Functional Coatings Broaden Laser Applications

LASER COMPONENTS

High-power coatings make possible the construction of even higher power laser systems.

by Martin Schacht

Coated surfaces have played an important role in commercial laser technology for about 30 years. However, it was not until recently that development and production of functional optics faced changes, including increases in reflection and transmission behaviour in certain spectral ranges. Coatings are used in three primary laser application areas: dielectric high-power lasers, adaptive optics and gradient mirrors for unstable resonators. Because they can boost the performance of the final product, the method of coating and the choice of substrate are important considerations for manufacturers of optical components.

The constraints of several process parameters limit the performance of coatings produced conventionally by high vacuum vapor deposition. The overall pressure, as well as the partial pressure, is decisive because the average free path length is responsible for the stoichiometry – the proportions of elements and compounds in a substance. When heating the material at the bottom of the vacuum chamber, it is important that the same material composition (i.e. with no breaking of molecules) condenses at the top of the amorphous coating layers on the substrate surface. The trick is to optimise those pressures according to the requirements of the final product.

On the other hand, surface adhesion of the vaporized particles should always be at maximum. The adhesion is determined by the kinetic energy of the vaporized molecules and single atoms during condensation. By heating the substrate, the molecules receive additional energy during condensation, which has the same physical effect as a higher-speed, kinetic energy toward the substrate surface. The mobility of the vaporized particles on the substrate is closely associated with the substrate temperature during the condensation phase and has crucial influence on the microstructure of the resulting coatings.

The three-zone model established by Movchan and Demchishin distinguishes three characteristic temperature ranges with regard to the relationship between the substrate temperature and the melting temperature of the dielectric. This yields the optimum temperature, where the vapor particles can mobilize themselves in the best way possible on the substrate surface to eliminate any residual humidity. Substrates must be heated on their optimal temperature of about 300°C because conventional drying doesn´t remove humidity. Heating also contributes to better adhesion of the layers.

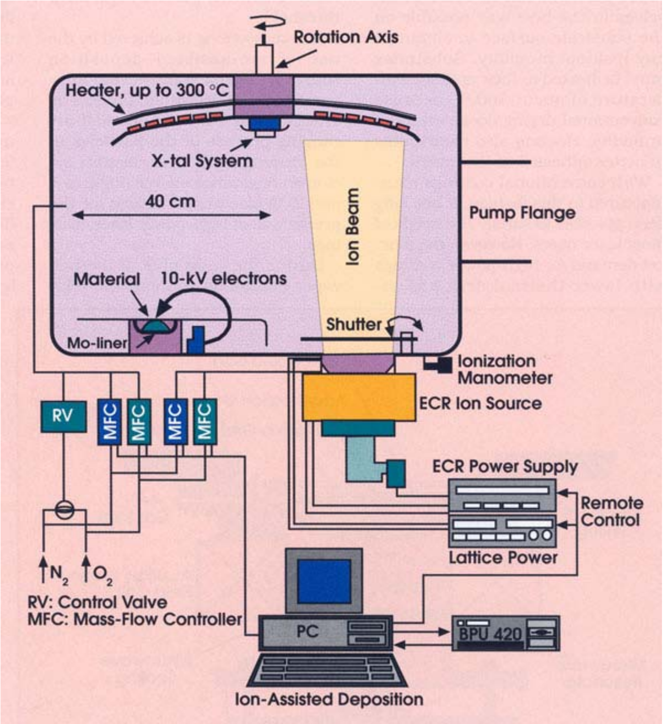

Figure 1*. In the typical ion-beam-supported vapor deposition equipment setup, the relatively low thermal particle energy of about 0.1 eV dissipates quickly.*

With conventional coatings manufactured in this fashion, it has long been possible to satisfy the needs of most laser users. However, the market demand for high-power coatings with lower thermal drift has increased. Decreasing thermal drift was possible only by compacting the coatings. This minimized the number of embedded H_2O molecules without embedding other dopant molecules and changing the stoichiometry of the vapor particles. Dopant molecules are primarily metallic pollutants from the vapor source or from the walls of the coating chamber. At high target excitation, they also come into the vapor deposition stream and are added to the substrate surface. This can result in an unwanted increase of absorption in the coating layers, which drastically reduces the damage threshold.

The compacting is achieved by the use of ion-assisted deposition sources, plasma sources that support the vapor deposition process by energetically favoring the self-arranging process of the particles in the forming layer. The electron cyclotron resonance source (Figures 1 and 2) is also an ion source for the production of high-power laser coatings.

During the conventional thermal vapor deposition process the relatively low thermal particle energy of only about 0.1 eV dissipates quickly, creating porous coatings with the typical column structures. A molecule hitting the substrate surface binds on the spot. Because no further thermal excitation processes take place, a spatial rearrangement is no longer possible.

