Inorganic double helix: A flexible semiconductor for electronics, solar technology and photo catalysis

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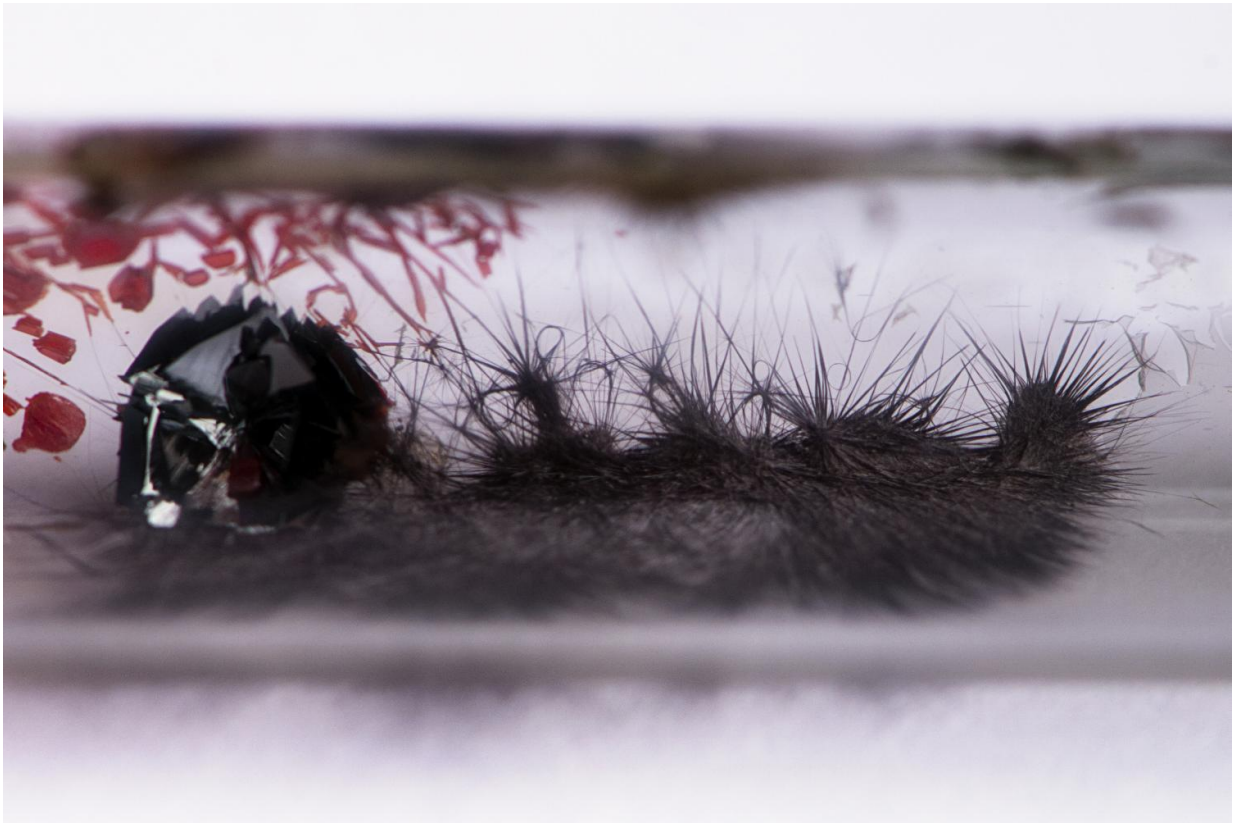


On the left side crystals of residual black phosphorus and tiniodide. The material is easy to produceand shows extraordinary optical and electronic properties, as well as extreme mechanical flexibility. Credit: Andreas Battenberg / TUM

It is the double helix, with its stable and flexible structure of genetic information, that made life on Earth possible in the first place. Now a team from the Technical University of Munich (TUM) has discovered a double helix structure in an inorganic material. The material comprising tin, iodine and phosphorus is a semiconductor with extraordinary optical and electronic properties, as well as extreme mechanical flexibility.

