Nevertheless, a few hurdles must be overcome before SBA dielectrics will make a significant impact on large-scale transistor manufacturing. Perhaps the biggest problem at the moment is the slow response of the sodium ions to an external electric field. Consequently, the capacitance of the SBA films is reduced at higher frequencies. Solid-polymer electrolytes typically suffer from a similar problem, and in this case the frequency response can be substantially improved by increasing the ions' concentration and mobility[4].

Another limitation of the SBA process reported by Katz *et al.* is that the temperature required to anneal the sol–gel-deposited SBA films (400 °C or more) is at present too high for large-area transistor applications, such as flat-panel displays. If this temperature can be lowered to near 250 °C, SBA may again become as popular as it once was. ❐

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MAGNETIC SHAPE MEMORY

Magnetoelastic sponges

Nickel–manganese–gallium foams connected internally by sizeable single-crystalline elements provide magnetic-field-induced strains comparable to free-standing bulk single crystals, and demonstrate feasibility for the application of magnetic shape memory.

Mehmet Acet

The discovery of giant magnetic-field-induced strains of about 10% in single crystals of the magnetic shape-memory alloy Ni–Mn–Ga under 2-T magnetic fields (attainable by permanent magnets) brought a new dimension to the concept and design of field-triggered actuators[1,2]. However, because Ni–Mn–Ga single crystals are difficult to grow, costly and brittle, investments in wide-spread applications of such actuators have been very limited. The good news is that many of these problems can be overcome by using foams of these materials, as reported by Chmielus and coauthors on page 863 of this issue[3]. The authors demonstrate that polycrystalline foams of Ni–Mn–Ga prepared under certain conditions create a network of single crystals that can collectively show magnetic-field-induced strains up to an impressive 4% — surpassing by far any field-induced strain in polycrystalline materials (in particular in Terfanol D with 0.15% strain).

Magnetic-field-induced strain in Ni–Mn–Ga relies on the presence of a diffusionless, solid–solid phase change, otherwise known as the martensitic transformation. The transformation temperature separates the high-temperature, high-symmetry cubic austenite phase (with low magnetic anisotropy) from the low-temperature, lower-symmetry-modulated orthorhombic martensite phase (with high magnetic anisotropy). The martensite phase has a twin structure and strong magnetocrystalline anisotropy. The twin boundaries are highly mobile and are set into motion when an external magnetic field is applied. Crystallographically, several twin variants are possible. If a single crystal of Ni–Mn–Ga is prepared so that it has only a single variant, giant magnetic-field-induced strains can occur.

The origin of magnetic-field-induced strains is shown schematically in Fig. 1. For simplicity, we show a single-variant single crystal with a tetragonal unit cell with lattice dimensions a and c, such that $c/a < 1$,

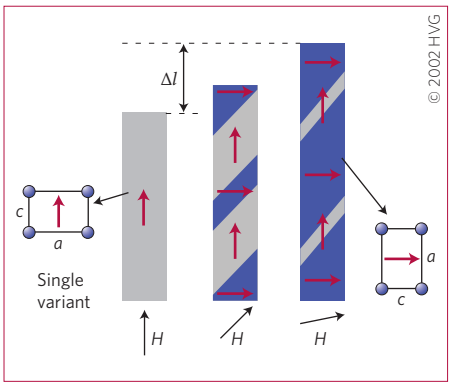

Figure 1 | Schematic of magnetic-field-induced strain. A magnetic-field-induced length change Δl occurs when a field H, originally parallel to the c-axis, is gradually rotated (red arrows indicate the easy-magnetization axes). A new variant (coloured blue) with the c-axis parallel to the field grows at the expense of the original variant (coloured grey).

and the c-axis is the easy magnetization direction[4] (Fig. 1). If the magnetocrystalline anisotropy is large, rotating an applied field H will cause a gradual growth of a variant (coloured blue) with the c-axis along the field direction at the expense of the original variant (coloured grey). This can lead to a large change (Δl) in the external dimensions of the crystal.

The situation in foams is essentially the same. Foams are prepared by selecting an appropriate salt or ceramic 'space holder' with given size, around which the material is filled. The space holder is subsequently etched away. Figure 2a depicts a foam with monomodal pore size (shown as circles). Such Ni–Mn–Ga foams were previously studied by the same groups reporting in the present issue[5]. The material between the pores (the blue area outlined by a bold line, Fig. 2a) is the foam consisting of single-crystalline 'struts' connected to each other at polycrystalline nodes, resulting in a 'bamboo like' structure as the authors had earlier described. In such foams, the easy-magnetization axes of neighbouring crystallites do not necessarily coincide, as shown by the red arrows. It was reported that the maximum field-induced strain in these foams did not exceed 0.15% because of the presence of node constraints that hinder domain-wall advancement and therefore a uniform magnetization. Nevertheless, this size, still considered 'large' with respect to strains observed in regular bulk polycrystalline material, was the source of motivation for further trials.