Wit ion-assisted deposition and electron cyclotron resonance, particles move at a much higher average speed on their way to the substrate. With energies in the range of 5 to 10 eV, the energetic potential of the particles has reached that of surface binding energies, enabling processes like diffusion, particle swaps and momentum transfer. The higher mobility of the molecules after hitting the substrate surface produces a higher package density.

Ion deposition sources formerly used a plasma for the energy transfer that required a DC discharge between an anode and a cathode for excitation. The erosion of the cathode filament by interaction with the reactive gas oxygen and the resulting pollution of the equipment and the layers with filament material are important disadvantages of such an arrangement.

On the other hand, electron cyclotron resonance sources of the second generation produce an alternating electromagnetic field for plasma excitation, which is generated by a magnetron and coupled into the process chamber by a hollow waveguide system and a quartz half-dome. Only with such a nonfilament and metalfree arrangement is it possible to produce coatings with few dopant molecules. This is a great advantage over comparable ion-assisted deposition sources.

With electron cyclotron resonance sources, we get an alternating field of the frequency f by the cyclotron resonance condition:

$$\omega = 2\pi \times f = e \times B/m$$

where e is the elementary charge, m the electron mass and B magnetic flux density. The magnetic flux density typically has an order of magnitude of about 1000 Gauss with coil currents of more than 100 A. The resulting resonant frequency usually is adjusted at exactly 2.46 GHz because this is a radio-frequency range released by telecommunications authorities for industrial use according to interference. This microwave radiation with a wavelength of about 12 cm powers up to about 600 W. With adjustment, such sources work constantly and reliably for a longer time.

It is also possible to manufacture hard coatings without heating the substrates, so that even polycarbonate or plastic-coated glass and sapphire fibers can be coated. Also, very thick packages can be stacked up with a large number of layers; e.g., high-reflective alternating coatings (high-reflective mirrors) for the near to mid-infrared range. The damage thresholds, measured at Hannover Laser Zentrum in Hannover, Germany, reach more than 70 J/cm^2 at 1064nm and a 10-ns pulse duration.

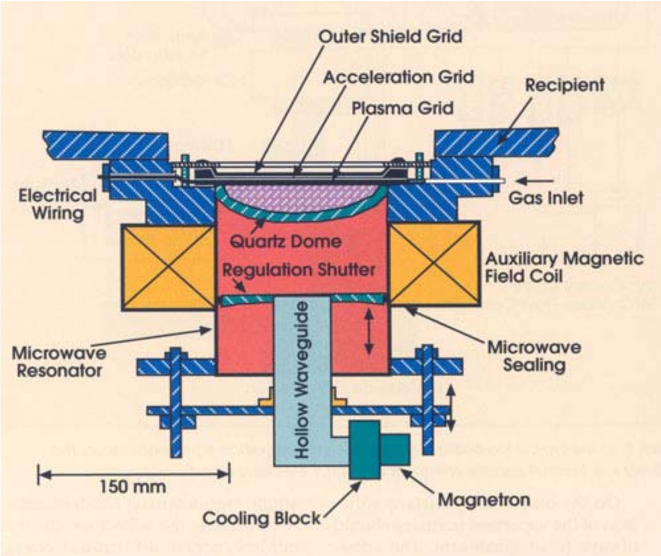

***Figure 2**. With ion-assisted deposition and electron cyclotron resonance, particles move at a much higher average speed on their way to the substrate.*

Adaptive laser optics

With adaptive optics, a new technology improved the imaging and beam quality in time variant optical systems by real-time correction of time-dependent aberrations that arise primarily from temperature drift. This is done using mirrors that are deformed locally by means of mechanical actuator elements to equalize the measured wavefront deviations. This method of wavefront compensation prevents a substantial deterioration of the beam quality and increases gain. It could enable a high-power laser system to be built that would produce beam quality very close to that of a single-mode laser.

The substrate material of deformable mirrors typically consists of an etched silicon foil with an area of 1 cm^2 and only a few microns thick, onto which a metal coating and several dielectric coatings are deposited (Figure 3). The dielectric coating raises the damage threshold as well as the reflectivity. Piezoelectric actuators, working with frequencies of some kilohertz, deform the mirrors.

Adaptive optics did not arise from a single pioneering invention, but evolved from many individual developments over a long period. It is an interdisciplinary area, because know-how and techniques were put together from many fields, including optics, electronics and materials technology, and were used for manufacturing optical systems.

