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The potential of new building block-like nanomaterials: van der Waals heterostructures

A new review examines the potential uses and scientific, technical and manufacturing problems facing 'van der Waals heterostructures' - an emerging science which uses building block-like nanomaterials. Van der Waals heterostructures are nanomaterials built by layering different materials, each one atom thick, on top of each other, to create materials with unique properties and uses.

Graphene, a honeycomb-like two-dimensional (2D) crystal, is just one atom thick. It has chemical, electrical and mechanical properties unlike its three-dimensional (3D) graphite form. There has been a boom in research to exploit these properties for various applications, which range from carbon-based computer chips and solar cells, to tissue engineering and drug delivery.

Researchers are now identifying and probing the properties of other 2D crystals and the ways they may be combined. The combined layers of different 2D crystals are called 'van der Waals heterostructures', named after the weak 'van der Waals' chemical bonds which hold the different layers together.

By swapping or changing the number and order of the different 2D-crystal layers, it is hoped that new materials, with properties not found in their component parts could be made. As different layers of materials are stacked on one another their physical and quantum properties can, in effect, combine, interfere or cancel one another, to greater or lesser degrees depending on the materials, leading to the new properties. The authors of this study review this fledgling research area by discussing the potential of van Der Waals heterostructures. Among the possible applications they consider are room temperature superconductors, which would allow new highly efficient electric motors and generators, and potentially power transmission without any loss of energy.

However, there are problems that must be overcome before van Der Waals heterostructures can be used in applications. For example, while there are many materials from which 2D crystals could be made, few are stable under ambient conditions. The surfaces of larger 3D crystals can undergo chemical reactions which protect the rest of the crystal; however, for a single atom thick 2D layer of the same material, these reactions would destroy them. This limits the number of useful materials which could be used, or presents complex manufacturing hurdles to overcome.

So far, around 12 suitable 2D crystals, which are stable under ambient conditions, have been identified. The researchers developed three broad principles to help identify more. Firstly, 3D crystals with high melting temperatures are most likely to have stable 2D crystals. Secondly, parent crystals must be relatively chemically inert. Finally, insulating and semiconducting materials are likely to be more stable than metallic ones.

The researchers say that despite their complicated fabrication, van der Waals heterostructures can now be produced for laboratory purposes within a few days. In the future, the most likely manufacturing technique for use in industry will probably involve growing separate sheets of 2D crystals and then layering, rather than growing, one on top of another.

Scientific and industrial interest in van der Waals heterostructures continues to grow, mirroring that of graphene. As the number of materials and techniques expands, the authors suggest this could cause a snowball effect, with a potentially endless choice of possible van der Waals structures leading to as yet unimagined applications, benefiting a wide range of areas, from renewable energy to medicine. However, as with all new technologies, they may fall short of being able to realise current aspirations, such as super-efficient electric motors and generators.

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