. In 2014, Arguilla et al effectively built an FET photodetector by performing two-probe photoconductivity measurements of single crystals of Ge-H and $Ge_{0.91}Sn_{0.09}H_{0.91}(OH)_{0.09}$ placed across a pair of Ag/Au contacts.[9]

In 2016, the author reported on the comparison between bulk Ge and 2D Ge-H as a Schottky diode (Fig 1). Suspensions of Ge and Ge-H particles in benzonitrile were drop-cast on top of gold and aluminum interdigitated electrodes. The forward and reverse bias directions of the resulting diodes were opposite for the two materials, and both the rectification and the current are higher for the Ge-H device.[2]

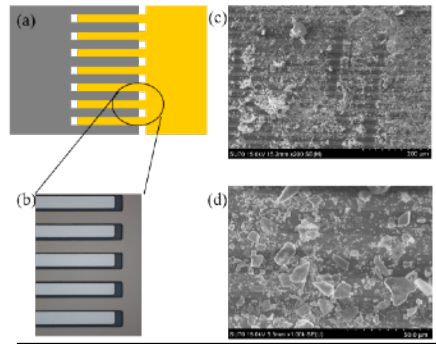

Fig 1: Images of the fabricated devices. (a) Drawing showing configuration of interdigitated Au/Al electrode (b) optical microscope image of interdigitated electrodes. (c) and (d) SEM images (200 µm and 50 µm scales) of Ge-H deposited on electodes (bright lines are gold electrodes; aluminum electrodes appear darker).

In 2020, Liu et al fabricated a Ge-H photoelectrochemical (PEC) photodetector.[10] As prepared Ge-H crystals were dispersed in ethanol and exfoliated by sonication creating a Ge-H ink. This dispersion was spin-coated onto ITO coated glass to create the working electrode for the photodetector.

Potential Photovoltaic devices

The work done to date shows the potential of 2D Germanium for use in photovoltaics. However, no one has reported on the fabrication of a germanane/ene photovoltaic device. There are different potential designs and fabrication methods that may be worth exploring including:

Spin-coated germanane

The work of Liu et al[10] points towards one possible design by spin-coating a layer of Ge-H ink (Fig. 2). Open questions include whether additional layers are needed to develop a sufficient internal field, and whether this design benefits from the increased mobility of the Ge-H if the sheets align in the plane. It is possible that the solid metal electrode could be replaced with metal lines to create a largely transparent device.

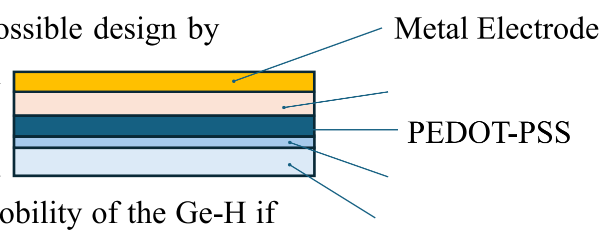

Fig. 2: Schematic of a possible Ge-H PV.

Segregation-grown germanene

Another potential design would involve the growth of germanene between an Ag(111) layer and a graphene layer (Fig. 3). The graphene would protect the germanene from oxidation. Similar questions to the first proposed design would need to be answered.

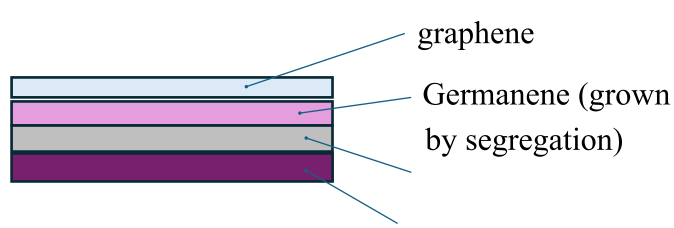

Fig. 3: Schematic of a possible Germanene PV.

Work is underway to fabricate and test solar cells using these designs.

[1]Santosh et al, Materials Science and Engineering: B, 259, 114584, September 2020.

[2]Sahoo et al, Applied Physics Letters, Vol. 109, 023507, 2016.

[3] Ng and Pumera, Advanced Materials, 35, 2207196, 2023.

[4]Bianco et al, ACS Nano 7, 4414, 2013.

[5] Dávila et al, New Journal of Physics. 16, 095002 2014.

[6] Yuhara et al, ACS Nano, 12, 11632-11637, 2018.

[7]Suzuki et al, Small Methods, 2400863, 2024

[8]Suzuki et al, Japanese Journal of Applied Physics, 59, SN1004, 2020

[9]Arguilla et al, Chemistry of Materials, 2014

[10]Liu et al, Small, 2000283, 2020.