Graphene tunnelling junctions: beyond the breaking point

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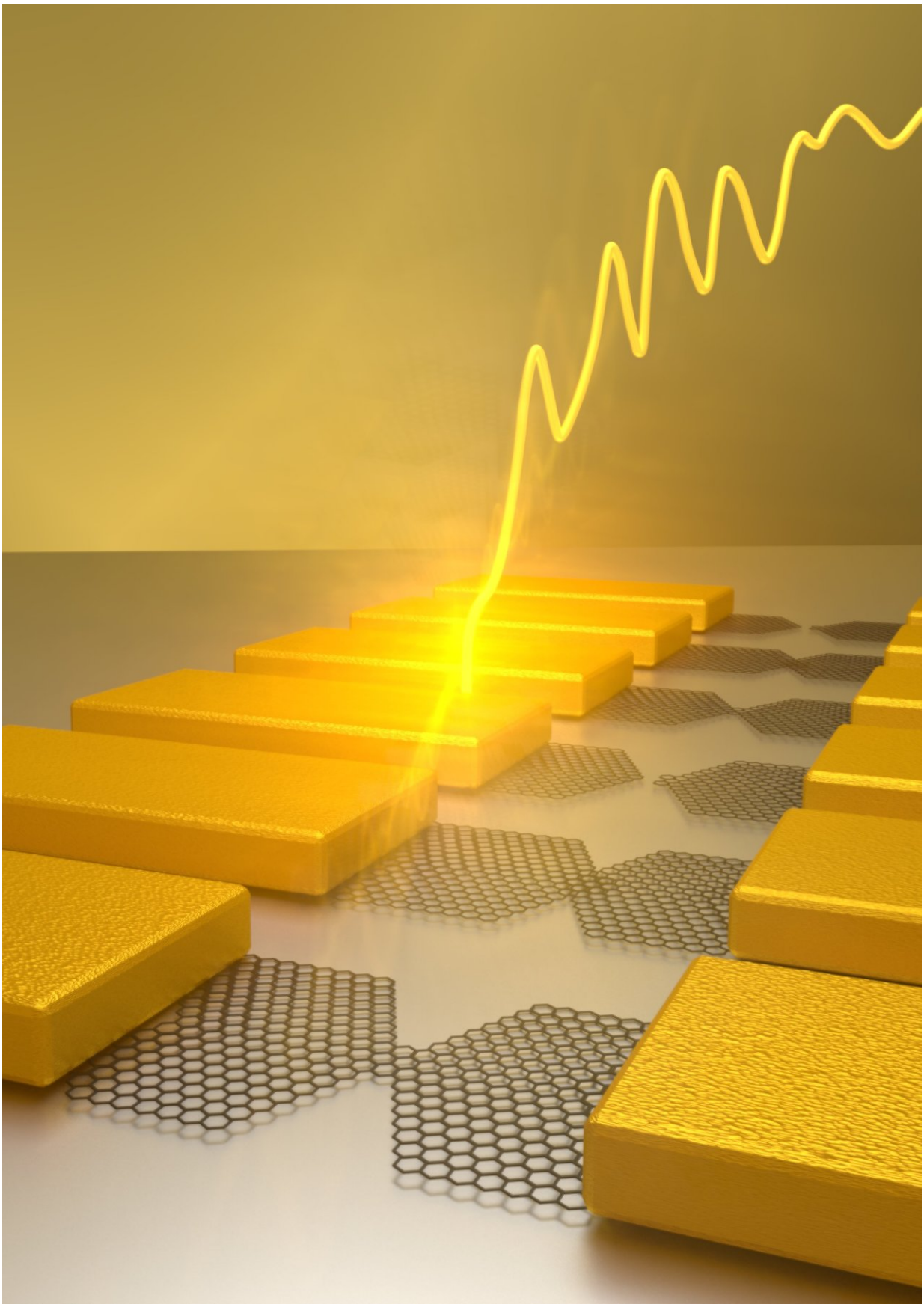

Credit: TU Delft/Sabina Caneva

Molecular electronics is a burgeoning field of research that aims to integrate single molecules as active elements in electronic devices. Obtaining a complete picture of the charge transport properties in molecular junctions is the first step toward realizing functionality at the nanoscale. Researchers from Delft University of Technology have now studied the charge transport in a novel system, the graphene mechanical break junction, which for the first time allowed direct experimental observation of quantum interference effects in bilayer graphene as a function of nanometer-displacements. This new platform could potentially be used for electronic fingerprinting of biomolecules, from DNA to proteins, which in turn can have important implications for the diagnosis and treatment of diseases.

Nanogaps separating two electrodes are envisaged as the basis for the next generation of sensing technologies. The aim is to exploit quantum electron tunneling as the sensing principle, in which the electronic structure of the target molecule trapped in the nanogap is directly probed. Graphene, a monolayer of carbon atoms in a hexagonal lattice, combines many of the requisites for an electrical sensor material: high conductivity, atomic thinness, flexibility, chemical inertness in air and liquid, and mechanical strength, as well as its compatibility with standard lithographic patterning techniques.

At the Kavli Institute of Nanoscience in Delft, a research group is developing robust graphene-based mechanically controlled break junctions (MCBJs), which allow the formation of a size-adjustable tunnelling gap at the sub-nanometre scale, i.e. the size can be tailored to

the size of the biomolecule to be probed.

Mind the gap

The MCBJ experiment is conceptually very simple. The device consists of a graphene bowtie structure supported on a flexible metal substrate. The substrate is gradually bent, causing stretching of the graphene. This graphene bridge eventually breaks and a nanoscopic gap is formed. Importantly, the junction conductance can be reversibly switched by almost six orders of magnitude during 1,000 opening-closing cycles; i.e. it acts as an electrical switch that can be turned on-off mechanically. The impressive mechanical stability allows for the collection of statistically significant data, capturing various behaviours of the junctions over time and in different environments (e.g. different molecule orientations, in air, vacuum, liquid).

In collaboration with the theory group led by Prof Jaime Ferrer at the University of Oviedo (Spain), the researchers also confirmed the interference of electron waves during measurements in air at room temperature. The findings are an important step for both fundamental physics and for future applications of graphene as an electromechanical switch or biosensing platform.

Electronic fingerprinting

The graphene MCBJ is a unique device that is on the one hand a model system for studying quantum transport at room temperature, and on the other can be a powerful sensing tool to probe biomolecules with very high resolution. The researchers are currently exploring the potential of this platform for electronic fingerprinting of biomolecules, including amino acids and short peptides: the aim is to discriminate molecules with slight chemical difference according to their electronic structure, which can be 'read' when the molecules are trapped in the nanogap. This would

provide the first steps into "tunneling-based" biosensing with graphene, a compelling vision at the Departments of Quantum and Bionanoscience at TU Delft.

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More information: Sabina Caneva et al. Mechanically controlled quantum interference in graphene break junctions, *Nature Nanotechnology* (2018). DOI: 10.1038/s41565-018-0258-0

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