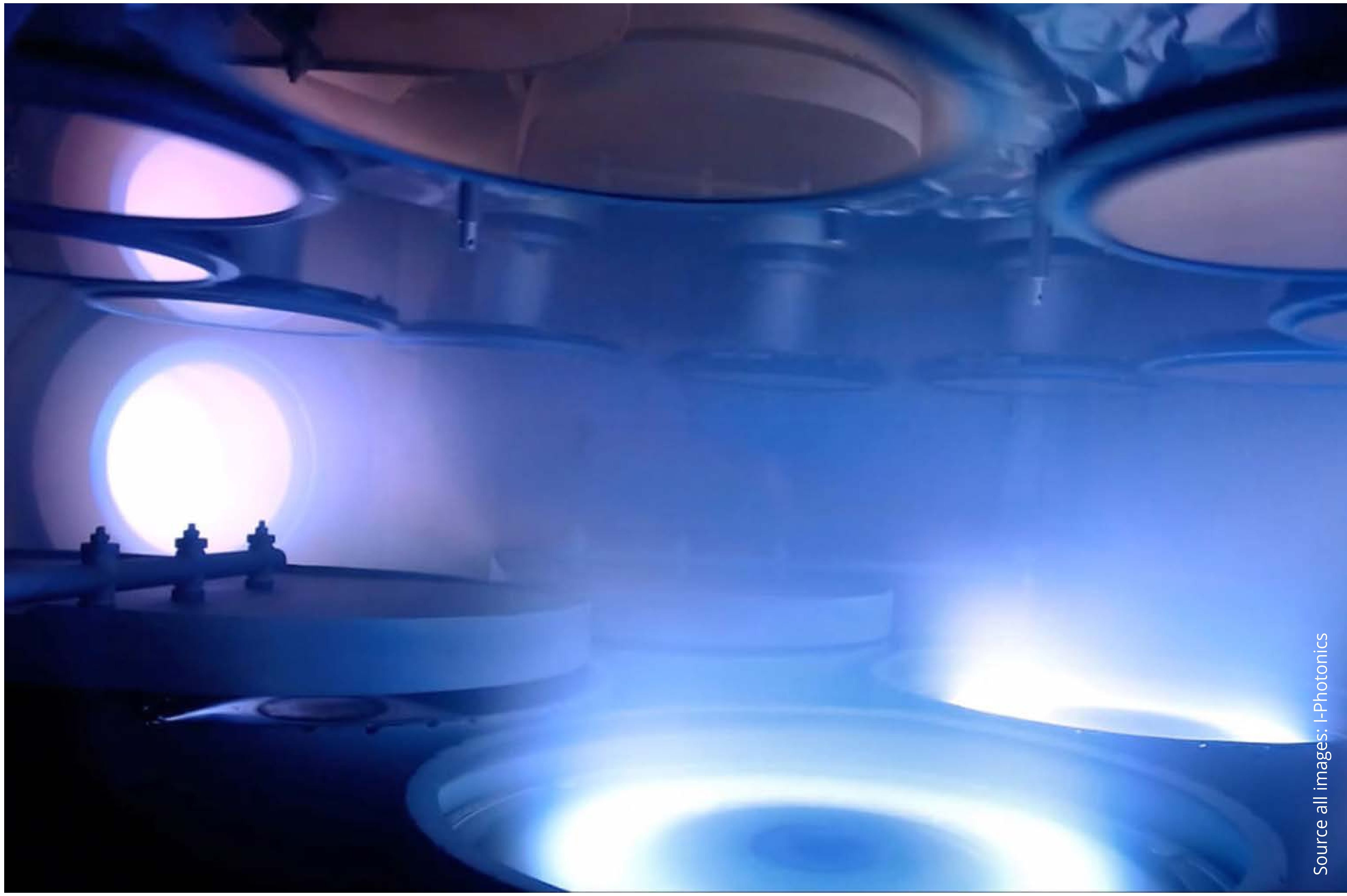
PARMS coating technology for UV to IR laser applications

Improved plasma-assisted reactive magnetron sputtering to fabricate high-precision optical coatings in mass-production

Alexander Myslivets, Henadz Rabatuyeu, Nadzeya Khinevich, and Eugene Hohlov

Reactive sputtering using a medium frequency (MF) dual magnetron source is an advanced technique widely employed in various thin film deposition applications. For producing high-quality optical filters based on oxides with low losses, it is crucial to exclude any form of arcing, including both strong arcs and microarcs. These requirements are solved by plasma-assisted reactive magnetron sputtering (PARMS), which also provides a high deposition rate contributing to the economically efficient production of high-end optical filters.



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In today's rapidly advancing world, engineering and functional optical materials have to meet ever-increasing requirements. The development of advanced technologies and materials usually leads to the need to reduce bulk materials to micro and nanometer sizes whose properties are different from those of bulk state. Usually, the formation of multicomponent thin film structure allows to meet the required optical specification.