Flexible yet robust - this is one reason why nature codes genetic information in the form of a double helix. Scientists at TU Munich have now discovered an inorganic substance whose elements are arranged in the form of a double helix.

The substance called SnIP, comprising the elements tin (Sn), iodine (I) and phosphorus (P), is a semiconductor. However, unlike conventional inorganic semiconducting materials, it is highly flexible. The centimeter-long fibers can be arbitrarily bent without breaking.

"This property of SnIP is clearly attributable to the double helix," says Daniela Pfister, who discovered the material and works as a researcher in the work group of Tom Nilges, Professor for Synthesis and Characterization of Innovative Materials at TU Munich. "SnIP can be easily produced on a gram scale and is, unlike gallium arsenide, which has similar electronic characteristics, far less toxic."

Countless application possibilities

The semiconducting properties of SnIP promise a wide range of application opportunities, from energy conversion in solar cells and thermoelectric elements to photocatalysts, sensors and optoelectronic elements. By doping with other elements, the electronic characteristics of the new material can be adapted to a wide range of applications.

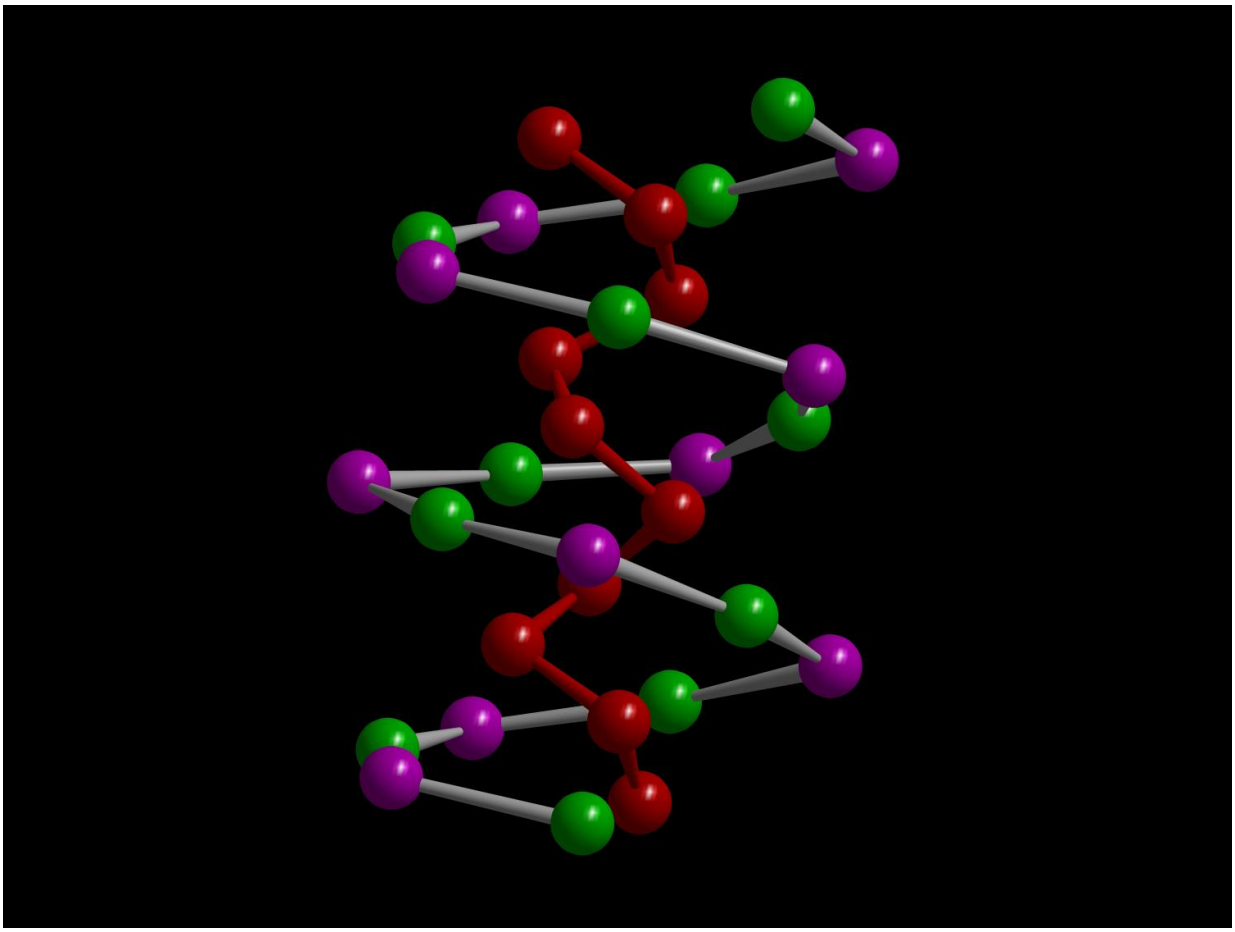
Due to the arrangement of atoms in the form of a double helix, the

