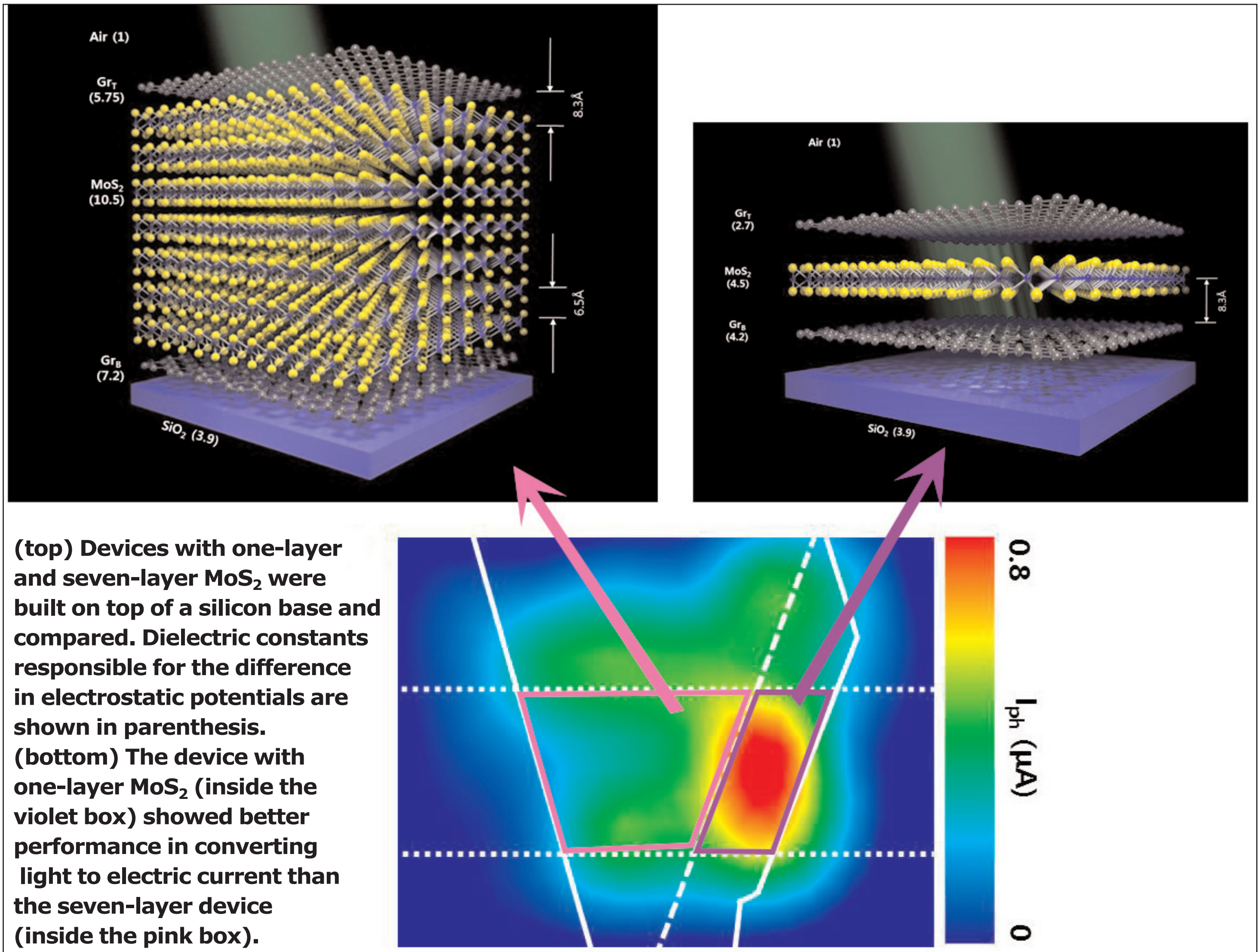
South Korea's Institute for Basic Science develops thinnest photodetector