Since the reactive magnetron sputtering was introduced and applied to the production of thin films in 1974, this technique become one of the most used and efficient technologies for optical coatings production.

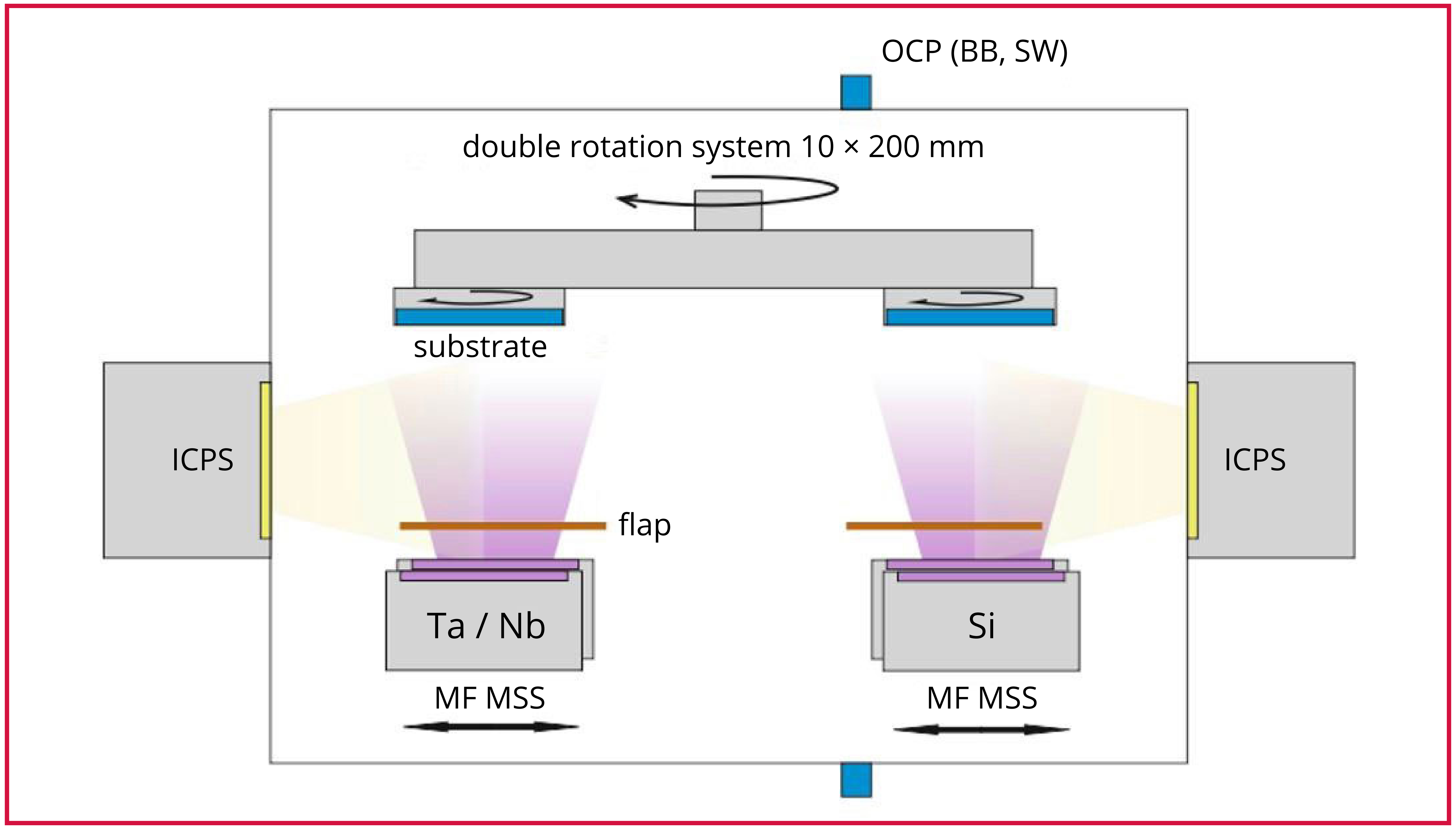

Fig. 1 Scheme of PARMS coating machine Meridian

Alexander Myslivets

Alexander Myslivets holds a master's degree in microelectronics. He started his career as a vacuum plant operator and has progressed to the role of chief process engineer, with more than eleven years of experience in developing thin-film technologies and coatings.

His expertise extends across optics, microelectronics, and solar cells, establishing him as a key contributor to technological innovation and process excellence.

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The magnetron sputtering process uses a magnetic field to confine plasma over a target, causing material ejection from the surface. The target is held at a negative voltage, attracting positively charged ions from the plasma, which bombard the target's surface. This bombardment causes atoms of the target material to eject and deposit onto the substrate, forming a homogeneous thin film. This process allows to create thin films with a high degree of precision and homogeneity, making magnetron sputtering a key method in modern nanotechnology and materials science.

