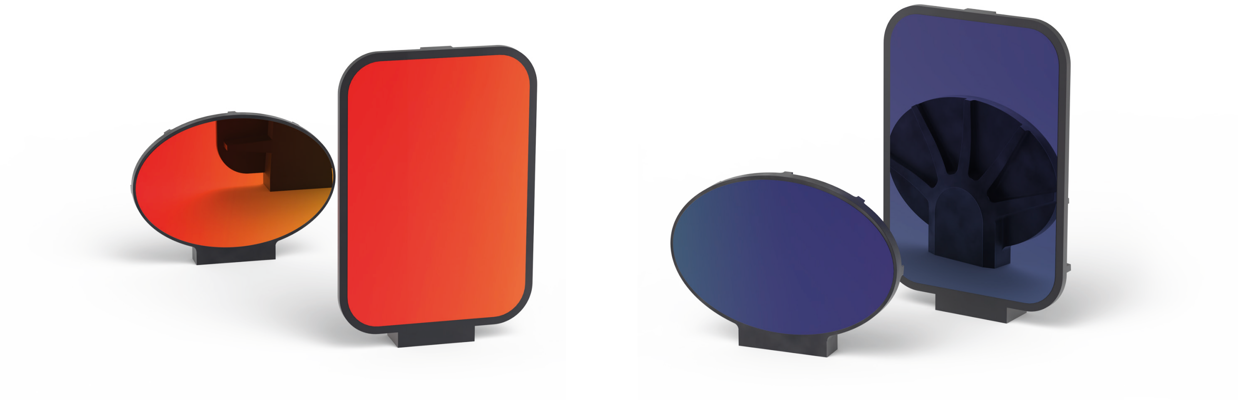

Modified SiC mirrors: low-loss solution from UV to Mid-IR

Galvo-scanning systems, laser material processing, sensing and other applications

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Improving laser applications

Every day, new applications for laser light emerge and current ones – from laser manufacturing and processing to LiDARs – are growing in both importance and market size. A considerable number of these applications use galvo scanning systems to control the laser beam and guide it to perform a specific task. Altechna now has a low-loss solution to do these tasks as efficiently as possible.

To begin with, laser-processing operations (such as micromachining, additive manufacturing, marking, and others) heavily depend on a system's energy output. The more energy from the initial laser beam can be transmitted to the processed object, the faster the operation can be completed, and the more difficult the challenges that can be tackled. Furthermore, lower beam energy losses inside the system mean less internal heating that can affect or even damage surrounding components inside the device.

Heating might also cause thermal lensing and focal shift phenomena that worsen the system's precision. To avoid this, active cooling solutions are required, which take up additional space, increase costs and make the system more complex – unless internal heating can be eliminated by using low-loss optical components.

To better comprehend the potential impact of lowering energy losses by even a fraction of a percent, we need to know how widely galvo scanners are used. The material processing (marking, micromaterial processing and kW+ material processing) segment alone accounted for almost a third of revenue in the laser market by application in 2021. Followed by the additive manufacturing market, that has grown 30% in the last two years and is expected to continue accelerating and reach over $9 billion by 2024. In addition, the LiDAR market has grown five times over the past 10 years, with a burst in automotive LiDAR systems. If these giant industries that use galvo scanning systems are not enough, add security, scanning and imaging systems, as well as R&D, space telescopes and many more applications whose progress and growth is also highly dependent on the continuous improvement of galvo systems.

For all of these applications, improvement depends not only on the laser itself, but also on the beam guidance system, in which the mirrors of galvo scanners are of the utmost importance. Each step of their production, from choices of application-oriented materials to a time-efficient and competitively priced manufacturing process, is therefore crucial on the way to perfection. Understanding the significance of minimizing losses in these laser systems inspired Altechna to seek and provide energy-saving solutions for galvo scanning devices.

Galvo scanning mirrors

The end result of any laser system that uses galvo scanners depends on the scanner's ability to both accurately and precisely guide the laser beam to its destination (Figure 1). Having top-quality mirrors inside the system is therefore crucial, as these are responsible for keeping the beam undistorted and pointing in the right direction 24/7 despite surrounding heat and constant changes in position. They must have good and stable flatness, high thermal conductivity to dissipate heat, and very high mechanical strength and rigidity to avoid mechanical deformations. The latter features depend on the material that forms the mirror's substrate.

