Freestanding semiconductor nanomembranes: from materials to devices

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Semiconductor-based freestanding membranes (FSMs) have emerged as promising materials for advanced device applications due to their lightweight and flexible nature. Which make them an excellent enabling technology which can potentially impact the integration of III-V on silicon, due to their easy stackability. However, the production of high-quality single-crystalline FSMs, particularly from elemental materials like germanium (Ge), remains challenging by using existing techniques. In this work, we propose a novel approach called the Porous germanium Efficient Epitaxial LayEr Release (PEELER) process, which enables the fabrication of wafer-scale detachable monocrystalline Ge nanomembranes (NMs) on porous Ge (PGe) with substrate reuse capability.

Through the PEELER process, we demonstrate the creation of monocrystalline Ge NMs with surface roughness below 1 nm, using a nanoengineered void layer that enables layer detachment. Moreover, these Ge NMs exhibit compatibility with the growth of III-V materials, as confirmed by high-resolution transmission electron microscopy (HRTEM) characterization of their crystallinity.

Furthermore, we have developed a chemical reconditioning process of the Ge substrate, which allows for its reuse, enabling the production of multiple freestanding NMs from a single parent wafer. This breakthrough significantly reduces the consumption of Ge during the fabrication process, paving the way for a new generation of low-cost flexible optoelectronic devices.

As a proof-of-concept demonstration, we utilize the PEELER technique to grow a solar cell device. Our experimental results reveal a highly efficient device, highlighting the practical applicability and superior performance of Ge NMs produced using the PEELER process.

The PEELER process represents a significant advancement in the field of freestanding membranes and offers a scalable method for the production of high-quality, wafer-scale monocrystalline Ge NMs. These findings contribute to the development of low-cost flexible and stackble optoelectronics, enabling the realization of innovative devices for various applications.