The main disadvantages of reactive magnetron sputtering are the high level of arcing on magnetrons, resulting in high defectiveness of coatings, and a decrease in sputtering rate due to oxidation of the working surfaces of the magnetron system. Researchers continue to explore new materials and innovative approaches to enhance the capabilities and applications of this technology.

What is PARMS technology?

State-of-the-art plasma-assisted reactive magnetron-sputtering is a combination of the classical magnetron sputtering technique with the additional use of radio-frequency (RF) high-density plasma sources for oxidation that allow dielectric coatings to be deposited using metal targets. This ensures high productivity in the manufacture of high-end products with extreme precision on an atomic scale.

Traditionally, the principle of PARMS is based on a two-step process. First, a thin oxide layer is deposited with a controlled oxygen deficiency. This is followed by an RF plasma-assisted process, where reactive oxygen is used to transform the sputtered layer into a stoichiometric oxide layer.

This process is repeated until the desired final layer thickness is achieved and stopped by a time control or optical monitoring system.

This technical note highlights the capability of the new PARMS-based Meridian coating machine, which was developed by I-Photonics to produce high-performance optical coatings using Ta_2O_5/SiO_2 oxide pairs. The Meridian coater features several enhancements that improve the reproducibility and quality of thin-film coatings, providing precise optical properties in a range from UV to IR wavelengths, making it suitable for mass production.

Coater description

The batch-type coating machine (Fig. 1) includes medium-frequency magnetron sputtering systems (MF MSS) with metal targets as a source of material and radio-frequency (RF) inductively coupled plasma sources (ICPS) for substrate cleaning and sputtering assisting. All of the components are located in a common vacuum chamber. The usage of round dual magnetrons is advantageous due to its excellent long-term stability and high deposition rate. The substrates are mounted on a 10 × 200 mm double rotation planetary system above the surface of the magnetrons. A single-wave (SW) or spectral broadband (BB) optical monitoring system (OCP) is used to control the optical thicknesses of layers directly on one of the planets.

In detail for a PARMS process, argon plasma is generated near target surface by the MF power of the magnetron system. The ions are accelerated by a negative voltage of the magnetron towards the sputtering target with the desired coating material.

Loading area	Planetary system 10 × 200 mm 3,150 cm^2
Deposition rate Ta_2O_5/SiO_2, A/sec	up to 8/6
Uniformity across full sputtering area	≤0.2 %
Absorption level	<10 ppm; λ = 1,025 nm
LIDT	>100 kW @ 1,025 nm cw
Coating quality	20 – 10 according to ISO
Cycle time (from loading to unloading) for HR_1025	<4 hours

Table 1 Main technical parameters

A low-energy high-density oxygen plasma is generated by the RF power of the plasma source in the area between the magnetron and the surface of the substrates.

The main advantages of this design are:

- The large distance between the target and the substrate (approx. 300 mm) helps to avoid defects caused by the arcs in dielectric films. It also enhances the stability of coating uniformity during the lifetime of the target without the use of additional masks. The coating nonuniformity over ten planets is less than ±0.2 %.
- Magnetrons are mounted on a positioning mechanism that allows them to be moved during the sputtering process enabling more precise control of nonuniformity, achieving accuracy down to 0.04 %.
- Removing masks and minimizing the number of elements between the target and substrate reduces material pilling from parasitic surfaces, which in turn increases sputtering machine life and reduces the likelihood of substrate defects.
- To reduce arcing, surface sputtering is performed in quasimetallic mode. In this case, argon gas is supplied directly to the target surface and reactive oxygen gas is supplied through the plasma source which assists the magnetron area as well as the substrate area and makes it possible to work also at very low pressures. By controlling the total pressure in the chamber, the partial pressure of argon and oxygen, the power of magnetrons, and the power of plasma sources, it is possible to achieve high rates of dielectric layer deposition without arcing in the chamber.
- The earlier-mentioned technological features enable balancing the sputtering and oxidation processes of the target surface thereby reducing coating stress – a crucial factor for coating with thicknesses ranging from ten to fifty microns.

Henadz Rabatuyeu

Henadz Rabatuyeu is a senior technology engineer, specializing in the development and implementation of innovative optical coatings and deposition technologies. He is responsible for the launch and optimization of advanced equipment designed for high-precision optical coatings.

Henadz also oversees process adjustments to ensure that final products consistently meet state-of-the-art specifications, driving technological excellence and reliability in every project.