In the search for mechanical stability under stressful conditions, silicon carbide (SiC) substrates seem to be a perfect fit. High levels of hardness, strength and thermal conductivity mean that SiC is ideal for optomechanical systems in which an element needs to adjust its position up to 1,000 times per second and preserve its initial form at various temperatures and humidity levels [1]. The rigidity of silicon carbide allows it to be reliably formed into complex 3D structures that save up to 70% of the weight while maintaining, or even increasing, resistance to mechanical deformations. A low weight helps to minimize inertia and thereby increase scanning speed. For all of these properties, silicon-carbide-based mirrors offer a better overall performance in comparison to fragile glasses or toxic beryllium, and have replaced them in various scanning systems and even astronomical telescopes [2].

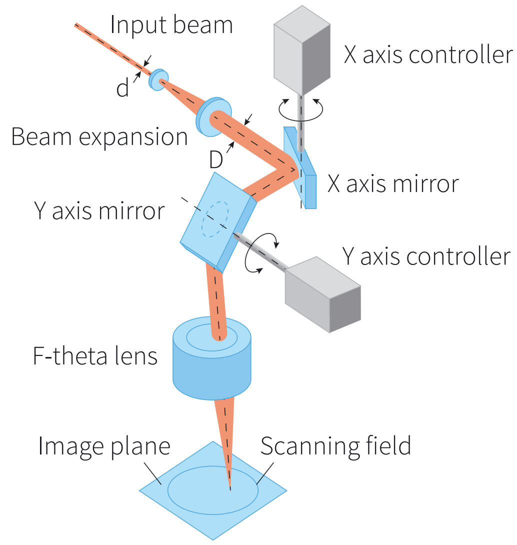

Figure 1. Typical example of a laser scanning system.

The reason for optical losses

We've established that, mechanically, a silicon carbide substrate is the very best choice for mirrors in galvo scanning systems, but its optical suitability doesn't come as standard. The fastest and cheapest method for manufacturing SiC substrates – reaction bonding [3] – produces surfaces that contain up to 50% unreacted silicon and carbon. This means that there are areas of extremely stiff silicon carbide and significantly softer silicon, so the surface is filled with holes and interfaces of these materials. From an optical point of view, such surfaces (Figure 2) scatter 355 nm laser irradiation over 1,000 times more than a standard surface of fused silica substrate. The reflection coefficient of any reflective dielectric coating on an SiC base would therefore be significantly lower compared to one deposited on a fused silica base, purely because of the substrate's roughness-induced scattering losses.

To eliminate these losses, the surface of an SiC element needs to be additionally modified after manufacturing, but standard measures cannot be applied effectively. Due to the hardness of silicon carbide, it is very difficult and time-consuming to polish the surface to the necessary roughness, as the process would require multiple steps with diamond abrasives of different sizes, without the guarantee of a final nanometer-perfect result. Moreover, pits can be contaminated with polishing materials, leading to new types of issue rather than solving them.

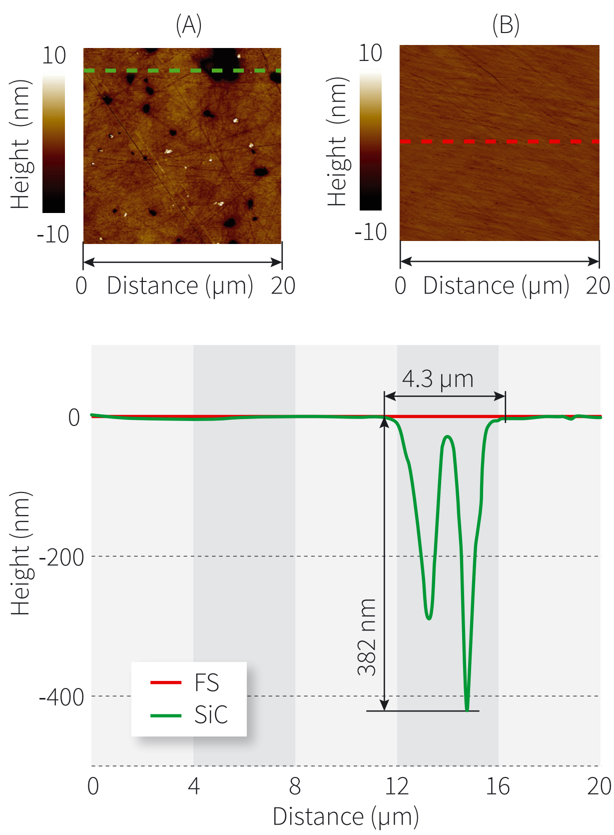

Figure 2. Surface roughness comparison of an unmodified SiC surface (A) and a standard fused silica surface (B) and their cross-section.

