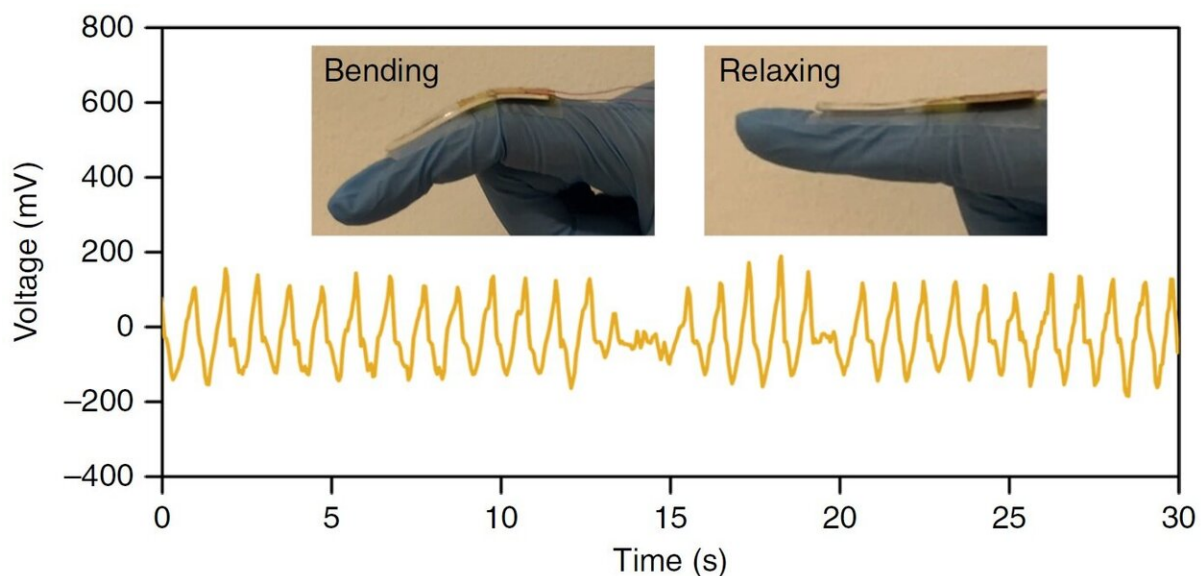


Liquid metal synthesis for better piezoelectrics: Atomically-thin tin-monosulfide

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Output voltage in a practical, wearable device: voltage output during tensile bending and relaxing (two-electrode device). Credit: FLEET

An RMIT-UNSW collaboration has applied liquid-metal synthesis to piezoelectrics, advancing future flexible, wearable electronics, and biosensors drawing their power from the body's movements.

Materials such as atomically thin tin-monosulfide (SnS) are predicted to

exhibit strong piezoelectric properties, converting mechanical forces or movement into electrical energy. This property, along with their inherent flexibility, makes them likely candidates for developing flexible nanogenerators that could be used in wearable electronics or internal, self-powered biosensors.

However, to date, this potential has been held back by limitations in synthesizing large, highly crystalline [monolayer](#) tin-monosulfide (and other group IV monochalcogenides), with difficulties caused by strong interlayer coupling. The new study resolves this issue by applying a new liquid-metal technique, developed at RMIT, to synthesize the materials. Subsequent measurements confirm that tin-monosulfide synthesized using the new method displays excellent electronic and piezoelectric properties. The resulting stable, flexible monolayer tin-monosulfide can be incorporated in a variety of devices for efficient energy harvesting.

The work started over two and a half years ago and strong collaborative work between RMIT and UNSW allowed its fruition. Ms Hareem Khan, the first author of the paper, showed remarkable perseverance to surmount many technical challenges to demonstrate the viability of the concept, with Prof Yongxiang Li.

