Nanometrology Project Produces Technology That Advances Super-Smooth Optical Thin Films

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Magnetron sputtering produces super-smooth thin films and can be used for high-throughput production.

Nanometrologie-Projekt liefert eine Technolgie, die superglatte optische Dünnschichtfilme ermöglicht
Magetronsputtern produziert super-gleichmäßige dünne Schichten und kann für die Produktion mit hohem Durchsatz verwendet warden.

Un projet de nanométrologie produit une technologie qui fait progresser les films optiques fins et super lisses
Le crépitement du magnétron produit des films fins et super lisses qui peuvent être utilisés dans des productions à haut rendement.

Un progetto di nanometrologia genera soluzioni tecnologiche che migliorano le deposizioni ottiche di film sottili a bassissima rugosita' residua
La tecnica di sputtering tramite magnetron produce strati sottili estremamente "lisci" e puo' essere impiegata in produzioni su grandi volumi.

The smoothness of thin films in optical coatings is important because it affects scatter and haze and determines how the coating is damaged by lasers. Thin films produced by conventional electron beam evaporation are not sufficiently smooth for many applications, even with the addition of ion assist. Ion beam sputtering is known to produce super-smooth thin films, and the technique is used to deposit high-performance optical filters for applications such as ring laser gyroscope mirrors, high laser damage and telecommunications.

Unfortunately, the technique is limited as a production tool because deposition rates are comparatively low. The semiconductor and optical layer analysis and definition using interference microscopy (SOLADIM) project in the UK is aimed at developing new nanometrology technologies. Through the project, it has been discovered that closed-field magnetron sputtering also produces thin films that are super smooth. This sputtering technique also can be used for high-throughput production.

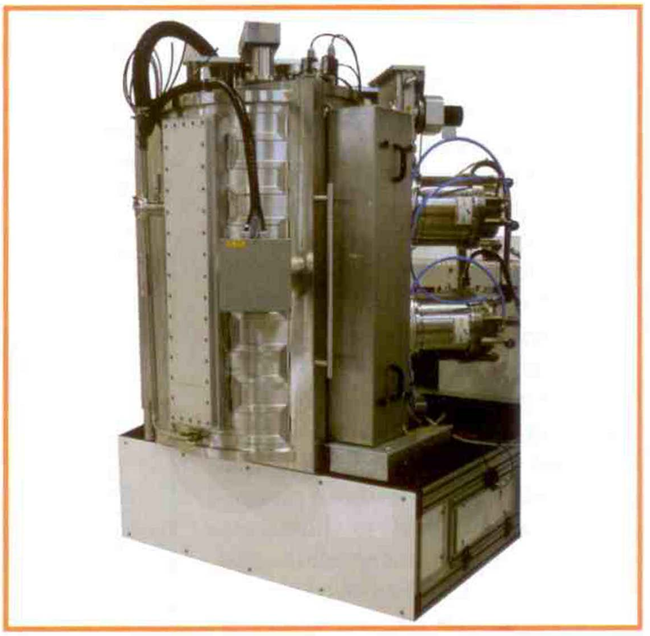

Figure 1. The CFM850 closed-field optical coating system has two 1-m linear magnetrons and a 0.5-m-diameter substrate carrier. The drum is removable for higher throughput.

The project brought scientists with metrology expertise together with experts in semiconductor growth and optical film deposition. It has centred on the use of coherence correlation interferometry, a white-light interference tool recently developed by Taylor Hobson Ltd. of Leicester, UK.

The major advantage of coherence correlation interferometry over atomic force microscopy is that it is a fast, noncontact technique that takes data from a relatively large area, typically measuring 300 × 300 μm. The technique produces a quantitative three-dimensional image with 0.01-nm vertical (Z) and 400-nm lateral (X,Y) resolution. The data then can be used to generate accurate quantitative parameters such as root mean square surface roughness. The availability of rapid metrology

