In 2014, research groups in the United States and China reported on work towards a promising candidate that could fulfil both needs: phosphorene, an atom-thick layer of the element phosphorus that does have a natural band gap. The work is part of a trend that David Tománek, a condensed-matter theorist at Michigan State University in East Lansing, dubs the “post-graphene age” — in which researchers are exploring alternatives in the hope of overcoming graphene’s deficiencies.

Unlike graphene, phosphorene acts as a semiconductor that can easily be switched on and off. This property could substantially lower the energy needed to power transistors, in turn lowering the heat that they generate. Phosphorene might be useful for making thin, flexible electronics that could be more easily cooled than silicon ones. First flexible devices and circuits based on few-layer BP on a highly bendable polyimide (PI) substrate were already fabricated.

Physicists have been studying black phosphorus — a layered material held together by weak chemical bonds — since the 1960s. But it was only last year that they began trying to isolate single layers. Just as in graphene, phosphorene atoms are arranged hexagonally, but in phosphorene the surface is slightly puckered. With its band gap, phosphorene can be switched between insulating and conducting states, and it is still flat enough to confine electrons so that charge flows quickly, leading to a relatively high mobility that is prized by electrical engineers.

In December of 2013 two groups reported that they had stripped black phosphorus to two or three atomic layers by using sticky tape to peel the layers off a larger sample — the same method used in 2004 to isolate layers of graphene. The puckered crystal structure distinguishes its physical properties from plane-structured graphene with a thickness-tuned bandgap ranging from 0.3 to ∼2eV. Its exceptional electrical properties include high hole mobility (∼1000 cm^2/Vs) and high field-effect current modulation. A number of remarkable properties that actually make this now two-dimensional material a good candidate for next-generation electronics.

Few-layer BP obtained by mechanical exfoliation from high-quality bulk BP crystal is extremely sensitive to the ambient environment, with modification typically commencing within one hour of exposure. It has to be used in a vacuum or effectively encapsulated or changing electrical and physico-chemical properties. Authors propose to apply nanodiamond foils fabricated in their lab for simultaneous selective encapsulation and transfer of electrical signal.

Authors would like to apply this phenomenon for sensing purposes. The main aim of the study is to investigate various methods of phosphorene synthesis and perform deep studies on their electronic parameters versus different biological environments. We plan to focus our project of various important proteins and their sensing using flexible phosphorene devices. In near future they could be applied in wearable, even internal, biosensors that monitor even our most intimate biological processes or interact with our neural system (stretchable electronic or bioelectronics).