Last step for a perfect combination

As we have already established, the mechanical properties of silicon carbide make it a perfect material for the substrate in a galvo scanning mirror, but the optical properties of the surface are a major downside. Achieving high reflectance for energy conservation, similar to what can be achieved on fused silica substrates, requires an intelligent approach to control the surface's roughness. As mentioned above, straightforward polishing would be a very long, inefficient, and expensive process, so Altechna decided to go with the process we do best – coating.

Smoothing out the surface

Altechna's approach to this challenge comprises optimized sub-layer deposition and a polishing procedure before application of a low-loss reflective coating. Naturally, the coating process cannot be tailored to purposefully fill the biggest cavities to smooth out the base for low-loss mirrors. However, with a sufficient deposited material layer, followed by an optimized polishing procedure, the surface of the component is no longer covered in holes that would induce irradiation losses in the actual mirror [4]. After many experimental iterations, we have managed to decrease the root-mean-square (RMS) roughness of the SiC substrate's surface from 30.9 nm to 0.35 nm, as can be seen in results from atomic force microscope (AFM) measurements (Figure 3). This is almost equal to the average RMS roughness of 0.3 nm for the substrate surface of standard fused silica, meaning that such a base is perfect for a low-loss dielectric mirror coating. Moreover, to ensure that the laser beam's wavefront reflecting from the mirror is not distorted, surface tension needs to be strictly controlled not only for the coating itself, but also for the sub-layer. We've successfully managed to control the P-V flatness of the final part to the required application values.

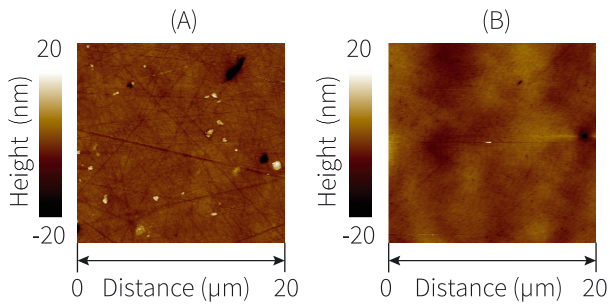

Figure 3. Surface roughness comparison of SiC (A), and SiC with a polished sub-layer (B).

Low-loss UV mirror solution

After modifying the surface of the SiC substrate, it was time for Altechna to provide our best dielectric coating solution for a UV low-loss mirror. As can be seen in Figure 4, we have managed to reach over 99.5% reflectance at 355 nm at a 0° angle – equal within the margin of error to the reflectance of the same coating on a standard UVFS substrate. Another proof of the base modification's advantage is the RMS roughness of the modified surface with dielectric HR coating. Because of the sub-layer, the roughness drops from 4.72 nm on unmodified SiC + HR to 0.8 nm on modified SiC + HR and that evidently correlates with lower losses and improved spectral performance.