fibers, which are up to a centimeter in length can be easily split into thinner strands. The thinnest fibers to date comprise only five double helix strands and are only a few nanometers thick. That opens the door also to nanoelectronic applications.

"Especially the combination of interesting semiconductor properties and mechanical flexibility gives us great optimism regarding possible applications," says Professor Nilges. "Compared to organic solar cells, we hope to achieve significantly higher stability from the inorganic materials. For example, SnIP remains stable up to around 500°C (930 °F)."

Just at the beginning

"Similar to carbon, where we have the three-dimensional (3D) diamond, the two dimensional graphene and the one dimensional nanotubes," explains Professor Nilges, "we here have, alongside the 3D semiconducting material silicon and the 2D material phosphorene, for the first time a one dimensional material - with perspectives that are every bit as exciting as carbon nanotubes."



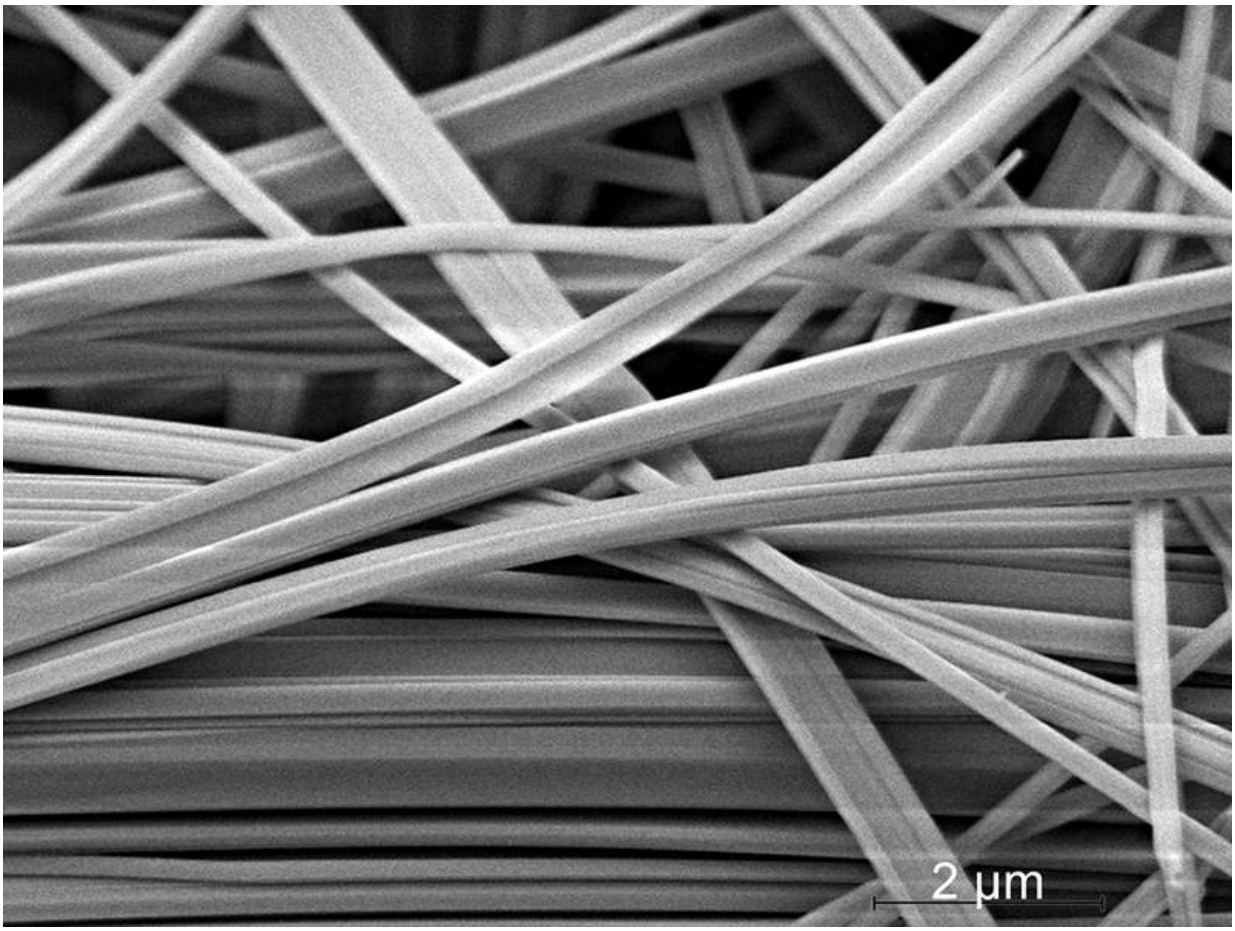
The new material comprising tin, iodine and phosphorus possesses a double helix structure which provides the semiconductor with extreme mechanical flexibility. Credit: Prof. Tom Nilges / TUM

