COATINGS FOR LARGE-AREA LOW-COST SOLAR CONCENTRATORS AND REFLECTORS

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Coatings for large-area low-cost solar concentrators and reflectors

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ABSTRACT

Large-optics coating facilities and processes at Pacific Northwest Laboratory (PNL) that were used to develop large-area high-performance laser mirrors for SDIO are now being used to fabricate a variety of optical components for commercial clients, and for novel applications for other DoD clients. Emphasis of this work is on technology transfer of low-cost coating processes and equipment to private clients. Much of the technology transfer is being accomplished through the CRADA (Cooperative Research and Development Agreement) process funded by the Department of Energy (DOE).

Keywords: optical, coatings, sputtering, polymer, multilayer, solar

1. INTRODUCTION

Seven years ago, Pacific Northwest Laboratory constructed a large-optics coating facility to develop and fabricate high-performance multilayer laser-mirror coatings on large substrates. The facility is unique in that precision multilayer optical coatings can be applied to curved and rotationally asymmetric substrates as large as 2.1 m in diameter. Nitride, oxide, carbide, and metallic coating materials are deposited by low-temperature magnetron-sputtering techniques using advanced cathode designs and ion assist. The facility consists of

1) a 3-m coating chamber outfitted with magnetron sputtering cathodes, electron-beam evaporation sources, ion sources, and double-planetary substrate holders,
2) a cleaning station capable of handling 2-m substrates,
3) a small metrology lab, and
4) a fiber-optic diode-array spectrophotometer for measuring and profiling the optical performance of coatings on large substrates.

The 3-m coating chamber is shown in Figure 1. All process control equipment is fully automated.

Figure 1. PNL 3-m large-optics coating chamber
With the reduction of DoD funding for the development of optical coatings for large optics, new applications for this chamber were sought. In addition to new DoD applications, the facility is now being used to fabricate multilayer enhanced-metal reflectors for low-cost large-area solar concentrators using both magnetron-sputtered metal and dielectric coatings, with future extension to vacuum-evaporated polymer coatings. Other new applications include

- Ti/Ti:Al lamellar composites on flexible webs
- EMI cladding for heater wire
- EMI-shielding coatings on flexible webs
- microwave-absorbing coatings on flexible webs
- heat mirrors
- bulk micromachining
- protective coatings on cylindrical substrates and webs

The facility has also been established as a DoD user facility for development and experimentation in large-area optical coatings.

This paper describes important changes in the large-optics coating chamber and additional deposition equipment that has been added to pursue these new non-DoD technological areas. Solar reflectors and the resulting new coatings will be described. Future work and new technological areas being pursued will also be discussed.

2. NEW APPLICATIONS

2.1. Vacuum roll-coater capabilities

A major change from the magnetron-sputtering configuration of the chamber shown in Figure 1 was the installation of a drop-in roll-coating system, shown in Figure 2. The roll-coating system, or web drive, was designed and installed in the chamber for deposition of sputtered multilayer coatings, polymer coatings, and combined sputtered/polymer coatings onto flexible substrates or webs. This system was used to fabricate new types of coatings and thin films, including prototype magnetic metal/insulator coatings, Ti/Ti:Al and Al/Al2O3 lamellar structures, durable low-cost solar reflectors, and magnetic-shielding coatings on flexible substrates. Continuous plastic, mylar, and metal webs were coated. Once demonstrated in this system, the process and materials were further developed and demonstrated in PNL’s new vacuum roll-coating facility shown in Figure 3, to be presented in another paper in this Proceedings.1

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Figure 2. Schematic of the PNL drop-in roll-coating system in the 3-m chamber with center section removed.
Two magnetron cathodes were installed in the base of the web drive to permit simultaneous deposition of two coating materials. Appropriate cathode-enclosure placement permits deposition of material combinations such as Fe$_{0.2}$Ni$_{0.8}$ (permalloy)/Ta$_2$O$_5$, Al/Al$_2$O$_3$, and Ti/Ti:Al. An ion gun was used to preclean the flexible substrate. The coatings displayed excellent adhesion to plastics, polyethylene, mylar, and copper substrates, even after excessive flexing. Figure 4 shows a scanning electron micrograph of a multilayer Fe$_{0.2}$Ni$_{0.8}$/Ta$_2$O$_5$ magnetic/electric-field-shielding coating. The magnetic metal layers are about 500-Å thick, and the oxide is about 1600-Å thick. The coating shown has 200 layers and was deposited at a web speed of 1 m/min. Note the excellent layer-to-layer thickness uniformity. Recent coatings have as many as 200 layers with a total thickness of 100 μm.

