

effects of TGF- $\beta$  on cell proliferation and death but leaves intact the positive effects of SMADs on malignant progression. In fact, there is evidence that the three *RUNX* genes have multifunctional roles in different tumours and, perhaps, at different stages of cancer<sup>12,13</sup>.

To muddy the waters still further, although Li *et al.*<sup>3</sup> provide convincing evidence that *RUNX3* helps to suppress gastric cancer, it seems that a retrovirus activates the *Runx3* gene in T-cell lymphomas in mice<sup>14</sup>. Clearly, much remains to be done to unravel the complexities of this interesting gene family and its roles in cancer.

The bad news about the new wave of tumour-suppressor genes is that they are hard to find. But, unlike the old-style tumour suppressors, they may be good drug targets because they are not mutated, and so could perhaps be reactivated using small molecules that prevent or reverse methylation. Some drugs of this sort are now under development

or in clinical trials<sup>15</sup>. Such new-wave drugs may be what is needed to tackle the new generation of tumour suppressors. ■

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## Materials science

# Cooking up tougher ceramics

D. P. Thompson

Ceramics based on silicon nitride have already proved their worth in terms of engineering applications. A technique that allows greater control over their final structure opens up yet further possibilities.

Microstructural control is at the heart of materials science, especially when a tailored combination of mechanical properties is required. In the field of nitrogen ceramics, where the final microstructure is produced by ‘liquid-phase sintering’, it is difficult to control the morphology of the final product; the little that can be done is achieved by controlling the starting composition and the processing parameters — principally, time and sintering temperature. Now Shen *et al.*<sup>1</sup> (page 266 of this issue) introduce a technique that opens the way towards significantly greater microstructural control.

Silicon-nitride-based ceramics tend to have the edge over their competitors in engineering applications, thanks to their low density and toughness. When silicon nitride, aluminium oxide and aluminium nitride are reacted together, they form ceramics called ‘sialons’, after their constituent elements Si, Al, O and N. There are two common forms of sialons,  $\alpha$ -sialons and  $\beta$ -sialons, and in their atomic arrangements they are like  $\alpha$ - and  $\beta$ -silicon nitride. Since the early 1970s<sup>2</sup> it has been known that  $\beta$ -sialons readily form with a needle-like (or ‘acicular’) morphology. The sialon grains may be elongated (with aspect ratios as high as ten), resulting in a tough final product.

Similar acicular morphologies have been

produced for  $\alpha$ -sialon ceramics by using unusual starting materials<sup>3</sup>, an excess of liquid phase or an oxygen-rich starting composition<sup>4</sup>. But 30 years of research have achieved only limited control of the aspect ratio for either  $\alpha$ - or  $\beta$ -sialons prepared by conventional sintering procedures.

During liquid-phase sintering of sialons, a chemical force drives the formation of the final phases from the mixture of oxides and nitrides that comprise the starting material. The phases at the final stage of the procedure are essentially the matrix sialon phase (possibly with small amounts of other crystalline phases) and liquid, and these two phases are generally close to thermodynamic equilibrium at the temperature concerned.

Subsequent grain growth occurs by ‘Ostwald ripening’, whereby the small crystals that are initially present dissolve in the liquid and re-precipitate onto larger crystals, as these are thermodynamically more stable. Generally, the very small grains present in the starting powders will have dissolved rapidly in the early stages of sintering, and, apart from the large acicular  $\beta$ -sialon grains that grow from the silicon nitride needles present in the initial mixture, most of the remaining grains are of similar size. The result is a low driving force for Ostwald ripening, which consequently takes

place slowly, over a period of several hours, even at quite high sintering temperatures.

Moreover, most conventional sintering furnaces reach the final sintering temperature only slowly, and the composition of the liquid phase changes continuously with increasing temperature to remain in equilibrium with the main sialon phase. As a result, there is little additional driving force for grain growth apart from the Ostwald ripening mechanism.

Shen and colleagues<sup>1</sup> use a very rapid sintering technique — ‘spark plasma sintering’ (SPS) — that enables samples to reach the sintering temperature in less than five minutes. This generates conditions in the sample whereby the composition of the liquid phase is grossly out of equilibrium with that of the matrix sialon grains, thereby creating a strong chemical driving force for the liquid and matrix to equilibrate. The resulting transport of material provides an alternative mechanism for grain growth — the so-called dynamic Ostwald ripening effect. For both  $\alpha$ - and  $\beta$ -sialon phases, this results in elongated, needle-shaped grains; the increase in length of the needles after such short sintering times is quite remarkable.

The results also show that the process has a minimum temperature threshold. This might be related to the properties of the liquid — for example, unless the temperature is high enough, the liquid may be too viscous to allow the molecules to diffuse easily. Alternatively, high temperatures may be required to break the covalent bonds in the silicon and aluminium nitride powders so that they dissolve in the liquid.

Shen *et al.* carried out their work in a research-scale SPS furnace, and scaling up the process to allow large-scale production of sialon components with a controlled high-aspect-ratio acicular grain morphology may seem a long way off. Nevertheless, the dynamic Ostwald ripening principle seems applicable to all nitrogen ceramics, regardless of the matrix form ( $\alpha$  or  $\beta$ ) or the sintering additive (another way of modifying the liquid’s properties). The door has been opened and, without doubt, further use of SPS will allow far more detailed study of the grain growth mechanism in nitrogen ceramics. As a result, the principles governing the development of tough, needle-shaped microstructures will be determined with greater precision, and the prospects look good that a new range of high-toughness sialon ceramics will emerge. ■

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