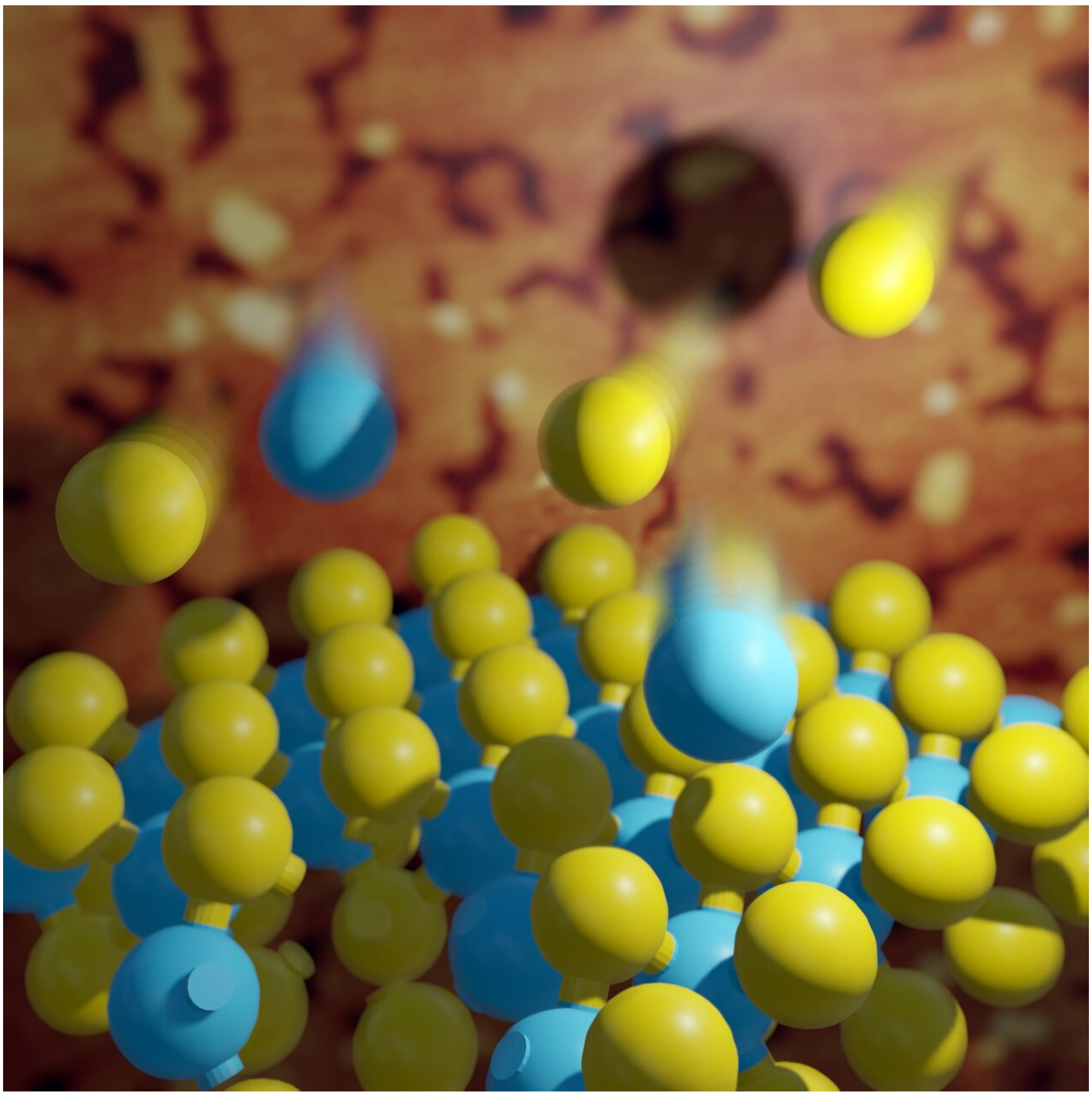
Breakthrough in research on production of 2-D crystals with excellent optical properties