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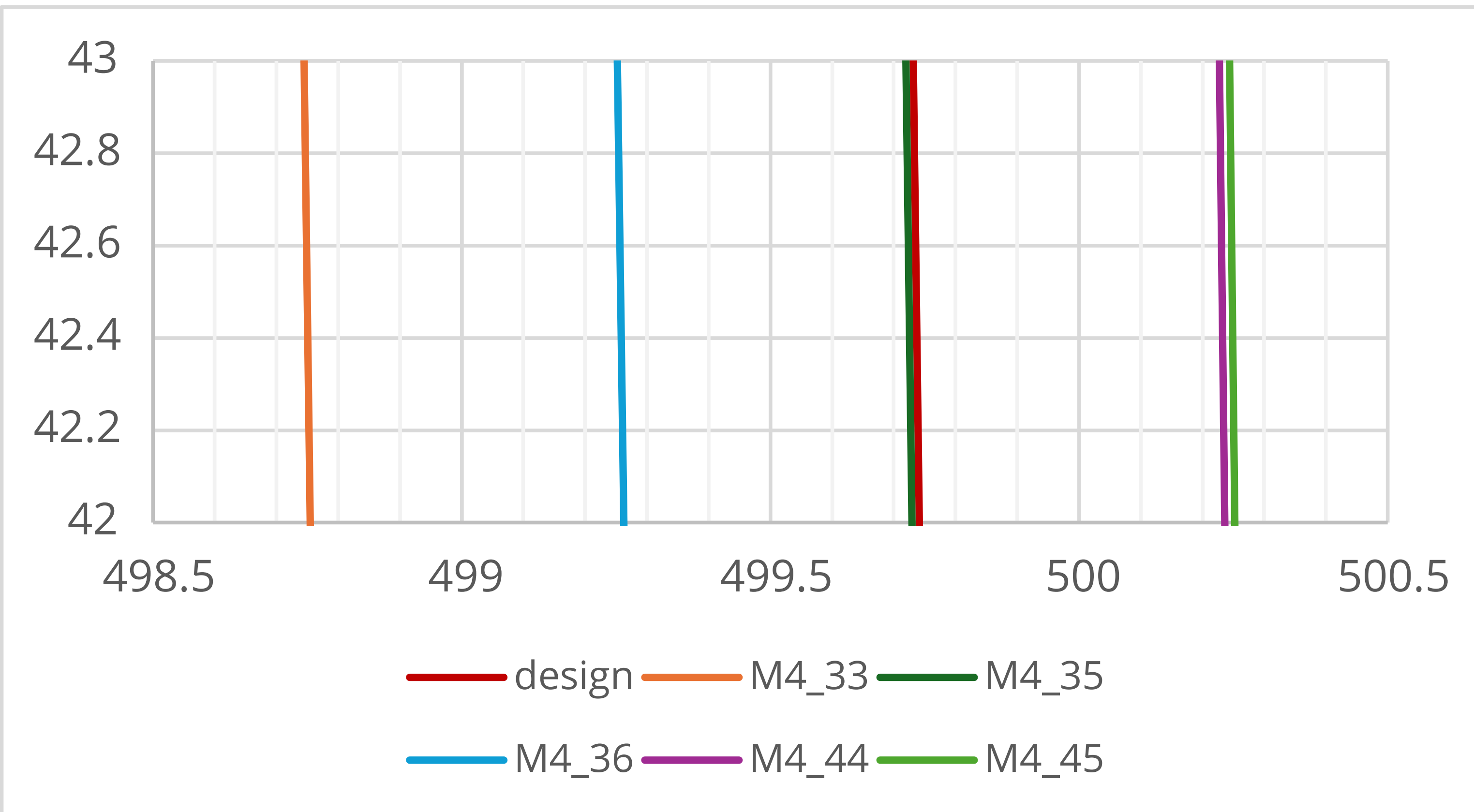
The main technical parameters of the system are shown in Table 1.

UV-VIS coatings

The PARMS technology-based coater Meridian produces thin layers with high density and a stable coating process that provides the possibility to produce complex interference coatings with more than two hundred layers and an average thickness of up to 40 µm in fully automated mode.