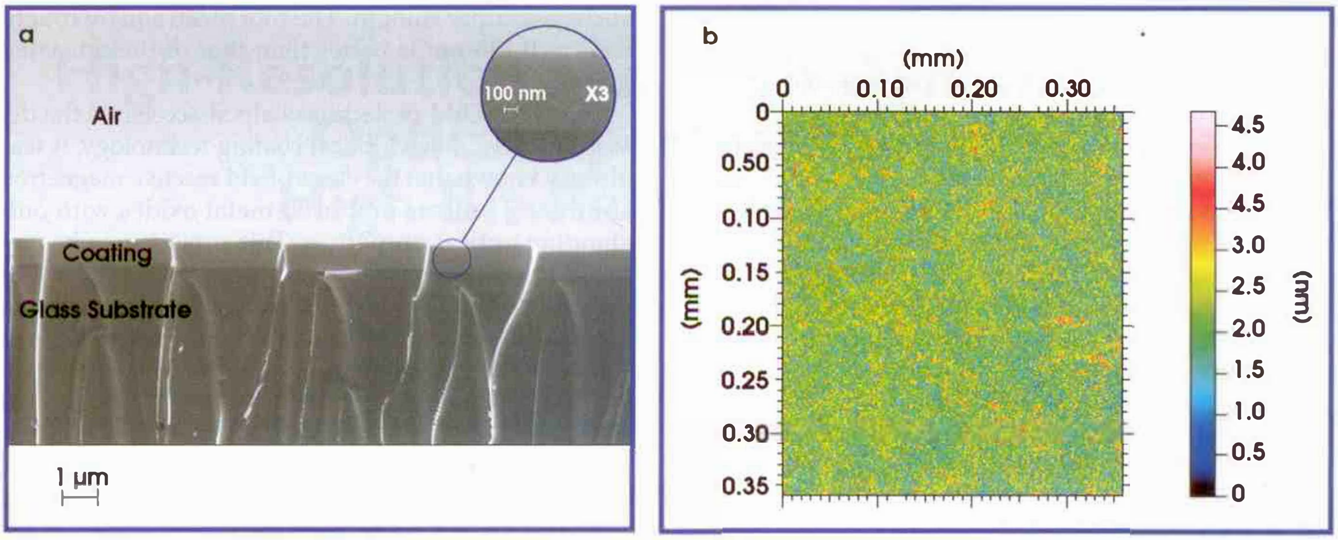

Figure 2. A scanning electron microscope image of a fracture cross section of 1-µm-thick niobia film on glass reveals a dense smooth coating (a). A coherence correlation interferometry image from the same film reveals a root mean square roughness of 0.452 nm (b).

has enabled fast optimization of the new closed-field reactive sputtering process.

Magnetron sputtering is acknowledged to have advantages over evaporation processes for deposition of the metal oxides used in optical coatings. The sputtering process is "cold," making it suitable for use on various substrates including polymers. The drum format provides more efficient loading for high-throughput production than a culotte does. The process is also easier to control and to maintain.

The CFM850 system from Applied Multilayers uses a 0.5-m-diameter drum substrate carrier (rotating at 50 rpm) and as many as six 1-m linear magnetrons (Figure 1). The targets are simple metals. Oxidation of the metal is achieved in an oxygen plasma around the drum, created by the unbalanced magnetrons and held by the closed field between the magnetrons of opposite magnetic polarity. The combination of high current densities (>5 mA/cm^2) with a substrate bias in the range of 25 to 40 V creates optimum thin-film growth conditions.

In this system, the oxidation of the metal target is held constant by feedback from the target voltage to the mass flow controller regulating the supply of oxygen. Individual thin-film thickness can be controlled with subnanometre precision using time only. Deposition rates of 0.5 nm/s are achievable even on a 0.5-m drum diameter. The closed-field process also can be used to produce pure metal thin films (such as reflectors), metal nitrides and metal carbides.

