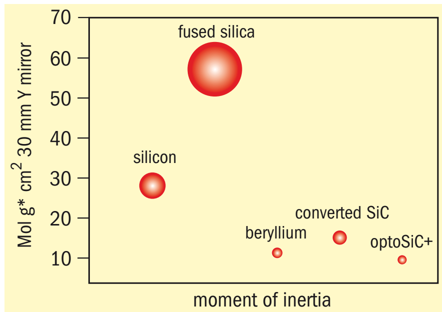
Silicon carbide meets optical grade standards

Silicon carbide boasts properties such as strength and stiffness. **Marie Freebody** speaks to Steve Hastings of optoSiC who believes that recent improvements in manufacturing techniques have enabled the material to be used as mirrors by the laser scanning industry.

All images: optoSiC



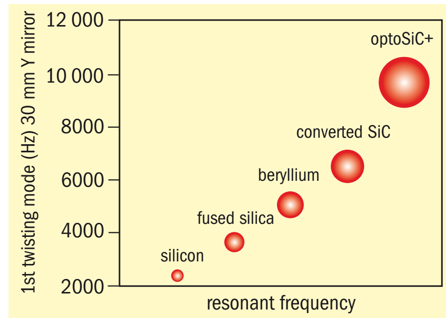


Fig. 1 (left): Silicon carbide is now an optical grade material suitable for use as scanning mirrors and laser optics. Fig. 2 (middle): Lower moment of inertia means more compact and higher performance motors can be used. These motors draw less current, which results in better repeatability and less drift. Fig. 3 (right): The higher the resonant frequency of the rotating scanning mirror, the higher the operational bandwidth of the entire system.

Silicon carbide (SiC) is not normally a material that you would associate with the optics industry. However, thanks to many years of work refining manufacturing processes, SiC is now available as an optical grade material ideal for use as scanning mirrors.

"SiC is manufactured for the semiconductor industry because of its thermal conductivity but this property is largely irrelevant when it comes to optics," Steve Hastings, technical consultant to optoSiC, told OLE. "SiC is a strong and stiff material and is ideal for scanning mirrors because of its flexural strength and stiffness – but it is incredibly hard to polish."

Since its inception in 2007, Germany-based firm optoSiC has managed to perfect the manufacture of SiC. Today, improved product performance and reduced fabrication costs have culminated in the launch of optoSiC+, a material that the company hopes will take the scanning mirror market by storm (see figure 1).

"We discovered that the porosity and homogeneity of SiC was unacceptable to the laser scanning market," said Hastings. "During polishing we would come across anything up to 200 micron-sized subsurface bubbles that were present from the pressing process. By polishing through these pockets, we would remove too much of the optical face and create inbalance in the mirror design."

In a bid to overcome these polishing and porosity problems, the company turned to a high-pressure compaction technique and the result was SiC with near zero porosity. "This removed all of the defects that would show up during polishing and meant that SiC could be polished to an optical grade material," Hastings explained. "It also improved the surface quality roughness average (RA) from 5 to less than 2 nm."

Manufacturing SiC mirrors

The starting point in the manufacturing process is an extremely fine SiC powder that is mixed with less than 1% bonding agents. This mixture is then hot isostatically pressed at very high pressure and CNC machined. "This produces the bulk forms of the mirror but with some extra material on the face," explained Hastings. "It is then taken for sintering, which thanks to a secondary compaction technique, takes eight hours instead of one week."

The material is checked for impurities and the bulk of the face is planarized away to leave a set amount to be removed by polishing. A cost-effective method of polishing is then used to produce an optical material that can compete with silicon, fused silica and beryllium.

"We use a clever process to polish the SiC mirror up to 1/250th of lambda (λ) (632.8 nm), however this is very expensive," said Hastings. "We normally specify anywhere between 1 λ rms for carbon dioxide (CO_2) wavelengths and up to about $1/8\,\lambda$ rms for Nd:YAG wavelengths. We regularly polish to $1/20\,\lambda$ depending on the customer's requirement."

After polishing, the mirror is checked for flatness and surface quality and is ready for optical coating. According to Hastings, optoSiC+ coats in a similar way to any silicon or fused silica products. The coatings must be highly reflective, which is important both in terms of optimizing the beam-to-target efficiency and preventing absorption of heat into the mirror.

"Unlike beryllium, which deforms when heated, SiC is incredibly thermally stable," said Hastings. "Heat comes not only from the laser beam but also through the galvanometer shaft into the mirror. Therefore, we are only looking at coatings with a reflectivity of over 99.8%."

The company currently has a CO_2 coating called UltraMAX R and is conducting trials on an Nd:YAG coating that it will launch at the Optatec show later this month (17–20 June) in Frankfurt, Germany.

Hastings believes that optoSiC+ can now compete with conventional scanning mirror materials such as silicon, fused silica and beryllium thanks to the optimized manufacturing process. He also believes many of the material's inherent properties such optoSiC

Fig. 4: Silicon carbide is such an effective material because you can engineer away so much bulk.

as low inertia, high resonant frequency, dynamic flatness and high surface quality make it particularly well suited to meet the demands of today's laser scanners.