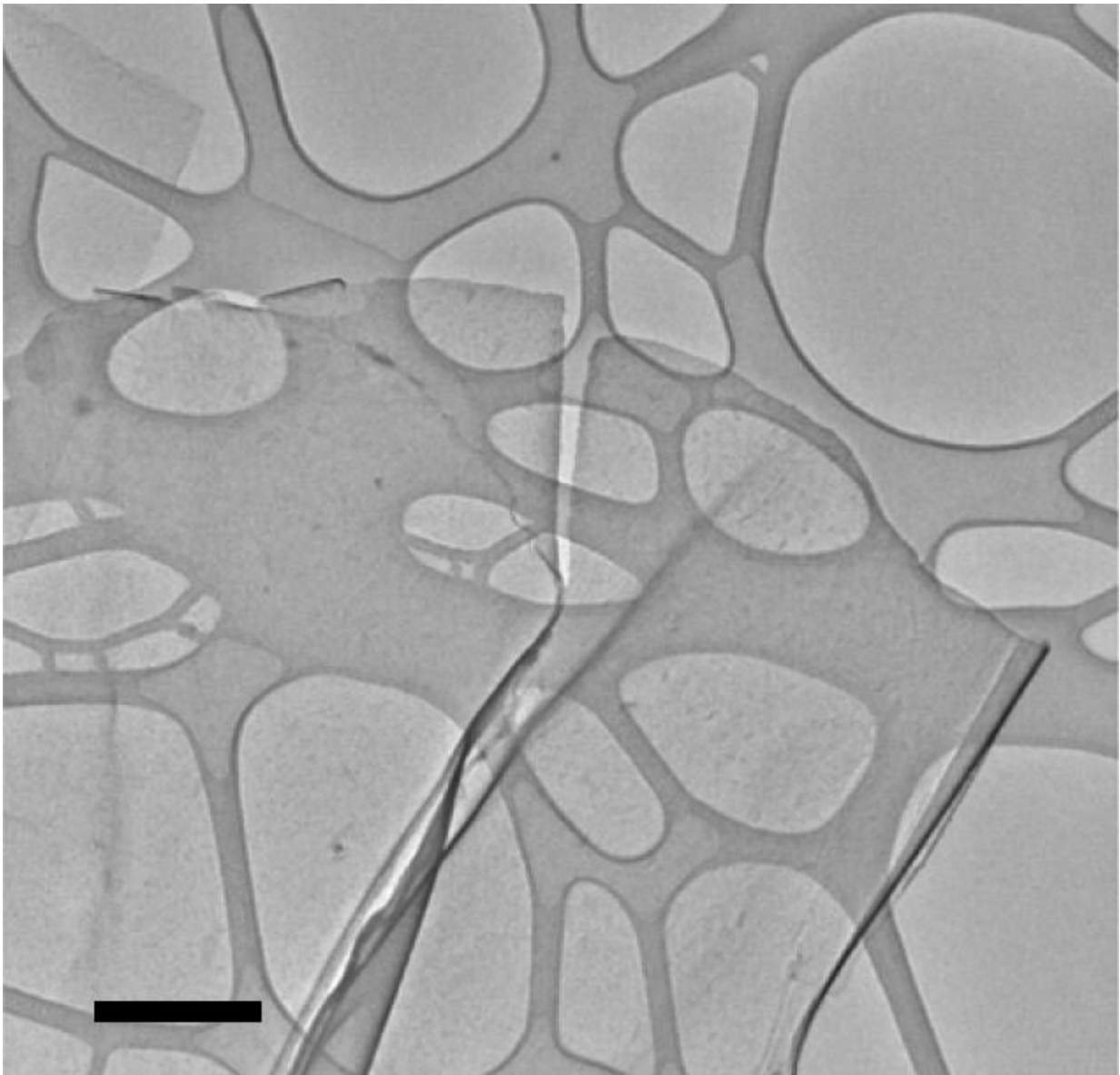
Liquid metal synthesis

The unprecedented technique of synthesis involves the van der Waals exfoliation of a tin sulfide (SnS), that is formed on the surface of tin when it is melted, while being exposed to the ambient of hydrogen sulfide (H_2S) gas. H_2S breaks down on the interface and sulfurises the surface of the melt to form SnS .

The technique is equally applicable to other monolayer group IV monochalcogenide, which are predicted to exhibit the same strong piezoelectricity. This liquid metal based method allows us to extract

homogenous and large scale monolayers of SnS with minimal grain boundaries.

Measurements confirm the material has [high carrier mobility](#) and piezoelectric coefficient, which translates into exceptional peak values of generated voltage and loading power for a particular applied strain, impressively higher than that any previously reported 2-D nanogenerator.



Transmission electron microscope (TEM) image: atomically thin (monolayer) tin-sulfide nanosheet (scale bar is 500 nm) Credit: FLEET

High durability and flexibility of the devices are also demonstrated. This is evidence that the very stable as-synthesized monolayer SnS can be commercially implemented into power-generating nanodevices. They can also be used for developing transducers for harvesting mechanical human movements, in accordance to the current technological inclinations towards smart, portable and flexible electronics.

The results are a step towards piezoelectric-based, flexible, wearable energy-scavenging devices. It also presents an unprecedented synthesis technique for large (wafer) scale tin-monosulfide monolayers.

Piezoelectric materials

Piezoelectric materials can convert applied mechanical force or strain into [electrical energy](#). Best known for the simple "piezo" lighter used for gas grills and stovetops, piezo-electric devices sensing sudden changes in acceleration are used to trigger vehicle air bags, and more sensitive devices recognize orientation changes in mobile phones or form the basis of sound and pressure sensors.

Even more sensitive piezoelectric materials can take advantage of the small voltages generated by extremely small mechanical displacement, vibration, bending or stretching to power miniaturized devices, for example biosensors embedded in the human body, removing the need for an external power source.

The study, "Liquid metal-based synthesis of high performance

monolayer SnS piezoelectric nanogenerators," was published in *Nature Communications* in July 2020.

More information: Hareem Khan et al. Liquid metal-based synthesis of high performance monolayer SnS piezoelectric nanogenerators, *Nature Communications* (2020). [DOI: 10.1038/s41467-020-17296-0](https://doi.org/10.1038/s41467-020-17296-0)

Provided by FLEET

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