The closed-field reactive magnetron sputtering process can be exploited in various formats with a choice of

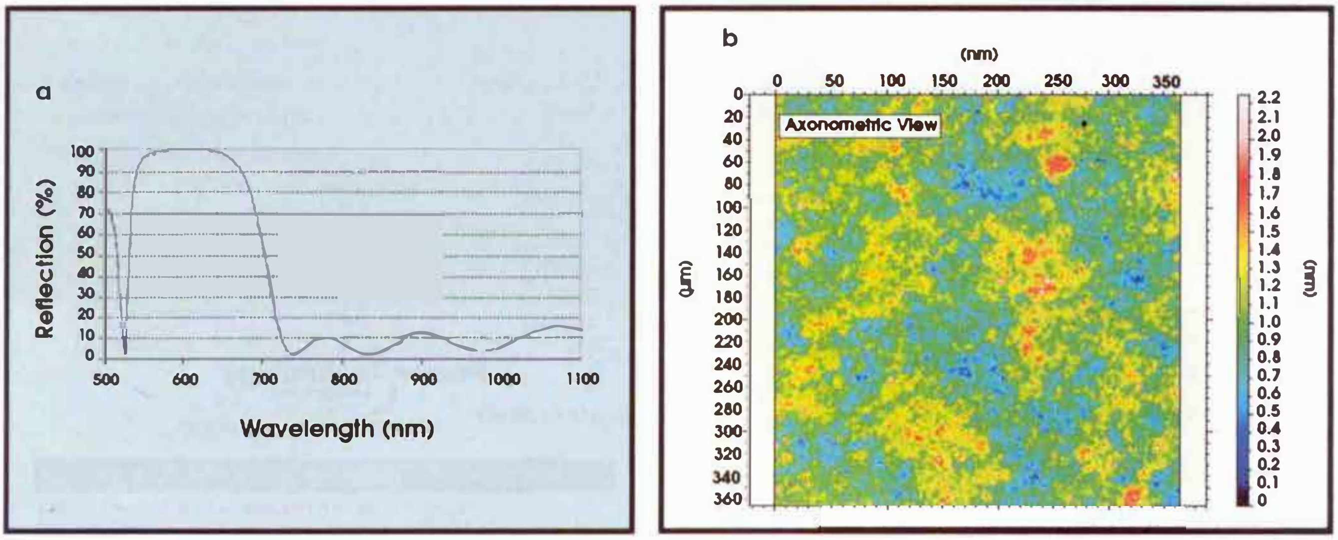

Figure 3. The reflection is shown from a simple 15-layer test edge filter (a), and a coherence correlation interferometry image from the surface of the same coating reveals a root mean square roughness of 0.188 nm (b).

magnetron lengths and drum diameters. The systems are scalable from the needs of a small R&D system through to high-throughput production tools. The process combines the throughput advantages of ion-assisted electron beam evaporation with the optical quality produced by ion beam sputtering.

A scanning electron microscope image of a fracture cross section of a 1-µm-thick niobia film produced using magnetron sputtering shows fracture lines that extend through the glass substrate and then through the niobia film (Figure 2a). The film is dense and reveals very little structure. However, the coherence correlation interferometry image from a 350-µm-square area of the same film of niobia (Figure 2b) shows more information. The peak to valley across this image is 5.69 nm, and the root mean square roughness is 0.452 nm. This is comparable with the measurement made on the original glass substrate (Schott D263) with roughness of 0.32 ±0.14 nm.

The coherence correlation interferometry technique also has been used to determine the surface roughness of multilayer optical coatings deposited using closed-field magnetron sputtering. The example in Figure 3a shows the reflection from a test edge filter comprising 15 layers of Nb_2O_5 and SiO_2, with a total thickness of 1.4 µm. The coherence correlation interferometry measurement taken from the surface of the edge filter is shown in Figure 3b. Even on this thick coating — which consists of multilayers — the outer surface is super smooth. The root mean square roughness of 0.188 nm is better than that of the uncoated glass.

The SOLADIM project has helped accelerate the development of a new optical coating technology. It was already known that the closed-field reactive magnetron sputtering process produced metal oxides with outstanding optical properties. This project now has revealed that the technology also produces films that are super smooth. These properties all are derived from the fundamental advantage of the closed-field process inherent in the combination of high ion current density and low ion energy. □

Acknowledgments

The authors are grateful for partial funding under the Micro and Nanotechnology Initiative and to the members of the SOLADIM consortium, including Tony Smith (Taylor Hobson), Roy Blunt (IQE), Richard Leach (NPL), Liam Blunt and Leigh Brown (Huddersfield University).

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