The shielding of low-intensity magnetic and electric fields to mitigate possible harmful biological effects is of interest. The DOE is currently funding PNL to develop shielding coatings. High-permeability μ-metal films were deposited onto flexible mylar substrates to evaluate the shielding effectiveness of thin-film magnetic materials. The adhesion of 10-μm-thick films was excellent. The coatings were not degraded after continuous flexing and crumpling. New high-rate third-generation magnetron cathodes, shown in Figure 5, are being used to deposit the magnetic materials. Magnetron sputtering of magnetic materials is often difficult because the target shunts the magnetic field of the cathode. Usually only very thin targets can be used. The new cathodes have a radically different magnetic-field geometry which permits use of magnetic targets as thick as 0.5 in. Deposition rates for these cathodes are at least ten times higher than for conventional reactively-sputtered and magnetic materials.

Figure 3. The interior of PNL's new vacuum roll-coating chamber.

Figure 4. Scanning electron micrograph of multilayer Fe$_{0.2}$Ni$_{0.8}$/Ta$_2$O$_5$ magnetic/electric-field shielding coating.
Developmental multilayer Ti/\(\text{TiO}_0.53\text{Al}_0.47\) lamellar composites were deposited onto flexible copper and mylar substrates. These materials show potential for having very high strength and flexibility for use as aircraft skins. The 1600-layer composites were deposited simultaneously with Ti and Ti:Al magnetron targets. The Ti layers were 200-Å thick, and the \(\text{TiO}_0.53\text{Al}_0.47\) layers were 1800-Å thick. Initial durability tests showed that, after prolonged flexing, the Cu substrate cracked and split, but the 144-μm-thick coating remained unchanged and even supported the cracked Cu substrate.

2.2. Large-area solar concentrator panels

PNL presently has a CRADA with United Solar Technologies (Olympia, WA) to develop the process for applying high-reflective coatings to large-area solar concentrator panels, and to coat several sets of prototype panels. A completed solar concentrator consists of 14 aluminum panels. The completed structure has a diameter of 14 ft and a concentration factor of 300,000. Seven-ft-long "Gore" sections of advanced solar concentrators, shown in Figure 6, are coated with highly-reflective Ag or Al metal layers. A SiO\(_2\) or Al\(_2\)O\(_3\) coating is currently applied by reactive magnetron sputtering to enhance reflectance and protect the metal layer. A typical reflectance spectrum of an Al\(_2\)O\(_3\)-protected silver layer is shown in Figure 7.

The specular reflectance of the aluminum panels, as formed, is not adequate to achieve the desired concentration. Surface imperfections (scratches, digs, etc.) and roughness degrade the reflectance of the bare aluminum. A solar reflectance of at least 0.91 is required to achieve the desired performance. A 50- to 100-μm-thick acrylate-polymer "smoothing" layer is applied before metal layer deposition to fill in defects and enhance the specularity of the bare Al. Evaluations are ongoing of methods designed to improve adherence of the polymer to the substrate and the metal to the polymer layer. United Solar Technologies is presently performing durability testing on test sections.

3. FUTURE WORK

Continuing development of high reflector coatings for solar concentrators will involve evaluation of polymer coatings to replace the sputtered dielectric coatings, development of hybrid sputtered/polymer protective/enhancement layers, and deposition of polymer dirt-sloughing layers. The goal is to reduce the cost of the panels by replacing the sputtered coatings with polymer coatings wherever possible. Polymers can be deposited at significantly higher rates than sputtered coatings. Critical issues are the durability, adhesion to the metal layer, and coverage of the polymer coatings.

With the authorization by SDIO, the PNL large-optics chamber and associated equipment has been designated as a DoD user facility for large optics. DoD contractors and staff are encouraged to bring coating experiments involving multilayer coatings on large optics to this facility. PNL staff or the contractor's staff trained by PNL will perform the coating work.
Figure 7. A reflectance spectrum of an Al2O3-protected Ag layer.

Figure 6. One panel of United Solar Technolgy's solar concentrator.
4. SUMMARY

Applications and customers for the large-optics coating facility at PNL have changed from primarily DoD to private industrial and energy efficiency. The addition of new equipment such as a roll coater for flexible substrates, new third-generation magnetron cathodes, and polymer-deposition sources have expanded the facility's range of applications and customer base. The facility, originally used to fabricate precision-multilayer optical coatings on large optics, is now used to 1) fabricate multilayer magnetic/insulator-shielding coatings, high-strength lamellar composites, and solar reflectors on flexible substrates, 2) apply protective high-reflector coatings on solar concentrator panels, 3) apply specialized coatings to large substrates and components, and 4) process large-batch bulk micromachining. The facility has also been established as a DoD user facility.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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