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COMMENTARY

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Sub-lattice amorphization as a new driver of room temperature plasticity in inorganic semiconductors

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BACKGROUND

Metals exhibit excellent ductility due to isotropic metallic bonding, enabling large-scale plastic deformation through dislocation motion. In contrast, inorganic semiconductors, typically bonded via covalent or ionic interactions, possess strong directional bonding that inhibits dislocation movement, rendering them brittle at room temperature. This fundamental distinction constrains the manufacturing processes of these materials, necessitating subtractive techniques such as cutting, grinding, and etching. The ability to impart metal-like plasticity to inorganic semiconductors would significantly enhance their manufacturability and expand their applications in flexible electronics, wearable devices, and bio-integrated technologies.[1]

Since 2018, a class of inorganic semiconductors, including Ag_2S,[2] Bi_2Te,[3] Mg_3Bi_2,[4] etc., has been identified with room temperature plasticity, presenting new opportunities for flexible semiconductor devices. However, the underlying deformation mechanisms vary significantly among these materials. A recent study by Wang et al., published in *Nature Materials*, unveils a previously unrecognized mechanism governing the exceptional plasticity of $Ag_2Te_{1-x}S_x$ ($0.3 \leq x \leq 0.6$): anion sub-lattice amorphization coupled with disorder-driven Ag ion diffusion (Figure 1). This finding provides a fundamental understanding of plasticity in inorganic semiconductors and suggests new strategies for designing deformable functional materials.[5]

Through a combination of synchrotron-based X-ray diffraction (XRD), *in situ* transmission electron microscopy (TEM), and molecular dynamics simulations, Wang et al. at Zhejiang University elucidated the deformation behavior of $Ag_2Te_{1-x}S_x$. Their results reveal that minor mechanical stress can trigger sub-lattice amorphization in the Te/S anion framework, enabling plastic strains without structural collapse. The process, termed "iterative sub-lattice amorphization," allows for extraordinary elongation (up to 10,150%) through a rolling-induced amorphization-recrystallization cycle.

Moreover, this work demonstrates that the intrinsic superionic conductivity of $Ag_2Te_{1-x}S_x$ plays a crucial role in its plasticity. Unlike conventional metals and alloys, where dislocation-mediated deformation dominates, $Ag_2Te_{1-x}S_x$ deforms via a unique mechanism wherein the rigid anion sub-lattice transforms into a metastable amorphous phase while maintaining local bonding integrity. This mechanistic insight paves the way for the rational design of other plastic semiconductors.