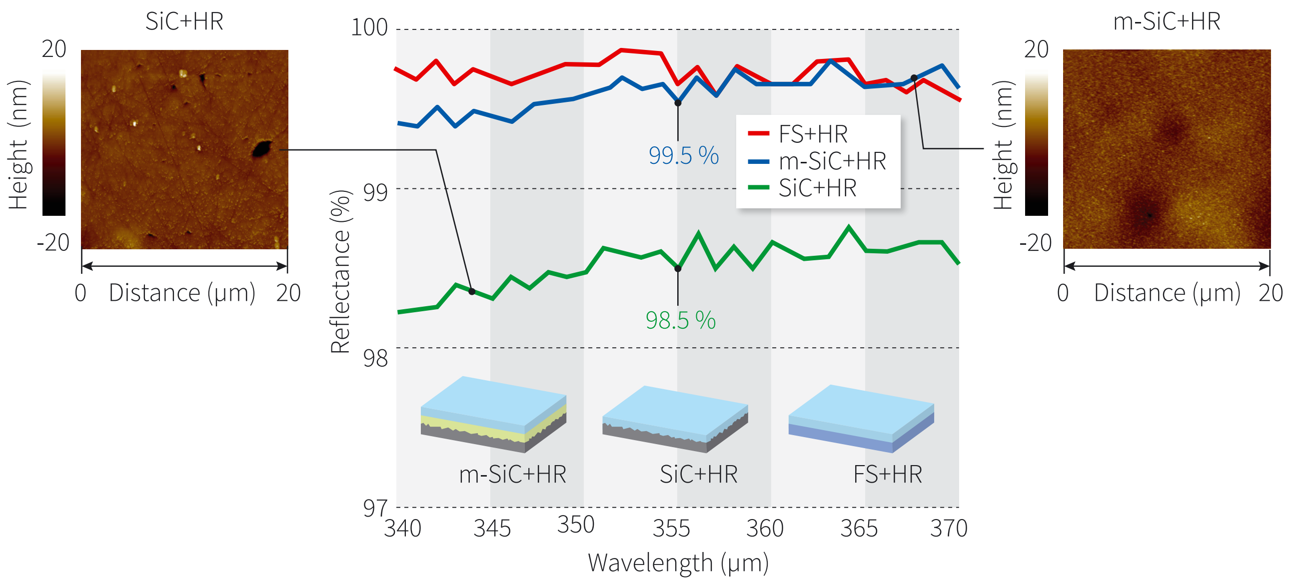

Figure 4. Reflectance spectra of a UV HR dielectric coating on unmodified (SiC+HR) and modified (m-SiC+HR) SiC substrates, and a fused silica substrate (FS+HR) with surface roughness measurements.

The surface of the mirror coating is smoother and, more importantly, without holes or cracks that scatter incoming laser light.

As mentioned before, to keep the initial laser beam wavefront undistorted, both the base of the coating – which is now the sub-layer – and the coating itself have to provide a certain level of flatness. Altechna delivered this, as needed for the custom applications not only to preserve beam energy, but to guide it while maintaining perfect shape. And, of course, precise control of the process was proven by confirming batch-to-batch repeatability.

A successful verification of modification principles allowed Altechna to continue with advanced low loss mirror coatings at other wavelengths on a modified SiC substrate. The spectral results of an HR (R>99.5% @ 1060-1085 nm+R>95% @ 1540-1600 nm, AOI=44°-46°) coating verified that silicon carbide preparation is also suitable for more complex low-loss coatings (Figure 5). These results go beyond "proof of principle" and distinctly show that, in general, any dielectric coating can be successfully applied to an SiC substrate with a sub-layer and maintain the intended characteristics in any spectral region.

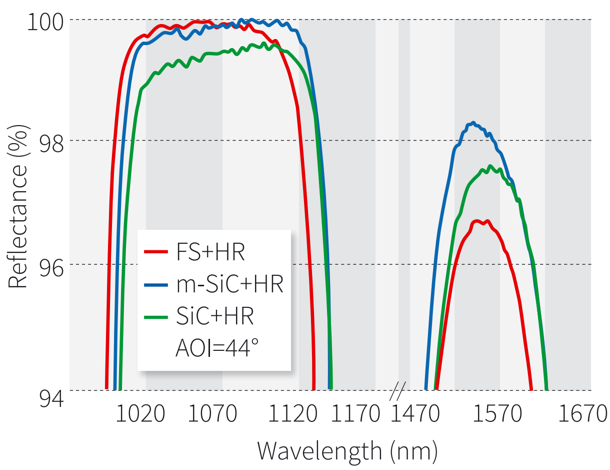

Figure 5. Reflectance spectra of an IR HR dielectric coating on unmodified (SiC) and modified (m-SiC) SiC substrates, and a fused silica substrate (FS).

Custom SiC mirror solutions

We are able to offer solutions for low-loss mirrors from the UV to mid-IR spectral range on silicon carbide substrates for individual galvo scanner systems and other applications. Feel free to contact our professional team and we will provide you with our best support: sales@altechna.com.

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