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Ultra-thin fibres can turn clothes into wearable electronics

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Scientists from Nanyang Technological University, Singapore (NTU Singapore) have developed ultra-thin semiconductor fibres that can be woven into fabrics, turning them into smart wearable fabrics.

The semiconductor fibres must be flexible and without defects for stable signal transmission. However, existing manufacturing methods cause stress and instability, leading to cracks and deformities in the semiconductor cores, negatively impacting their performance and limiting their development.

The researchers conducted modelling and simulations to understand how stress and instability occur during the manufacturing process, and found that the challenge could be overcome through careful material selection and a series of steps taken during fibre production. The researchers developed a mechanical design and fabricated hair-thin, defect-free fibres spanning 100 metres, which indicates their market stability. The fibres can also be woven into fabrics using existing methods.

To demonstrate the fibres' functionality, the researchers developed prototypes such as a smart beanie hat to help a visually impaired person cross the road safely through alerts on a mobile phone application; a shirt that receives information and transmits it through an earpiece, like a museum audio guide; and a smartwatch with a strap that functions as a flexible sensor that conforms to the wrist of users for heart rate measurement during physical activities.

The researchers believe that the innovation could enhance the development of semiconductor fibres that are ultra-long and durable, meaning they are scalable while offering electrical and optoelectronic (meaning it can sense, transmit and interact with light) performance. NTU Associate Professor Lei Wei attributed the fabrication of the semiconductor fibres to the interdisciplinary nature of the research team.

"Semiconductor fibre fabrication is a highly complex process, requiring know-how from materials science, mechanical and electrical engineering experts at different stages of the study. The collaborative team effort allowed us a clear understanding of the mechanisms involved, which ultimately helped us unlock the door to defect-free threads, overcoming a longstanding challenge in fibre technology," Wei said.

To develop the fibres, the researchers selected pairs of common semiconductor material and synthetic material — a silicon semiconductor core with a silica glass tube and a germanium core with an aluminosilicate glass tube. The materials were selected based on their attributes which complemented each other, such as thermal stability, electrical conductivity and the ability to allow electric current to flow through (resistivity).

Silicon was selected for its ability to be heated to high temperatures and manipulated without degrading, making it suitable for use in devices meant for extreme conditions such as sensors on protective clothing for firefighters. Germanium, however, allows electrons to move through the fibre quickly and work in the infrared range, which makes it suitable for applications in wearable fabric-based sensors that are compatible with indoor light fidelity (LiFi) wireless optical networks.

The researchers then inserted the semiconductor material (core) inside the glass tube and heated it at a high temperature until the tube and core were soft enough to be pulled into a thin continuous strand. Due to the different melting points and thermal expansion rates of their selected materials, the glass functioned like a wine bottle during the heating process, containing the semiconductor material which fills the bottle as it melts.

First author of the study Dr Zhixun Wang said it took extensive analysis to determine the right combination of materials and processes to develop the fibres. “By exploiting the different melting points and thermal expansion rates of our chosen materials, we successfully pulled the semiconductor materials into long threads as they entered and exited the heating furnace while avoiding defects,” Wang said.

The glass is removed once the strand cools and combined with a polymer and metal wires. After another round of heating, the materials are pulled to form a thin, flexible thread. In experiments, the semiconductor fibres showed excellent performance. When subjected to responsivity tests, the fibres could detect the entire visible light range, from ultraviolet to infrared, and transmit signals of up to 350 kHz bandwidth. The fibres were also reportedly 30 times tougher than regular ones.

The fibres were also evaluated for their washability, in which a cloth woven with semiconductor fibres was cleaned in a washing machine 10 times — results showed no significant drop in the fibre performance. The researchers will now work to apply the fibre manufacturing method to other challenging materials and to discover more scenarios where the fibres play key roles.

To demonstrate the feasibility of use in real-life applications, the researchers built a smart wearable beanie by weaving the semiconductor fibres into it, along with an interface board. When tested outdoors, light signals received by the beanie were sent to a mobile phone application, triggering an alert.

Co-author Dr Li Dong said the fibre fabrication method is versatile and easily adopted by industry. “The fibre is also compatible with current textile industry machinery, meaning it has the potential for large-scale production. By demonstrating the fibres’ use in everyday wearable items like a beanie, we prove that our research findings can serve as a guide to creating functional semiconductor fibres in the future,” Dong said.

The researchers plan to expand the types of materials used for the fibres and develop semiconductors with different hollow cores, such as rectangular and triangular shapes, to expand their applications. The research findings were published in the scientific journal *Nature*.

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