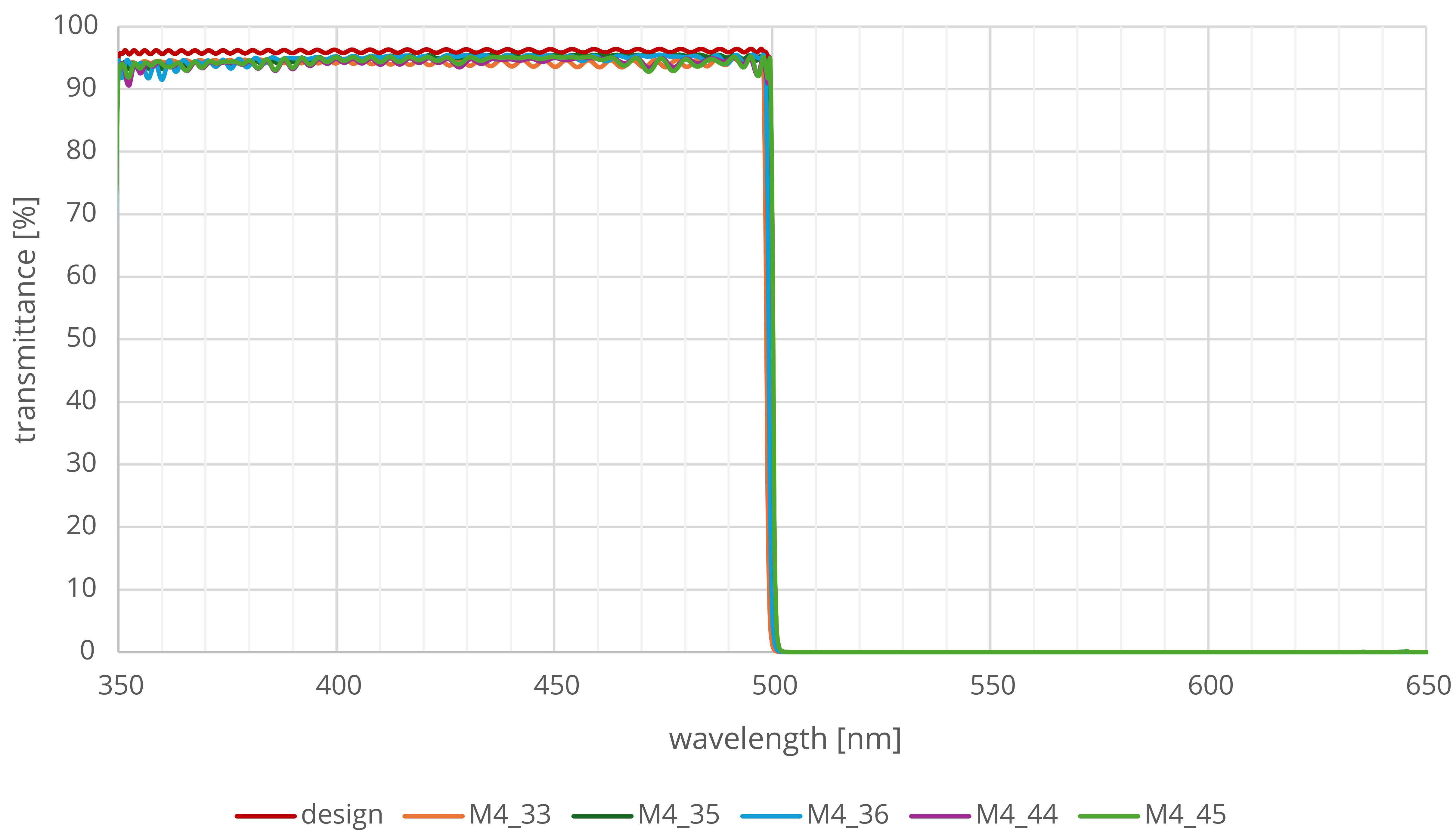


Fig. 2 Optical spectra of the short-wave bandpass filter at 350 – 500 nm range, 110 layers of Ta_2O_5 and SiO_2, total thickness 9.2 µm

Nadzeya Khinevich

Nadzeya Khinevich earned her PhD in physics from Kaunas University of Technology, Lithuania. She is currently a process engineer at I-Photonics, specializing in PARMS and IBS technologies, where she contributes to cutting-edge advancements in optical coating processes.

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The accuracy of optical monitoring of the sputtering process plays an important role in automated deposition mode and can affect the result of the interference pattern of the obtained coating structure, especially those with sharp transition boundaries. The combination of Ta_2O_5 and SiO_2 materials enables to produce coatings with the required light transmission value and minimal losses across a wide optical range of 350 – 5,000 nm (whereas it is possible to minimize the water absorption in the 2,700 – 3,000 nm range). The use of a single-wave high-resolution optical monitoring system provides sharp transition boundaries with spectral band tolerance up to 2 nm (Fig. 2).

Meridian demonstrates exceptional coating reproducibility and uniformity. Five processes performed at different times confirmed high accuracy with a process-to-process error of less than ±0.15 %. During the processes, 25 × 200 mm optical glass strips were loaded onto each of the planets to estimate the sputtering uniformity. The measured nonuniformity (U [%]) across all ten 200 mm planets was below 0.2 % (Fig. 3).