May 20 2020



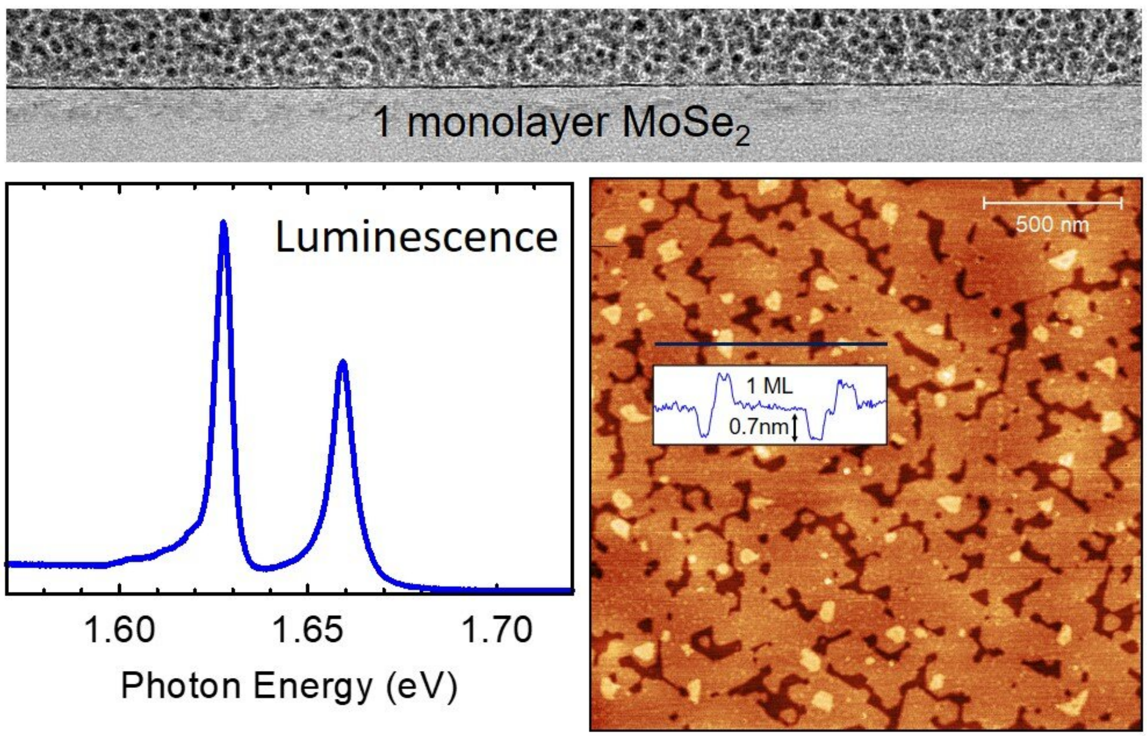
Artistic visualisation: monolayer of 2D material -- molybdenum diselenide (MoSe2) is grown by directing molecular beams of selenium (yellow) and molybdenum (blue) on atomically flat hexagonal boron nitride substrate. Thanks to this substrate, MoSe2 epilayer exhibits excellent optical properties. The image was chosen for the cover of the May 2020 issue of ACS Nano Letters. Credit: UW Physics, A. Bogucki, W. Pacuski

For the first time, monolayers of transition metal dichalcogenides with excellent optical properties were grown. A team of physicists from the University of Warsaw managed to overcome the technical difficulties faced by industry and scientists from around the world—namely the very limited size, heterogeneity, and broadening of the spectral lines of fabricated materials. Monolayers without these defects were grown by molecular beam epitaxy on atomically flat boron nitride substrates.

Two-dimensional crystals with a honeycomb structure, including the famous graphene, have already revolutionized nanoscience and have the potential to revolutionize common technologies, as well. Therefore, it is highly desirable to develop industrial-scale methods for their production.

However, despite substantial investments in the development of growth techniques for atomically thin crystals, the best quality monolayers are currently still obtained using exfoliation, i.e. due to the mechanical detachment of individual atomic layers from the bulk crystal. For example, graphene flakes exfoliated from bulk graphite exhibit superior electrical properties when compared to grown graphene. In contrast, the size of the mechanically exfoliated monolayers is rather small.