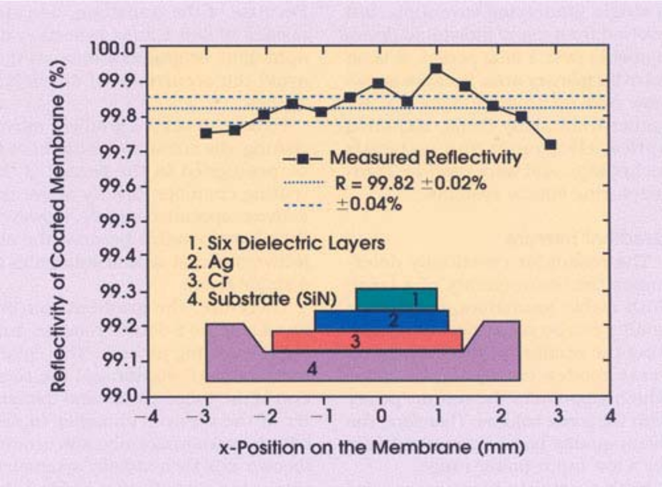

***Figure 3**. A piezoelectrically deformable foil with a coating of silver and six layers of dielectric coating is optimized for 1064 nm.*

Gradient mirrors

The resonator essentially determines the beam quality of a laser. With stable resonators, good beam quality can be accomplished by limiting the number of possible transverse modes using diaphragms, which also limits the output power with the mode volume. Therefore, the beam quality can be accomplished by limiting the number of possible transverse modes using diaphragms, which also limits the output power with the mode volume. Therefore, the beam quality can be optimised only for a low input power range.

With unstable resonators, the mode volume can be determined by the size of the output mirror. The beam quality does not depend on the pump power anymore because, with varied internal lenses, the focus radius and remote field divergence change in opposite directions at the same time.

The beam is coupled out around a higher reflective circular spot that has been coated on a non-reflecting substrate. One would suspect diffraction circular fringes at first. However, the so-called dot also can be accomplished with a nonconstant degree of reflection that continuously varies with the spot radius. Because of the transition, one also speaks of soft Gauss reflection diaphragms or gradient mirrors that avoid the occurrence of diffraction fringes.

To deposit such a gradient mirror coating, the substrate would have to be positioned in the center of the coating chamber directly above the active evaporation source. However, this is not possible, because the objective is to coat several substrates in a single batch.

Therefore, the gradient mirrors must execute a double rotation during the coating process. This "planetary motion" consists of the rotation of the substrate around the center of the vacuum chamber to distribute mass uniformly, and around its own axis for a radially symmetric thickness distribution behind the aperture (Figure 4).

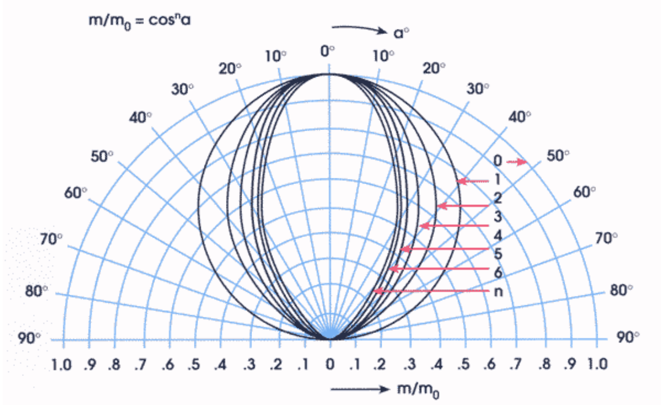

***Figure 4**. This illustrates the radial symmetric thickness distribution of a coating at rotation of the substrate during the coating process. The characteristics of an area evaporization source: a is the angle between the viewing direction and the symmetry axis of the evaporization source; m/m_o is the under angle a emitted mass, normalized to the under a= 0° emitted mass. The exponent n determines the shape of the vapor clouds: The bigger the n, the more directed is the cloud and the less material is emitted at greater angles.*

The reflection profile R is calculated for a Gauss-shaped course with the following:

$$R(r) = R_0 \times \exp(-2(^r/w)^n)$$

where R(r) is the reflection with regard to the radius, R_0 the center reflection, w equals $^1/e^2$ the radius of intensity reflection, r the radius and n the Gauss order exponent.

An Nd:YAG laser at a wavelength of 1064nm measured a reflection profile. The beam was split into measurement and reference beams. A short-focal-length lens focused the measurement beam. The mirror to be measured, mounted on an adjustable table, moved through the focus, and a large-area PIN photodiode detected the light that it transmitted.

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Summary

High-power coatings that are manufactured with electron cyclotron resonance sources in resonator optics and beam guidance make possible the construction of laser systems with even higher power, opening up the possibility of many new application areas. For example, adaptive optics produced as micromirror elements in single-chip technology in connection with fiber optics have the potential to revolutionize electric/optical control technology. The unstable resonator has been ignored for a long time, but with gradient mirrors, it has achieved greater importance.

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Meet the author

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