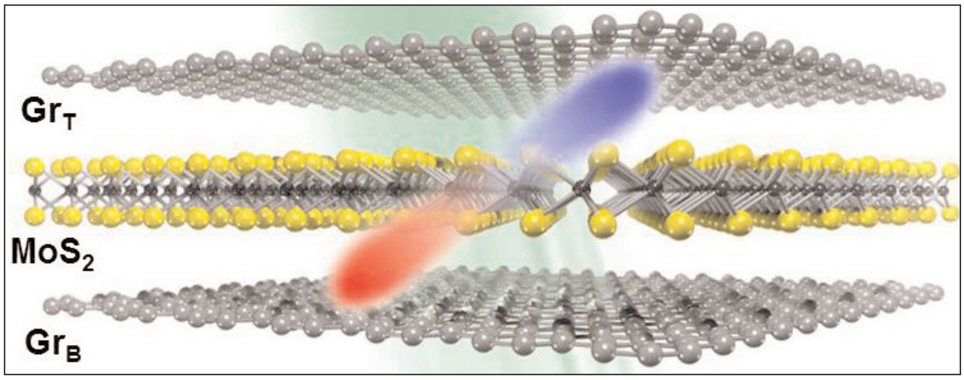
MoS_2 sandwiched by graphene enables 1.3nm-thick monolayer device to achieve higher photoresponsitivity than seven-layer device.

By using 2D technology comprising molybdenum disulfide (MoS_2) sandwiched in graphene, South Korea's Institute for Basic Science (IBS) Center for Integrated Nanostructure Physics at Sungkyunkwan University (SKKU) has developed what is reckoned to be the world's thinnest photodetector (Woo Jong Yu et al, 'Unusually efficient photocurrent extraction in monolayer van der Waals heterostructure by tunneling through discretized barriers', Nature Communications (2016); DOI: 10.1038/ncomms13278). With a thickness of just 1.3nm (10 times smaller than existing standard silicon diodes) the device could be used in the Internet of Things, smart devices, wearable electronics and photoelectronics.

Graphene is conductive, thin (just one atom thick), transparent and flexible. However, since it does not behave as a semiconductor, its application in the electronics industry is limited. So, to increase graphene's usability, IBS has sandwiched a layer of the 2D semiconductor MoS_2 between two graphene sheets and put it over a silicon base. They initially thought that the resulting device was too thin to generate an electric



(top) Devices with one-layer and seven-layer MoS_2 were built on top of a silicon base and compared. Dielectric constants responsible for the difference in electrostatic potentials are shown in parenthesis. (bottom) The device with one-layer MoS_2 (inside the violet box) showed better performance in converting light to electric current than the seven-layer device (inside the pink box).



Device with MoS_2 layer sandwiched between top (GrT) and bottom (GrB) graphene layers. Light (green ray) is absorbed and converted into electric current. When light is absorbed by the device, electrons (blue) jump into a higher energy state and holes (red) are generated in the MoS_2 layer. Motion of holes and electrons created by the difference in electronic potential between the GrT-MoS_2 and the GrB-MoS_2 junctions generates the electric current.

current but, unexpectedly, it did. "A device with one layer of MoS_2 is too thin to generate a conventional p–n junction, where positive (p) charges and negative (n) charges are separated and can create an internal electric field. However, when we shine light on it, we observed high photo-current," says Yu Woo Jong, first author of this study. "Since it cannot be a classical p-n junction, we thought to investigate it further."

To understand what they found, the researchers compared devices with one and seven layers of MoS_2 and tested how well they behave as a photodetector, i.e. how they are able to convert light into an electric current. They found that the device with one layer of MoS_2 absorbs less light than the device with seven layers, but it has higher photoresponsitivity. "Usually the photocurrent is proportional to the photoabsorbance; that is, if the device absorbs more light, it should generate more electricity, but in this case, even if the one-layer MoS_2 device has smaller absorbance than the seven-layer MoS_2, it produces seven times more photocurrent," says Yu.