Just as with carbon nanotubes and polymer-based printing inks, SnIP double helices can be suspended in solvents like toluene. In this way, thin layers can be produced easily and cost-effectively. "But we are only at the very beginning of the materials development stage," says Daniela Pfister. "Every single process step still needs to be worked out."

Since the double helix strands of SnIP come in left and right-handed variants, materials that comprise only one of the two should display

special optical characteristics. This makes them highly interesting for optoelectronics applications. But, so far there is no technology available for separating the two variants.

Theoretical calculations by the researchers have shown that a whole range of further elements should form these kinds of inorganic double helices. Extensive patent protection is pending. The researchers are now working intensively on finding suitable production processes for further materials.



Electronmicroscopic image of SnIP-needles (9700x, 5 kV) . Credit: Viola Duppel / MPI for Solid State Research

An extensive interdisciplinary alliance is working on the characterization of the new material: Photoluminescence and conductivity measurements have been carried out at the Walter Schottky Institute of the TU Munich. Theoretical chemists from the University of Augsburg collaborated on the theoretical calculations. Researchers from the University of Kiel and the Max Planck Institute of Solid State Research in Stuttgart performed transmission electron microscope investigations. Mössbauer spectra and magnetic properties were measured at the University of Augsburg, while researchers of TU Cottbus contributed thermodynamics measurements.

More information: Daniela Pfister, Konrad Schäfer, Claudia Ott, Birgit Gerke, Rainer Pöttgen, Oliver Janka, Maximilian Baumgartner, Anastasia Efimova, Andrea Hohmann, Peer Schmidt, Sabarinathan Venkatachalam, Leo van Wullen, Ulrich Schu?rmann, Lorenz Kienle, Viola Duppel, Eric Parzinger, Bastian Miller, Jonathan Becker, Alexander Holleitner, Richard Weihrich and Tom Nilges; Inorganic Double Helices in Semiconducting SnIP. *Advanced Materials*, Early view, Spet. 12, 2016. DOI: 10.1002/adma.201603135

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