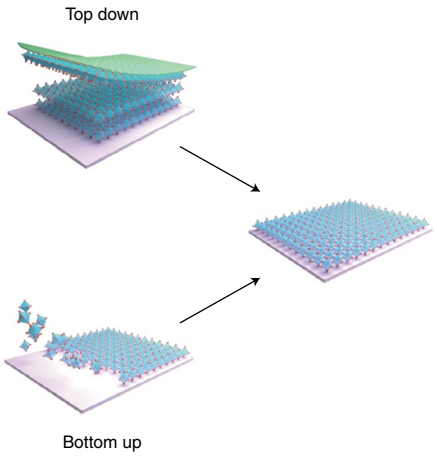
A stand out family

Research continues to showcase the versatility and application potential of perovskites, while our understanding of their structural and mechanical properties continues to improve.

Gustav Rose, a nineteenth-century German mineralogist and crystallographer, first discovered crystal calcium titanate in 1839 in the Ural Mountains and named it 'perovskite' after fellow Russian mineralogist Lev Perovski[1]. Little did he know that the broader family of perovskite materials — including both metal-oxide and metal-halide octahedral structures surrounded by inorganic or organic cations — would have made him so famous in the following centuries among researchers working in very different fields, such as superconductivity, ferroelectrics, water splitting, energy storage and photovoltaics. The chemical versatility of this structure lends itself to almost endless opportunities for optimizing its composition and properties. The chemical exploration of metal-halide perovskites has recently heralded a renaissance for photovoltaic research and has unveiled other intriguing properties, encouraging researchers to test perovskites in an even broader range of applications, such as lighting, electronics, radiation detection and catalysis.

In this issue of *Nature Materials*, two Review Articles and a Perspective article discuss some of the most recent outcomes of such exploration. In their Perspective, Rui Su and colleagues overview the potential of metal-halide perovskite semiconductors as a platform for the generation of exciton-polaritons. These quasiparticles, formed by the strong interaction between excitons and photonic modes in a semiconducting material embedded in an optical microcavity, have been used by scientists to demonstrate lasers with extremely low excitation threshold, all-optical transistors and logic gates, as well as systems for non-conventional computing. Metal-halide perovskites, with their high exciton binding energy and strong optical nonlinearity, are a boon for these devices, potentially allowing their operation at room temperature. Su and colleagues explain that large-area, defect-free and structurally homogeneous perovskite crystals will be key to ensure uniformity of the optoelectronic properties and improved optical quality of the fabricated microcavities; the resulting increase of the polaritons' lifetime and the possibility for them to form condensates and propagate over long distances will enable the realization of ever more complex logic circuits. Polaritonic applications have already been demonstrated using crystals of three-dimensional (3D) halide perovskites, as well as systems with reduced dimensionality such as nanocrystals, nano- and microwires, and 2D layered perovskites.



Adapted with permission from the Review Article by Ricciardulli and colleagues.

Graphene's legacy nicely exemplifies the breadth of research paths that can be opened by spatially confining a material to a thickness of one or few atoms. Similarly, limiting the thickness of 2D perovskites to only one or a few octahedra is unlocking properties that could prove particularly advantageous in applications. Beyond exciton-polaritonics, Antonio Gaetano Ricciardulli and colleagues highlight in their Review Article that 2D perovskites may find promising use as monolayers in photodetectors, transistors and spintronic devices. They discuss the challenges in controlling thickness and chemical composition across the sample during the synthesis of monolayers of 2D metal-halide and metal-oxide perovskites. The preferred top-down or bottom-up synthesis method (pictured) depends on the type of 2D perovskite targeted, either layered or non-layered. Chemical composition, thickness and the presence of organic cations all contribute to the optoelectronic properties of these materials, such as conductivity and carrier mobility. Like other 2D materials, changes in the dielectric environment can also be used to tune the electronic and excitonic response of 2D perovskites. Unlike graphene and stiffer materials, however, the typical soft and ionic lattice of perovskites makes them more sensitive to structural deformations due to external stimuli, which further influence the local properties of these materials.

Indeed, researchers are now putting the mechanical response of metal-halide perovskites in the spotlight. Recent studies, discussed by Dongtao Liu and colleagues in their Review Article, are showing that perovskite films, which are among the most brittle and fragile photovoltaic materials, can retain a relatively high amount of residual strain. Whether strain is a friend or foe for solar cells is up for discussion, as it has shown to either increase or decrease the optical bandgap, photoluminescence lifetime, carrier mobility and other parameters depending on the perovskite composition, deposition procedure and characterization conditions adopted. Its impact on the structural stability of the perovskite layers and interfaces also requires attention, as it may affect the long-term reliability of solar cells. While various approaches to engineer strain are being put forward, their mechanistic understanding requires careful and detailed investigation; the adoption of in situ and ex situ characterization techniques with high spatial resolution will help this systematic analysis.

Over the past few decades, perovskites have proved to be one of the most versatile playgrounds for materials scientists. Ultimately, each field of application will find its own champion within this broad family, be it oxide- or halide-based, fully inorganic or hybrid, 3D or with reduced dimensionality; yet, the advances made in one field on the synthesis, characterization and understanding of fundamental properties are likely to help progress in other areas of perovskite research too. Time will tell if another Nobel prize will be awarded to perovskites[1]; surely, their broad impact in fundamental and applied research is still on the rise, and it is easy to predict that this family will continue to stand out. ❐

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References

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