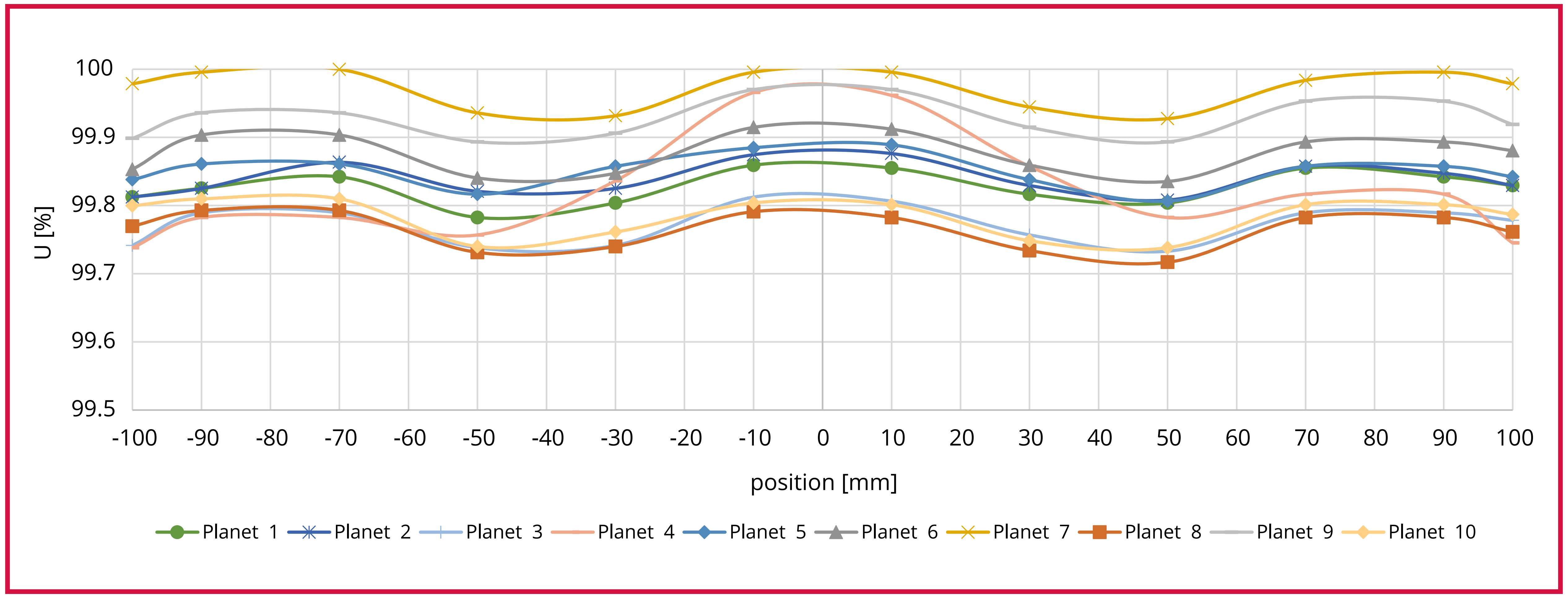

Fig. 3 Nonuniformity of short-wave bandpass filter across ten planets of the double-rotation planetary system

