Smaller, more powerful devices possible with new technique

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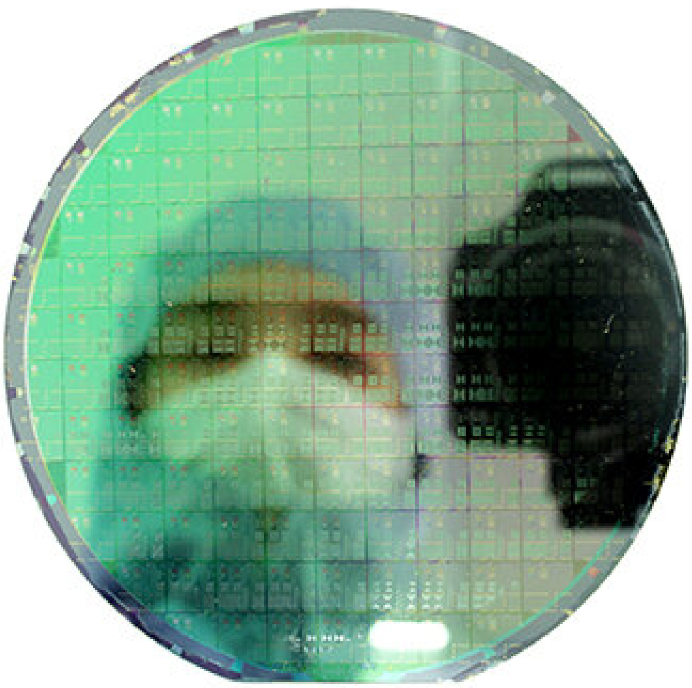


Researcher Arne Quellmalz says the new technique draws on the existing toolkit for semiconductor manufacturing. Credit: Arne Quellmalz, KTH Royal Institute of Technology

Shrinking semiconductors even further would enable a whole new silicon revolution. But because that's impossible, the next best hope is integrating semiconductors with 2-D atomically-thin materials, such as graphene, upon which circuits can be created on an incredibly small scale. A research team reports a new method to make this notoriously difficult combination work on an industrial scale.

The technique was reported today in *Nature Communications* by researchers from KTH Royal Institute of Technology in Stockholm, in collaboration with RWTH Aachen University, Universität der Bundeswehr München, AMO GmbH and Protemics GmbH, in Germany.

A reliable, industrially scalable method of integrating 2-D materials such as graphene with silicon semiconductors would help downscale electronics and usher in new capabilities for sensor technology and photonics.

However, the integration of 2-D materials to the semiconductor or a substrate with integrated electronics is fraught with a number of challenges. "There's always this critical step of transferring from a special growth substrate to the final substrate on which you build sensors or components," says Arne Quellmalz, a researcher in photonic microsystems at KTH.

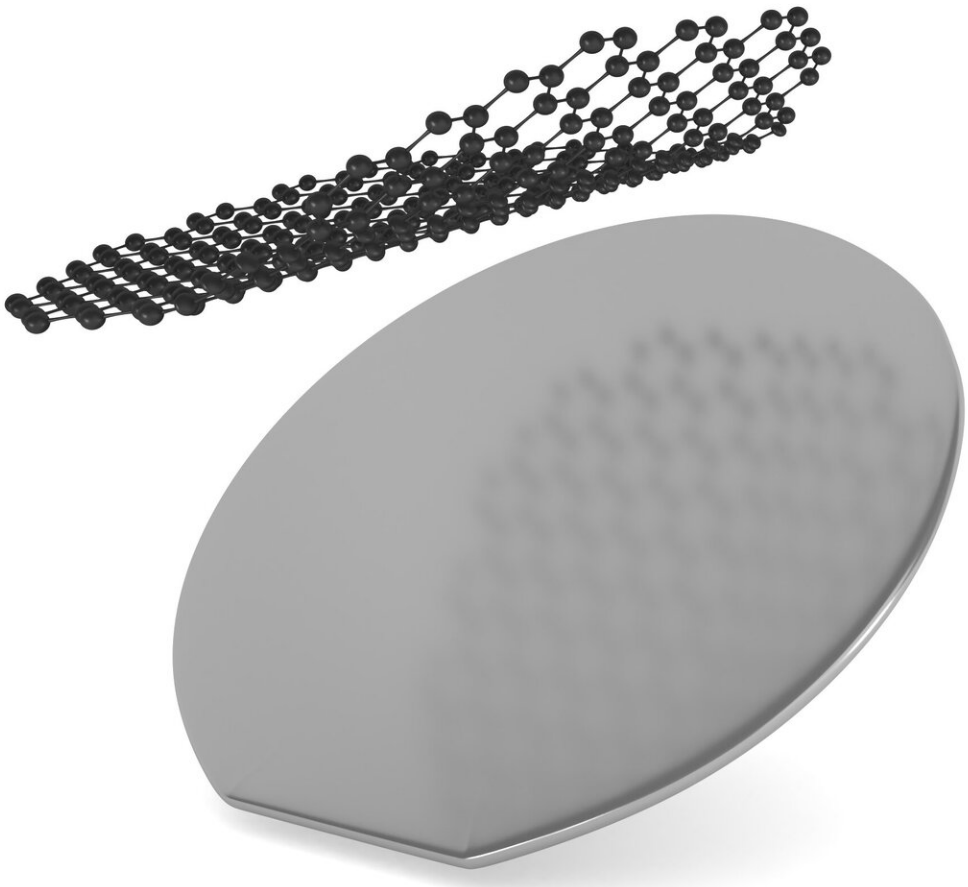
"You might want to combine a graphene photodetector for optical on-chip communication with silicon read-out electronics," Quellmalz says. "But the growth temperatures of those materials is too high, so you cannot do this directly on the device substrate."

A wafer integrated with 2-D material. Credit: Arne Quellmalz, KTH Royal Institute of Technology

Experimental methods for transferring grown 2-D material to desired electronics have been beset by a number of deficiencies, such as degradation of the material and its electronic transport properties, or by contamination of the material.

Quellmalz says that the solution lies in the existing toolkits of semiconductor manufacturing: to use a standard dielectric material called bisbenzocyclobutene (BCB), along with conventional wafer bonding equipment.

"We basically glue the two wafers together with a resin made of BCB," he says. "We heat the resin, until it becomes viscous like honey, and press the 2-D material against it."



A scalable method for the large-area integration of 2D materials. Credit: Arne Quellmalz (Graphene Flagship/KTH Sweden)

At room temperature, the resin becomes solid and forms a stable connection between the 2-D material and the wafer, he says. "To stack materials, we repeat the steps of heating and pressing. The resin becomes viscous again and behaves like a cushion, or a waterbed, which supports the layer stack and adapts to the surface of the new 2-D material."

The researchers demonstrated the transfer of graphene and molybdenum disulfide (MoS_2), as a representative for transition metal dichalcogenides, and stacked graphene with hexagonal boron nitride (hBN) and MoS_2 to heterostructures. All transferred layers and heterostructures were reportedly of high quality, that is, they featured uniform coverage over up to 100-millimeter sized silicon wafers and exhibited little strain in the transferred 2-D materials, the paper states.

More information: Large-area integration of two-dimensional materials and their heterostructures by wafer bonding, Quellmalz et al. *Nature Communications*, DOI: 10.1038/s41467-021-21136-0

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