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Status of Optical Coatings for the National Ignition Facility

C.J. Stolz, C. Weinzapfel, G.T. Rogowski, D. Smith, A. Rigatti, J. Oliver, J. Taniguchi, M. von Gunten, R. Bevis, M. Smith and V. Ivan

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Christopher J. Stolz, Carolyn Weinzapfel, and Gregory T. Rogowski
Lawrence Livermore National Laboratory, P.O. Box 808, L-487, Livermore, CA 94550
(925) 422-3562, e-mail: stolz1@llnl.gov

Doug Smith, Amy Rigatti, Jim Oliver, and Jason Taniguchi
Laboratory for Laser Energetics, University of Rochester, 250 E. River Rd., Rochester NY 14623

Marc von Gunten, Ron Bevis, Michelle Smith, and Vladimir Ivan
Spectra Physics, Inc., 1330 Terra Bella Ave., Mountain View, CA 94043

1. Abstract

Optical coatings are a crucial part of the pulse trapping and extraction in the NIF multipass amplifiers. Coatings also steer the 192 beams from four linear arrays to four converging cones entering the target chamber. There are a total of 1600 physical vapor deposited coatings on NIF consisting of 576 mirrors within the multipass cavity, 192 polarizers that work in tandem with a Pockels cell to create an optical switch, and 832 transport mirrors. These optics are of sufficient size so that they are not aperture-limiting for the 40-cm × 40 cm beams over an incident range of 0 to 56.4 degrees. These coatings must withstand laser fluences up to 25 J/cm^2 at 1053 nm (1ω) and 3-ns pulse length and are the 1ω fluence-limiting component on NIF. The coatings must have a minimal impact on the beam wavefront and phase to maintain beam focusability, minimize scattered loss, and minimize nonlinear damage mechanisms. This is achieved by specifications ranging from <50 MPa coating stress, <1% coating nonuniformity, <4Å RMS surface roughness, and a PSD specification to control the amplitude of periodic spatial frequencies. Finally, the primary mission of optical coatings is efficient beam steering so reflection and transmission losses are specified as R>99.5% and >99% for mirrors and polarizers, respectively, and T>98% for polarizers.

2. Introduction

Successful demonstration of crucial NIF technologies in 1995 on Beamlet, a single beam prototype, the Inertial Confinement Fusion (ICF) program embarked on development of optical technologies. The primary objective was to enable the manufacture of the 192 beam NIF laser at lower unit costs than Beamlet, with accelerated fabrication rates to meet the NIF assembly schedule, and at higher quality to meet the stringent user community demands.

The coating development program, lasting about four years, focussed on improving source stability, process monitoring, damage threshold, stress control, and chamber production readiness. A one-year facilitization phase addressed large-aperture post-deposition metrology and manufacturing equipment. Currently the coating vendors are in Pilot production coating the first ~10% of NIF optics.

3. Requirements

In the technology center of optical coatings, the primary objectives were many; identification of the best deposition process for NIF requirements including high laser damage threshold, scalability to meter dimensions, low coating stress, relatively low loss, and good uniformity. Two primary deposition methods were identified, Physical Vapor Deposition (PVD) and Ion Beam Sputtering (IBS). PVD coatings have supported the ICF programs for decades and were successfully used on Beamlet. An example of the scale of a PVD coating chamber used for ICF at Spectra-Physics is in Fig. 1. Although sputtered coatings offer some significant advantages over PVD coatings such as extremely low loss and stability regardless of operating environment, scalability proved to be formidable particularly for high damage thresholds in the 3-10 ns regime [1]. Scalability of spectral uniformity of meter-sized optics also proved to be challenging. Therefore, PVD coatings via reactive electron-beam deposition became the coating process of choice.

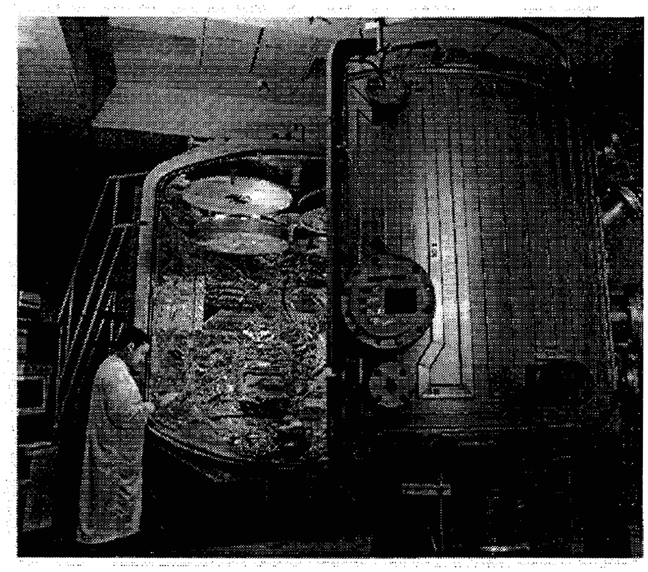

Fig. 1 PVD coating system (A2) at Spectra-Physics for coating four NIF optics per run.