The monolayer is thinner and therefore more sensitive to the surrounding environment. The bottom SiO_2 layer increases the energy barrier, while the air on top reduces it, thus electrons in the monolayer device have a higher probability of tunneling from the MoS_2 layer to the top graphene (GrT). The energy barrier at the GrT/MoS_2 junction is lower than the one at the GrB/MoS_2, so the excited electrons transfer preferentially to the GrT layer and create an electric current. Conversely, in the multi-layer MoS_2 device, the energy barriers between GrT/MoS_2 and GrB/MoS_2 are symmetric, therefore the electrons have the same probability to go either side and thus reduce the generated current.

For these reasons, up to 65% of photons absorbed by the thinner device are used to generate a current. Instead, the same measurement (quantum efficiency) is only 7% for the seven-layer MoS_2 apparatus.

"This device is transparent, flexible and requires less power than the current 3D silicon semiconductors. If future research is successful, it will accelerate the development of 2D photoelectric devices," Yu believes. ■

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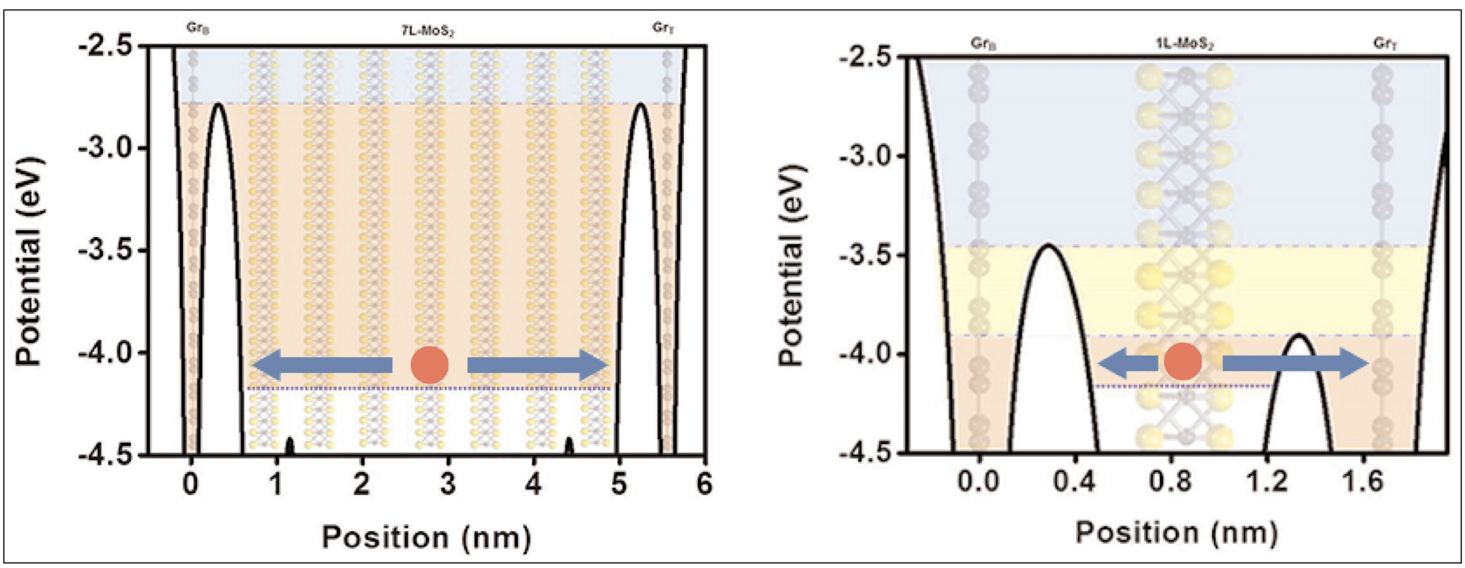

How the device with one-layer MoS_2 generates more photocurrent than the seven-layer MoS_2 one. In the one-layer device MoS_2 (right), the electron (red circle) has a higher probability to tunnel from the MoS_2 layer to the GrT because the energy barrier (white arch) is smaller in that junction. In the seven-layers MoS_2 device (left) instead, the energy barrier between MoS_2/GrT and MoS_2/GrB is the same so electrons do not have a preferred direction flow. More energy is generated in the one-layer MoS_2 device because more electrons flow in the same direction.