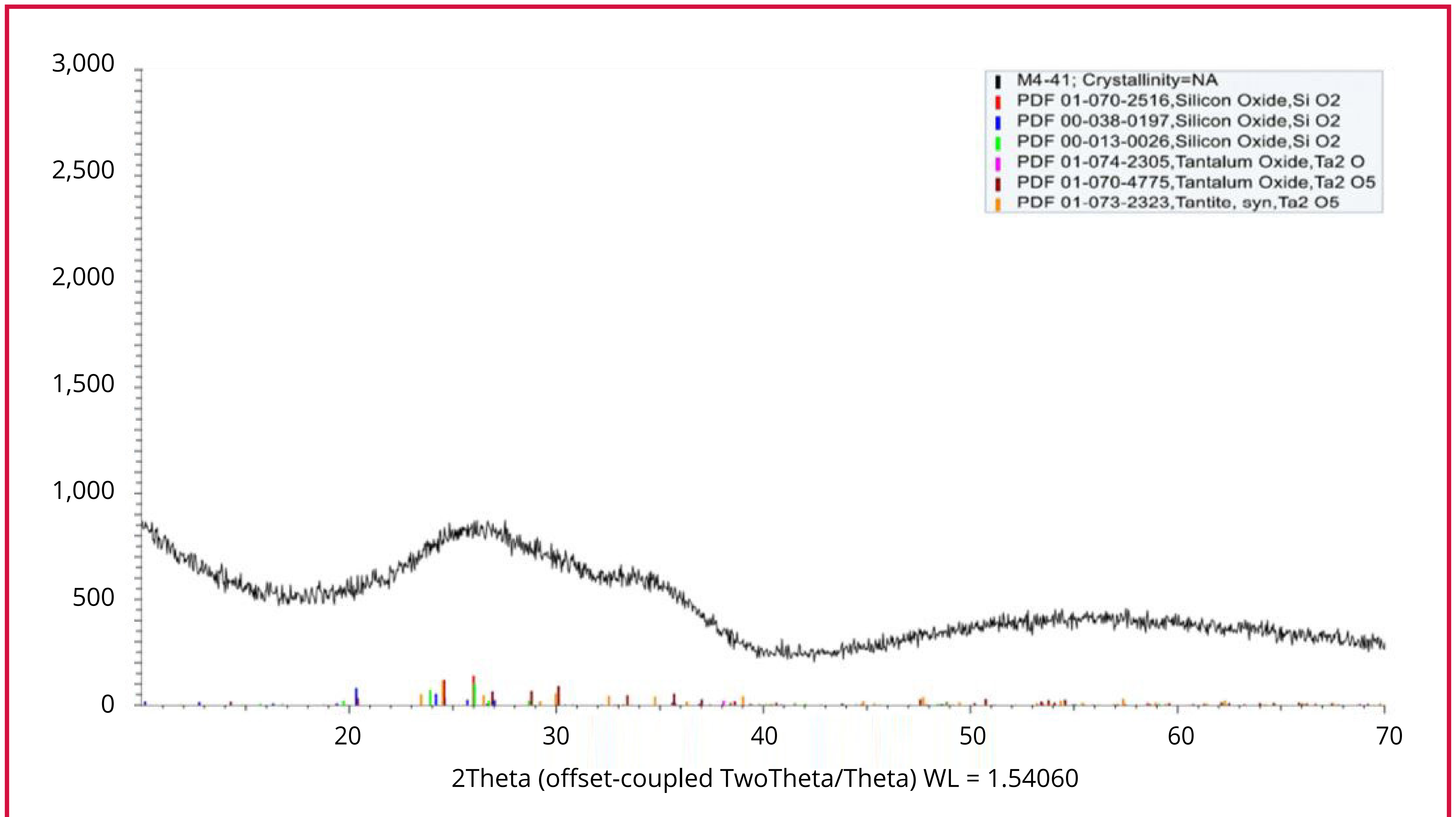

Fig. 4 XRD spectrum of the HR coating based on Ta_2O_5 / SiO_2 materials

Eugene Hohlov

Eugene Hohlov is the research and development director with with extensive expertise in designing production equipment for the display, solar, and automotive industries. His close collaboration with the marketing department and customers ensures a clear vision for product development, aligning innovations with market needs.

Eugene is responsible for overseeing, coordinating, and conducting research across various company departments. His efforts ensure the continuous improvement of both products and work processes, driving the company toward excellence and innovation.

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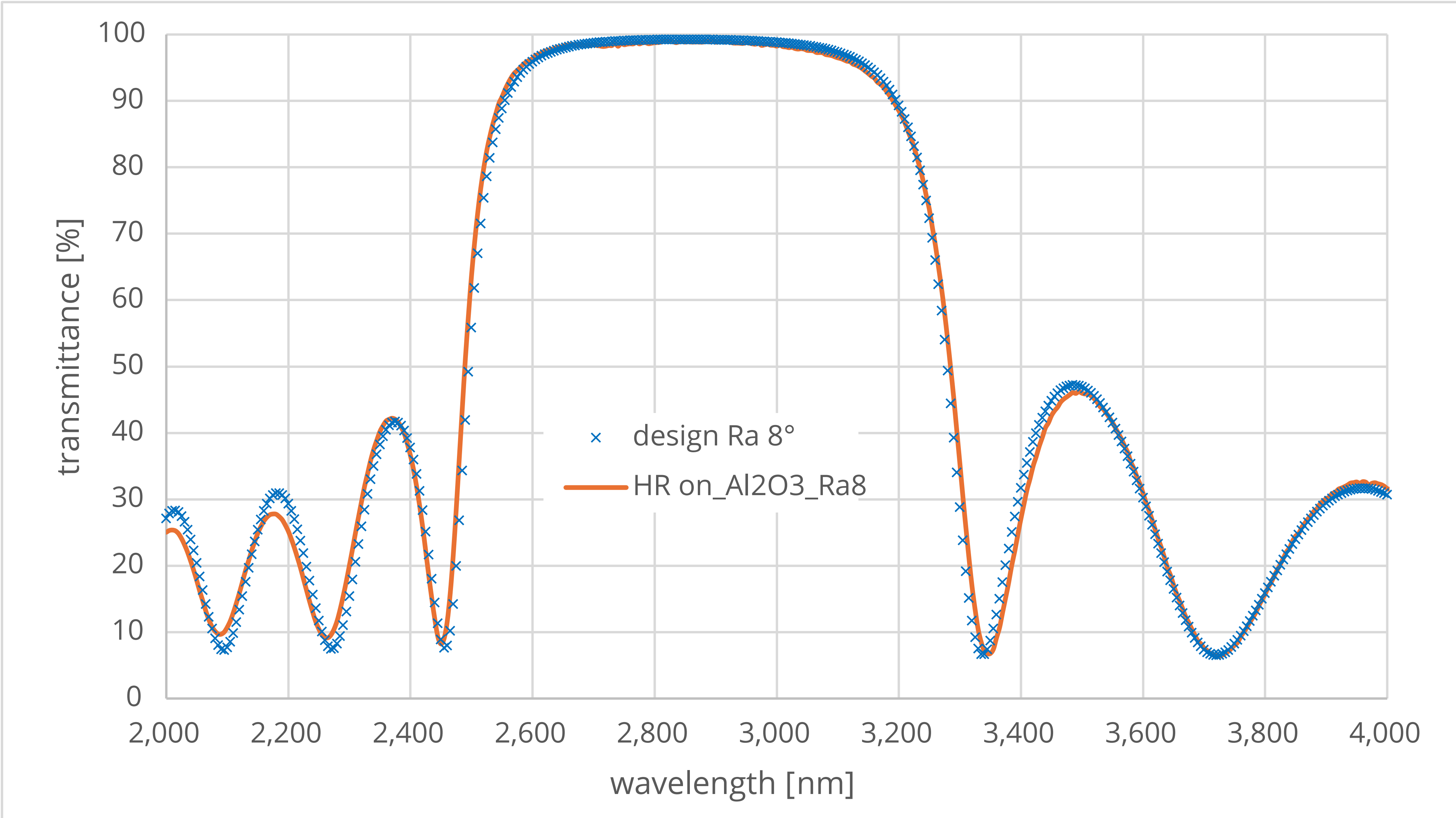
Mid-infrared coatings