In the present article[3], the authors report on their efforts to increase the strain by opening pores in the struts themselves to eliminate the nodes. Once the nodes are eliminated, the single crystallinity of such foams can extend over longer distances. The authors do indeed largely succeed by selecting space holders that give rise to a bimodal size distribution in the foam with extra smaller pores having dimensions smaller than the struts themselves (Fig. 2b). Under optimized conditions, field-induced strains in the order of 4–5% are attained.

The preparation of foams with such large field-induced strains can be considered a breakthrough in magnetic shape-memory technology. Limitations certainly remain, especially those related to attaching a load that causes a reduction in strain in single crystals. This will definitely be an issue that has to be dealt with in foams as well. Nevertheless, many ideas for the use of the magnetic shape-memory materials in diverse technological applications, such as micropumps, sonars and magnetomechanical sensors, to name but a few — and originally considered suitable only for single crystals — can now be largely realized with the use of foams.

Over many years, worldwide research on magnetic shape memory has not been limited to Ni–Mn–Ga, and much work has been carried out in the past decade on alternative systems[6]. These investigations have given rise to the observation of many other effects apart from field-induced strains, such as the magnetocaloric effect, giant magnetoresistance, exchange bias, and so on. Certainly, the present work on Ni–Mn–Ga foams with bimodal pore-size distribution will create new avenues of research on other potential magnetic shape-memory alloy foams in general, yielding many fresh and interesting results. ❐

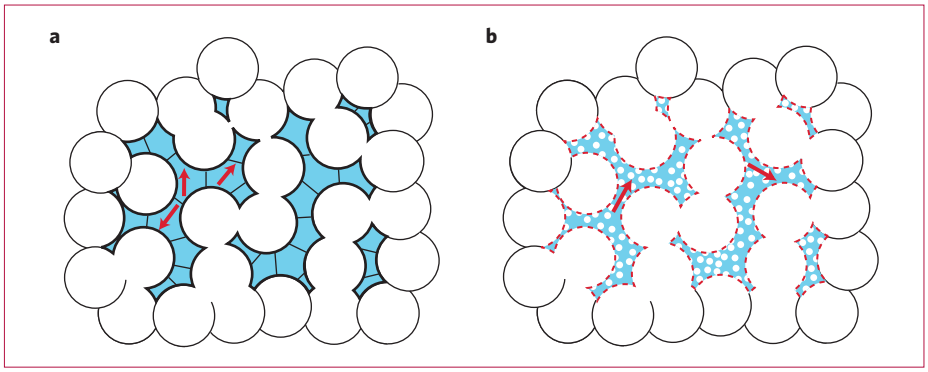

Figure 2 | Magnetic shape-memory foams. **a**, Foam with monomodal pore distribution. The foam material is the blue area bounded by the bold line. Red arrows indicate the easy-magnetization axes. Struts are bounded by polycrystalline nodes (lines traversing the material) limiting field-induced strain. **b**, Foam with bimodal foam distribution. The material is within the same blue area (outlined by the red dashed lines) as in **a**. Nodes are eliminated and the crystal grain can extend over longer distances, yielding a large field-induced strain.

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BIODEGRADABLE ALLOYS

The glass window of opportunities

Crystalline alloys often fall short in providing certain key properties desired for biomedical applications. But by using metallic glasses instead, problems such as hydrogen evolution can be dramatically reduced in biodegradable magnesium alloys.

Evan Ma and Jian Xu

Crystalline metallic alloys constitute an important group of biomedical materials, thanks to their unique combination of strength, ductility, fatigue resistance and reliability. Magnesium alloys, in particular, are being increasingly investigated for biomedical applications such as implants and stents[1–6]. This pursuit of Mg alloys is motivated by their low mass density (ρ = 1.74–2.0 g cm^{-3}) and elastic modulus (Young's modulus E of 41–45 GPa), both of which are similar to those of human bones (ρ = 1.8–2.1 g cm^{-3}; E = 3–20 GPa). Importantly, Mg alloys have high biocompatibility, and are biodegradable and also relatively inexpensive. However, despite these attractive properties, existing Mg alloys do suffer from serious drawbacks, one of which is that Mg corrodes too quickly in physiological conditions, into soluble magnesium hydroxide, magnesium chloride and hydrogen gas[4]. In particular, hydrogen evolution leads to gas pockets that cause adverse reactions and inhibit bone growth. On page 887 of this issue[7], Zberg *et al.* circumvent this problem by using ternary Mg–Zn–Ca alloys in the form of metallic glasses[8]. In their *in vitro* and *in vivo* degradation tests, these amorphous alloys show tissue compatibility as good as that of their crystalline counterparts, but without clinically observable hydrogen production.

In the past, all the alloys used for orthopaedics and coronary stents were adapted from existing alloys used in engineering, which are, of course, all crystalline materials. Examples include stainless steels, Co–Cr–Mo alloys, Ti alloys, and Ti–Ni shape-memory alloys. However, as these conventional alloys have not been specifically designed for particular