The largest process modification versus what was used on Beamlet was the use of hafnium metal instead of hafnia, an oxide, as the starting material [2]. This process change reduced the defect density by 4-10× for fewer laser damage initiation sites, and improved deposition plume stability to improve layer thickness control for higher spectral yields. Coating stress has been minimized for the humidity of the operating environment by turning the background oxygen pressure during silica deposition [3-4]. Laser damage thresholds were increased by understanding the causes of different damage morphologies including plasma scalds, pits, flat-bottom pits, and delaminations by process design modifications [5]. Coating uniformity was controlled by masking which proved particularly challenging for the planetary configuration at one of the coating vendors [6].

After development, a facilitization program was launched in 1999 to implement the process modifications into production facilities. This phase included facility modifications and equipment installations ranging from semi-automated ultrasonic cleaning stations, chamber readiness improvements including new controllers, and improved diagnostics. Metrology tools were also installed including an 18" 1ω phase interferometer installed in a humidity-controlled environment illustrated in Fig. 2; laser based photometer illustrated in Fig. 3, laser damage testers, and laser conditioning stations illustrated in Fig. 4.

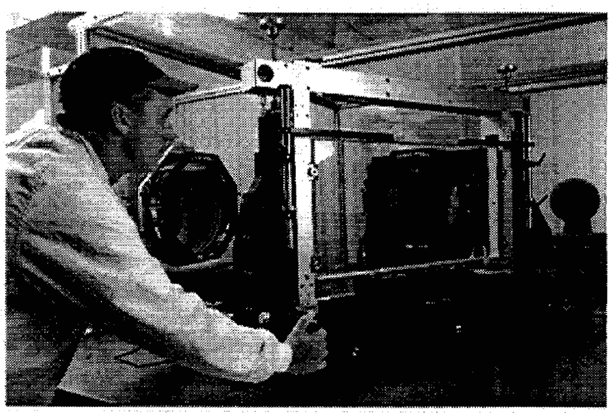

Fig. 2. 1ω 18" phase measuring interferometer controlled environment.

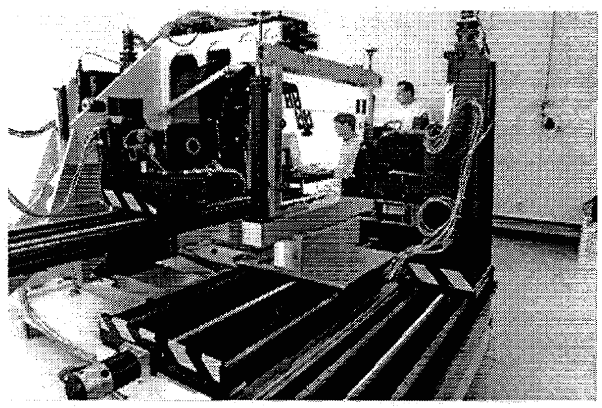

Fig. 3. 1, 2, and 3ω scanning laser in humidity photometer

Current NIF coating vendors are in a Pilot production program to identify and resolve manufacturing issues as part of production start up. With an expected production program of approximately 24 large optics per month over the next seven years, coating vendors will coat 460 m^2 of high-damage-threshold precision coatings on 100 tons of BK-7 material with yields expected to exceed 90%.

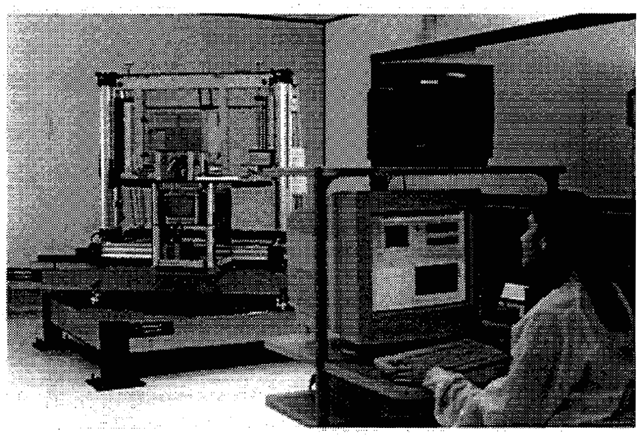

Fig. 4. Two laser conditioning stations are at each coating vendor to raster scan all high fluence coatings past a 1-mm diameter, 1064 nm laser beam.

4. Conclusion

A deposition process has been developed for manufacturing repeatable high fluence coatings, 2-4× higher than required for Nova, the last LLNL fusion laser. Coating vendors are facilitized to meet the capacity and metrological requirements for NIF. Pilot production has just begun to resolve production start up issues. NIF production will occur until 2007.

5. References

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