Mid-infrared (mid-IR) laser optics operating within the 2 – 3 µm wavelength range have various applications, each targeting specific wavelengths:

- 2 µm: Coherent CO_2 lidar for space applications, optical pumping of other laser materials and optical parametric oscillators (OPOs), medical diagnostics, materials processing, and spectroscopy.
- 2 – 3 µm: Broadband tunable laser spectroscopy, materials processing, free-space laser communications, trace gas sensing (atmospheric, industrial, semiconductor), environmentally durable coatings for intelligence, surveillance, or reconnaissance windows and domes (scratch resistance, water resistance, sand/erosion, etc.), medical diagnostics.



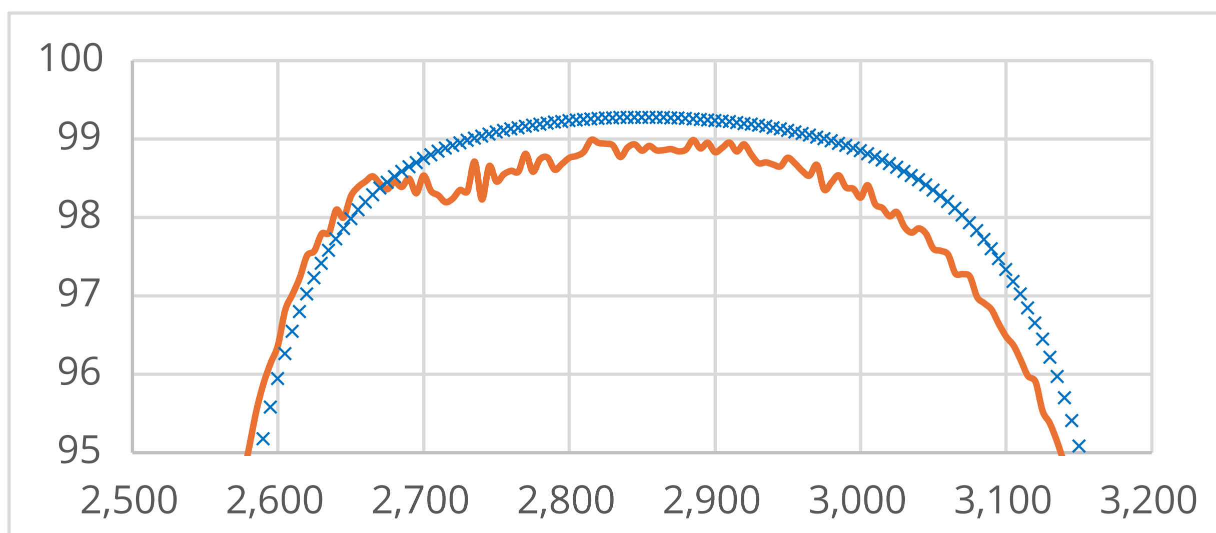


Fig. 5 Theoretical and measured spectra of HR coating on sapphire substrate

- 3 µm (especially 2.94 µm, 2.8 µm): erbium-doped lasers are of special interest in laser scalpel / laser surgery applications, dentistry, dermatology, material processing of textiles, plastics, polymers, or infrared countermeasures (IRCM).

Despite the widespread use of mid-IR optics, one of the structural challenges of thin films is their tendency to absorb moisture, which leads to increased coating absorption and negatively affects transmittance performance.

The Meridian sputtering system has proven its exceptional capability in producing high-quality fully amorphous structures without defects (Fig. 4), which effectively prevents moisture penetration in the coatings. This leads to minimal losses in the water absorption region, which is confirmed by the high reflection (HR) of the mid-infrared mirror. The mirror was designed using a pair of materials Ta_2O_5/SiO_2 optimized for the UV and visible ranges were sputtered on quartz (Al_2O_3) substrate with a central wavelength at 2,850 nm for 0 degrees incidence angle with a total coating thickness of 7.2 µm (Fig. 5).

The obtained results demonstrate the Meridian system's capability to produce low-loss coatings in the range of 2 – 3 µm, underscoring its effectiveness for precision optical coating applications.

These findings highlight the system's reliability and stability of the sputtering process and the multilayer optical structure formation; however, we continue to optimize the system and expand the potential of the machine. ■