membrane environment, the higher the probability that the segment will stay there. Moreover, an amphipathic segment would find a favourable location in the lipid–water interface near the opening site, decreasing the likelihood that it will partition into the membrane.

Hessa and colleagues' results establish rules for membrane-protein insertion and folding. The thermodynamic scale derived in this work provides a starting point for understanding the preferences for the insertion of isolated helices. It seems likely that other factors will also contribute to this process, however. For example, interactions between neighbouring helices are likely to be a major factor. If a previously inserted helix interacts strongly with a translocating segment, it could drive the putative equilibrium in favour of membrane insertion, even if that segment would not normally insert in isolation. Loop lengths and loop folding could have a similar role. In addition, other proteins (such as TRAM[2]) could be involved in chaperoning the transmembrane segments into the membrane. Nevertheless, the work of Hessa *et al.* builds a quantitative thermodynamic foundation that will allow these questions to be addressed. It also provides an important step towards the ultimate goal of predicting membrane-protein structure from sequence information. ■

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Materials science

Build your own superlattice

Guus Rijnders and Dave H. A. Blank

Artificial materials made from oxide building blocks turn out to be excellent ferroelectrics. This shows that materials with specific properties can be designed by atomic-scale tailoring of their composition.

Ferroelectric oxides are used in a wide range of applications — random-access memories in computers, accelerometers in airbags or inkjet printers, telecommunication signal-processing devices and high-frequency devices for ultrasonic medical imaging, to name just a few. Predictions[1] that the performance of a ferroelectric oxide can be significantly improved by combining it with other oxides in a carefully tailored lattice have now been borne out by experiment. On page 395 of this issue, Lee *et al.*[2] show that such a 'superlattice' has a 50% enhancement in ferroelectric polarization compared with barium titanate, its only ferroelectric component. One of the key aspects of their method is the degree of control achieved at the atomic level during the growth of this artificial material.

Ferroelectrics are materials in which positive and negative charge centres separate spontaneously so that one side of the material is positive and the other negative. This polarization of charge exists even in the absence of an external electric field and is stable until an electric field is applied to change its direction. Device applications often make use of the piezoelectric properties of ferroelectric materials; when a voltage is applied across a piezoelectric material, it undergoes a mechanical distortion in response and vice versa.

A potential application of ferroelectric materials lies in ultra-high-density memory devices, produced by controlling the ferroelectric domains at the nanometre scale[3]. Such storage devices would be non-volatile (and so able to retain the stored data for long periods of time without any power supply) and have short boot-up times.

Most materials used for ferroelectric devices are perovskites — oxides with a structure like that of the natural mineral $CaTiO_3$. Although the crystal structure of all perovskites is similar, their properties can differ significantly. For example, $CaTiO_3$ is a dielectric (resistant to electrical current), but replacing calcium with barium or lead produces piezoelectric materials. Partial substitution of titanium by zirconium in lead titanate gives lead zirconium titanate, at present the most widely used piezoelectric material.

Interest in perovskites received a boost with the discovery of high-temperature superconductivity in La–Ba–Cu-oxide in 1986 by Bednorz and Müller[4]. In the past decade, thin films of perovskites have been extensively studied to explore their electrical, magnetic and optical properties further. In the course of this work, progress has been made in controlling the growth of films at an atomic level, and Lee *et al.*[2] have built on several developments to make their superlattice structure — a stack of hundreds of thin perovskite layers.

To grow the films, Lee and co-workers used pulsed laser deposition, a technique that is particularly suitable for growing multi-component oxide structures. In this approach, a plasma is created by using laser pulses to evaporate oxide material from solid targets; this plasma has the same composition as that of the target. The approach can be used at relatively high oxygen pressures, which makes it possible to deposit stable units of perovskites under a wide range of conditions. To control the assembly of these units into a superlattice structure, Lee *et al.* make use of reflection high-energy electron diffraction.

When building up a superlattice, the layers must be grown carefully on top of each other so that their atomic lattices match. The termination (final atomic configuration) of each deposited layer will influence how well the layers grow, and consequently determine the device's performance. A prerequisite for controlling termination is an atomically flat substrate to start from. It was therefore a step forward when it became possible to prepare substrates that are terminated in a single configuration, and so are atomically flat[5,6]. Lee and colleagues need a conducting electrode, and use $SrRuO_3$, a metallic ferromagnetic perovskite, as a substrate. It can be grown atomically smooth, with a termination of SrO (refs 7, 8).

Previous work showed that superlattices can be designed with specific properties; for example, neither $BaCuO_2$ nor $SrCuO_2$ exhibits superconducting behaviour, whereas a superlattice consisting of thin layers of both oxides does so[9]. Another example is the superlattice of $SrZrO_3/SrTiO_3$. Neither of the two building blocks is ferroelectric, but the superlattice is[10].

Lee *et al.* assemble their superlattice with three different building blocks — $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ (Fig. 1, overleaf). The use of three different compounds breaks the inversion symmetry that often occurs in two-component superlattices[11]. Typically, ferroelectric materials display symmetric two-state polarization (that is, the applied electric field required to change it in either direction is equal). In the three-component superlattice, inversion symmetry is broken, resulting in asymmetric polarization and an extra degree of freedom for optimizing the ferroelectric properties.