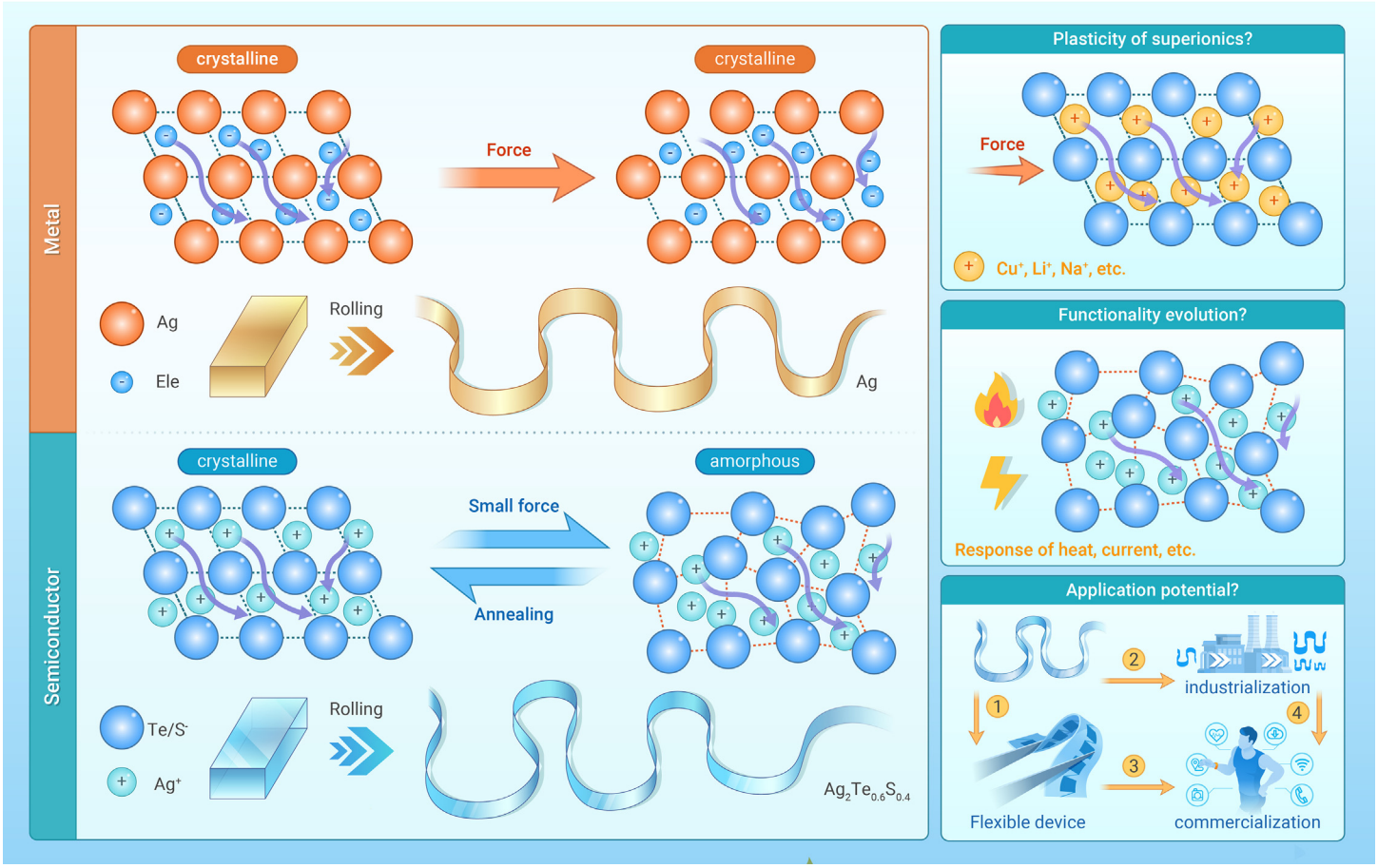

Figure 1. Deformation mechanisms of metals, crystalline, and amorphous inorganic bulk semiconductors

PROSPECTS AND CHALLENGES

The discovery of plasticity in inorganic semiconductors represents a significant breakthrough in materials science, yet several fundamental and applied challenges remain (Figure 1). First, while experimental results suggest that repeated rolling and annealing have a limited impact on performance, the underlying mechanisms require further elucidation. A critical question is whether similar deformation-induced amorphization mechanisms apply to other superionic conductors. Addressing this issue could guide the design of next-generation materials with tailored mechanical and electronic properties.

Second, the impact of plastic deformation on thermoelectric performance remains an open question. While amorphization enhances ductility, its effects on carrier mobility and electrical transport properties remain insufficiently explored. Currently, the thermoelectric performance of these materials might require further optimization, and the interplay between plasticity and thermoelectric properties needs to be systematically investigated. Future studies could focus on strategies to synergistically enhance both plasticity and thermoelectric performance through compositional tuning or controlled processing.

Third, a more comprehensive understanding of device integration challenges is essential. While this study demonstrates the feasibility of large-strain deformation via rolling, the seamless incorporation of plastically deformable semiconductors into existing device architectures—such as flexible electronics and wearables—remains an open question. In particular, the effects of plasticity on electrode interface stability and operational reliability warrant further investigation.

Despite these challenges, plastically deformable inorganic semiconductors offer vast technological opportunities. Potential applications range from flexible thermoelectric devices and stretchable photovoltaics to reconfigurable optoelectronics. In the long term, advancements in this field may pave the way for self-healing electronic circuits and bio-integrated implants that conform seamlessly to dynamic biological environments.

Moving forward, interdisciplinary collaboration among materials scientists, electrical engineers, and industrial researchers will be critical in unlocking the full potential of these materials. By addressing current limitations and refining processing methodologies, plastic inorganic semiconductors could play a transformative role in the future of flexible and wearable electronics.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Mori, T. (2023). A flexible feature for the long-reigning thermoelectric champion bismuth telluride. *Nat. Nanotechnol.* **18**:1255–1256. DOI:https://doi.org/10.1038/s41565-023-01464-6.
2. Shi, X., Chen, H., Hao, F. et al. (2018). Room-temperature ductile inorganic semiconductor. *Nat. Mater.* **17**:421–426. DOI:https://doi.org/10.1038/s41563-018-0047-z.
3. Lu, Y., Zhou, Y., Wang, W. et al. (2023). Staggered-layer-boosted flexible Bi_2Te_3 films with high thermoelectric performance. *Nat. Nanotechnol.* **18**:1281–1288. DOI:https://doi.org/10.1038/s41565-023-01457-5.
4. Zhao, P., Xue, W., Zhang, Y. et al. (2024). Plasticity in single-crystalline Mg3Bi2 thermoelectric material. *Nature* **631**:777–782. DOI:https://doi.org/10.1038/s41586-024-07621-8.
5. Wang, Y., Li, A., Hong, Y. et al. (2025). Iterative sublattice amorphization facilitates exceptional processability in inorganic semiconductors. *Nat. Mater.* DOI:https://doi.org/10.1038/s41563-024-02112-7.