Mirror inertia

Mirror inertia determines how fast a motor can accelerate a mirror up to the marking or jumping velocity required by the application. Lower inertia means faster accelerating times, which in turn leads to significantly reduced settling time after jumps and marks, and a much cleaner result. Higher inertias require higher current, which generates more heat and adversely affects positional repeatability and drift accuracy.

"optoSiC+ is an effective material because you can engineer away so much bulk and leave a core spine supporting a very thin optical skin," said Hastings. "Our design is effectively like a leaf. The central spine takes most of the torque load and the ribs coming off this spine extend diagonally upwards and support the optical skin." This protected design ensures that the moment of inertia is lower than beryllium for the same aperture even though beryllium has a lower density than optoSiC+ (see figure 2, p25).

Resonant frequencies

The action of rotating a scanning mirror backwards and forwards at extremely high repetition rates is fraught with complications. For example, the galvanometer's motor, the optical mount and the scanning mirror will all have a complex series of resonances acting on and against each other (see figure 3, p25).

"The rotating mirror must have a much higher resonant frequency than the operational range in which it is working," explained Hastings. "This ensures that you can use the mirror throughout the operational bandwidth of the system without having to filter out that resonance. Put simply, the higher the resonant frequency, the higher the operational bandwidth."

The elasticity of a material (the amount it bends) also affects its resonant frequency. Fused silica has an elasticity of 73 GPa, silicon 150 GPa, beryllium 303 GPa and optoSiC+ 420 GPa.

Dynamic flatness

Dynamic flatness has a direct effect on the shape of the focused spot as it travels across the target after reflection from the mirror. The company has performed extensive studies to find out what happens to the shape of the spot when the mirror is moving (see figure 5).

"High flexural strength, or stiffness, is important here for the mirror to actually follow the oscillating movement without deforming," explained Hastings. "The flexural strength of beryllium is 421 MPa which is fairly high, silicon is 69 MPa, fused silica is 49 MPa but optoSiC+ is 510 MPa."

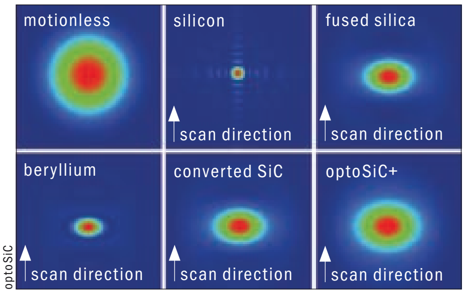
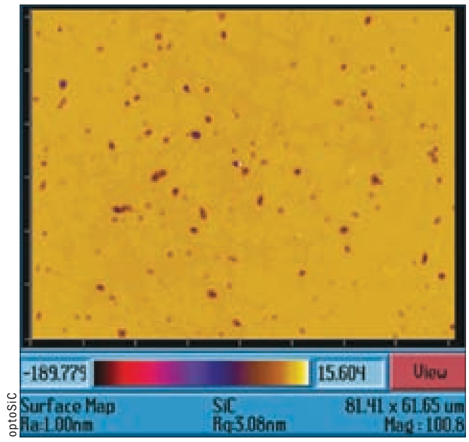


Fig. 5 (above): Dynamic flatness has a direct effect on the shape of the focused spot as it travels across the target after reflection from the mirror. Fig. 6 (right): optoSiC+ has an RA of less than 2 nm or around 1 nm after polishing.



In figure 5, the top left "motionless" image shows the spread of a Gaussian beam across a target when the beam has reflected off a stationary mirror. When the mirror is scanning, the closest beam profile to the original is produced by optoSiC+.

Comparing this with the analysis for silicon shows that a smaller portion of the energy is hitting the target, which according to Hastings, means that a huge amount of energy and focusability is lost. "Silicon performs so badly here because in order to get lower inertia, manufacturers have reduced the thickness of the material from 3 to 2.5 mm at 30mm apertures causing it to flex," he explained. "Beryllium performs badly because engineering away as much bulk as optoSiC+ causes the mirror to twist around the central rotation axis and dynamic flatness is lost. It also puts stresses into the material that might eventually cause fatigue."

Surface quality

The final crucial property is surface quality. In this case, imperfections on the mirror's surface dissipate the beam outwards instead of reflecting it cleanly, which causes spatial effects.

"Fused silica has the highest surface quality and can be polished to an RA of 0.3 nm, which is extremely good," commented Hastings. "This is something to work towards and optoSiC+ currently has an RA of less than 2 nm (see figure 6)."

Applications

optoSiC+ with a CO_2 coating operates at 9.3–11.2 µm and can withstand powers of over 5 kW while the Nd:YAG coating operates at 1064 nm. "We manufacture any mirror aperture size that fits within a 400 mm diameter," said Hastings. "This covers anything up to about a 250 mm aperture entry beam."

One of the biggest markets requiring scanning mirrors is the fabrics processing industry. Here, large panels of material are cut automatically, which requires very small spot sizes using large mirrors. "We also have enquiries for streak cameras, which are high-speed catcher cameras in which the mirror must follow a projectile. This requires a mirror that can get up to speed very quickly," said Hastings. "We also have enquiries from LIDAR developers and silicon carbide is also being used in the production of space optics." □