Growing thin layers on top of each other can lead to considerable 'epitaxial' strain in

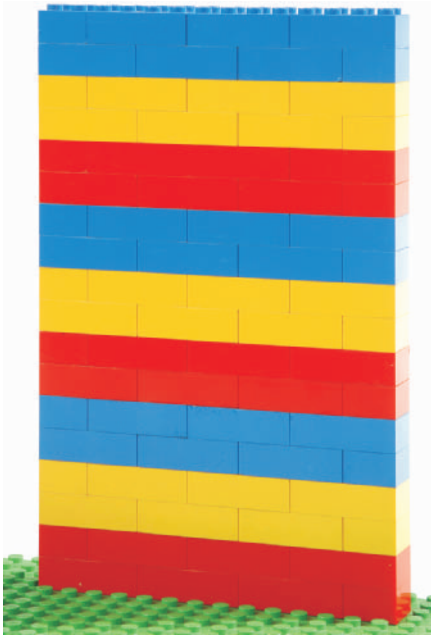

Figure 1 **Building regulation — a Lego version of the superlattice structure shown in Fig. 1d (page 396)[2]. The base constitutes the substrate, including the SrRuO$_3$ electrode, and the Lego wall is made of layers of three different bricks: SrTiO$_3$ (red), BaTiO$_3$ (yellow) and CaTiO$_3$ (blue). Lee *et al.*[2] demonstrate that an artificial material with favourable ferroelectric properties can be constructed by using these three perovskite building blocks.**

the structure, which is caused by differences between the lattice parameters of the layers. This effect influences the properties of the layers and the structure as a whole, and Lee *et al.* have exploited this phenomenon to increase the ferroelectric polarization of their material. The epitaxial strain decreases the in-plane lattice parameters of the BaTiO$_3$ layers, producing an increase in the ferroelectric polarization.

Lee and colleagues' ferroelectric superlattice is impressive, because it shows that such structures can be built with atomic precision and possess properties that surpass those of the individual building blocks. It also underlines the potential of designing artificial superlattices with unique properties. For example, most ferromagnetic materials show no ferroelectricity. But what would a superlattice made from ferroelectric and ferromagnetic building blocks be like? Would it show ferroelectric or magnetic behaviour, or have a mix of properties? New phenomena might even emerge. Here, then, is an invitation to materials scientists to design and build their own superlattice. ■

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Ecology

Paradise sustained

Shahid Naeem and Andrew C. Baker

Biodiversity stabilizes ecosystem functioning in small-scale, short-term experiments, but do such findings scale up to the larger world? A global study of fossil reefs from the past 500 million years suggests they do.

A watershed ecosystem that produces a steady volume of water may be more valuable than one that unpredictably alternates between flood and drought. A coastal ecosystem that provides a regular but modest supply of fish serves a community better than one that booms then busts. In most cases, then, the absolute magnitudes of ecosystem functions — such as the production of potable water and nutritious food — may matter little if they are unsustainable.

Over the past decade, some of the most intense research ever conducted in ecology has examined how the magnitudes and sustainability of ecosystem functions are governed by biodiversity, and whether a loss of biodiversity is a major cause of ecosystems becoming less productive and less stable[1–4]. In this debate, the 'ayes', who advocate a strong role for biodiversity in governing ecosystem function, point to the congruency of findings from the full triad of scientific methods (theory, observation and experiment). The nay-sayers find the evidence flimsy — weak effects derived from studies too small and too short-lived to be convincing.

On page 410 of this issue, Kiessling[5] provides evidence that may sway some nay-sayers — but there's a catch. Making use of an extensive palaeoecological database on thousands of reefs, spanning some 500 million years, Kiessling tested whether the local species richness of reef-builders on a given reef (and, by extension, the diversity of the entire community) could predict ecological change on these reefs. Using reef type, density, architecture and construction style as proxies for reef ecology, Kiessling found that higher-than-average species diversity in one time interval led to lower-than-average changes in reef ecology in the next. In other words, biodiversity may indeed govern sustainability. The catch is that this epoch-spanning data set cannot detect fluctuations in reef ecology of less than a few million years, which may disappoint some ecologists and ecosystems biologists following the debate.

For the ayes, the good news is that the positive biodiversity–stability relationship predicted from theoretical and empirical work may scale up — way up. Although some may quibble with Kiessling's use of both absolute and relative measures of species richness in his analyses, and others may question whether the variables he chose are appropriate measures of reef ecology, no one is likely to dispute the depth and scope of his perspective. Kiessling's study is global and covers an extraordinary length of time, one that spans three entire geological eras and witnesses the wholesale turnover of reef-building consortia, from cyanobacteria to calcified sponges, bryozoans, molluscs, calcareous algae, and corals both ancient and modern (Fig. 1). Given this, it is remarkable that Kiessling's findings agree with those derived from mathematical models, bottles, Petri dishes, aquaria, growth chambers and field plots, which often run for only a handful of generations.

However, the 'deep time' approach to the diversity–stability debate is not without pitfalls. In Kiessling's study, some data points that documented major ecological change following periods of relatively high biodiversity were excluded from the analysis. These data, which contradict the diversity–stability hypothesis, are from three out of the five major mass-extinction events covered by the study.

Kiessling rightly argues that some external influences (such as asteroid impacts) really are beyond the scope of biology to buffer. However, in recognizing and excluding these legitimate outliers, we should take care not to throw the evolutionary baby out with the ecological bathwater. Many of these mass-extinction outliers are superimposed on a backdrop of major evolutionary milestones, such as the rise of predation and herbivory as lifestyle strategies, and the acquisition of algal photosymbionts in today's stony corals[6] — events that are themselves likely to result in dramatic ecological shifts in reef communities. Resolving this debate over extended timescales will therefore require us to distinguish between ecology and evolution in determining stability and