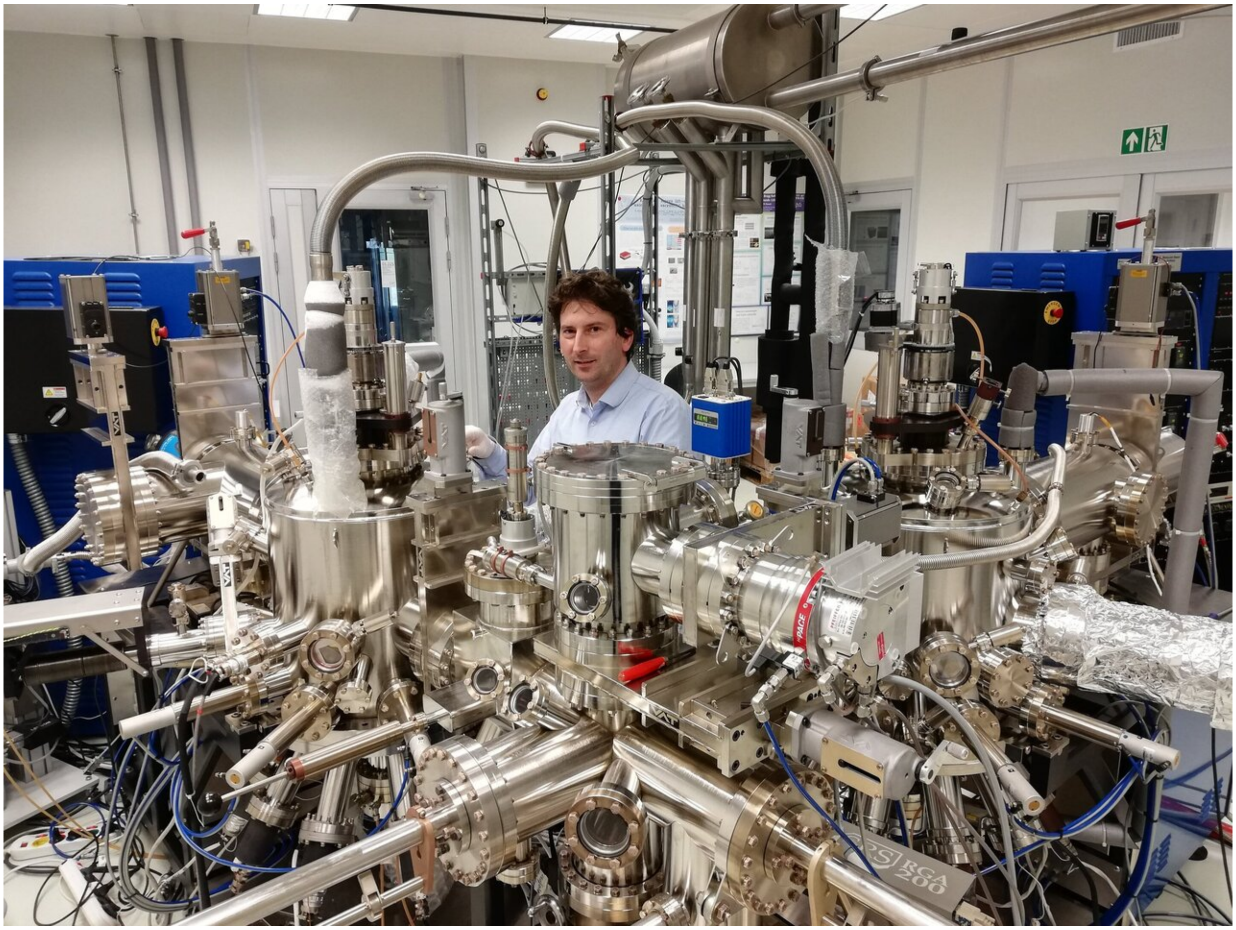
Similarly, optical properties of two-dimensional transition metal dichalcogenides (e.g. molybdenum diselenide) are fully revealed only for layers obtained as a result of exfoliation and after having been subjected to further mechanical treatment, such as placing them between layers of boron nitride. However, as already mentioned, this technique does not lead to atomically thin crystals on a larger scale, resulting in heterogeneity, limited size, and even to the appearance of corrugations, bubbles, and irregular edges.



Cross-section (top), luminescence (left), and atomic force microscopy image (right) of a MoSe2 monolayer grown using molecular beam epitaxy on hexagonal boron nitride substrate. Narrow lines in luminescence spectrum shows high optical quality of the layer. Credit: UW Physics

Hence, it is crucial to develop a technique for growing two-dimensional transition metal dichalcogenides that will allow for the production of monolayers with a large surface area. Currently, one of the most advanced technologies for producing thin semiconductor crystals is molecular beam epitaxy (MBE). It provides low-dimensional structures on large wafers, with high homogeneity, but its effectiveness in the production of transition metal dichalcogenides has been very limited so far. In particular, the optical properties of MBE grown monolayers have hitherto been rather modest, e.g. spectral lines have been broad and weak, showing little prospect for the use of the spectacular optical properties of transition metal dichalcogenides on a larger scale.

It is in this area that researchers from the Faculty of Physics of the University of Warsaw made a breakthrough. In collaboration with several laboratories from Europe and Japan, they conducted a series of studies on the growth of transition metal dichalcogenides monolayers on an atomically flat boron nitride substrate. In this way, using the MBE method, they obtained flat crystals, equal in size to the substrate, showing uniform parameters over the entire surface, including—most valuably—excellent optical properties.



Dr. Wojciech Pacuski in molecular beam epitaxy (MBE) laboratory at the University of Warsaw. Credit: UW Physics

The results of the work have just been published in the latest volume of the prestigious journal *Nano Letters*. The discovery directs future research into the industrial production of atomically thin materials. In particular, it indicates the need to develop larger atomically flat boron nitride wafers. On such wafers, it will be possible to grow monolayers with the optical quality, dimensions, and homogeneity required for optoelectronic applications.

More information: Wojciech Pacuski et al, Narrow Excitonic Lines

and Large-Scale Homogeneity of Transition-Metal Dichalcogenide Monolayers Grown by Molecular Beam Epitaxy on Hexagonal Boron Nitride, *Nano Letters* (2020). DOI: 10.1021/acs.nanolett.9b04998

Provided by University of Warsaw