Minimizing Contamination to Multilayer-Dielectric-Diffraction Gratings Within a Large Vacuum System

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Summary

Systematic approaches to minimize contamination of MLD gratings within the large GCC vacuum system have been implemented

- The presence of contaminants (particle or molecular) in the vacuum system puts the MLD gratings at risk with respect to lowered laser damage threshold
- Numerous protocols have been developed and implemented at LLE to minimize MLD grating contamination
- Exposed vacuum surfaces and components are cleaned through multiple qualified cleaning procedures
- Qualification, testing methods, and studies of materials for use within the GCC have been implemented
- Absorption getters to protect the gratings from molecular contamination have been tested

Keeping the GCC and MLD gratings clean is critical as the OMEGA EP Laser System becomes operational
Presentation topics

- Overview of OMEGA and OMEGA EP Laser Systems
- Overview of the grating compression chamber (GCC) and multilayer-dielectric-diffraction (MLD) gratings
- Vacuum chamber and component cleaning procedures
- Material and component test and qualification methods
- Issues
- Summary
The Laboratory for Laser Energetics (LLE) was established in 1970

LLE’s mission statement

- To conduct implosion experiments and basic physics experiments in support of the National Inertial Confinement Fusion (ICF) Program.
- To operate the National Laser Users’ Facility (NLUF).
- To develop new laser and materials technology.
- To conduct research and development in advanced technology related to high-energy-density phenomena.
- To provide graduate and undergraduate education in electro-optics, high-power lasers, high-energy-density physics, plasma physics, and nuclear fusion technology.

- Faculty equivalent staff: 103
- Professional staff: 212
- Associated faculty: 29
- Contract professionals: 29
- Graduate and undergraduate students: 153
The OMEGA EP (extended performance) is located next to the existing OMEGA facility.

**OMEGA**
- 60 beam, 351-nm UV system
- >30-kJ UV on target in 1 ns

**OMEGA EP**
- four 40-cm, 1054-nm beams
- two 2.6-kJ, short-pulse beams into OMEGA target chamber, 1 to 100 ps, IR
- two 6.5-kJ, long-pulse beams into OMEGA EP target chamber, 1 to 10 ns, UV
OMEGA EP short pulse lasers use large diffraction gratings to compress pulses from nanoseconds to picoseconds.

Chirped-pulse amplification to create picosecond pulse

- Longer (red) wavelengths at the chirped (stretched) incoming pulse front experience larger diffraction, but arrive at G4 at the same time as the shorter (blue) wavelengths.

- Maximum system output is limited by the laser-damage resistance of grating G4 (~2.7 J/cm² at 1053-nm, 10-ps pulse)
Tiled multilayer-dielectric-diffraction gratings are required to produce 2.6-kJ output IR energy per beam at 10 ps.

- Each tiled-grating assembly (TGA) is comprised of three multilayer dielectric (MLD) gratings consisting of alternating layers of HfO$_2$ and SiO$_2$.

- Grating specifications:
  - Dimensions: $43 \text{ cm} \times 47 \text{ cm} \times 10 \text{ cm}$
  - Grating period: 1740 lines/mm
  - Diffraction Efficiency: $>95\%$
  - Wavefront ($p-v$): $<\lambda/10$ at 1053 nm
  - Damage threshold: $>2.7 \text{ J/cm}^2$ at 10 ps measured beam normal
A critical component for OMEGA EP is the grating compression chamber (GCC) where the laser pulse is compressed in time.

- 15-ft × 15-ft × 70-ft internal dimensions (15,750 ft³)
- Isolated payload support pylons (quantity 24)
- 2.5-ft × 6.6-ft man doors (quantity 2)
- 7.5-ft × 15-ft payload entry door
- 3.3-ft × 6.6-ft top payload access port
- Weight: 400,000 lbs
- Internal wall material: 304L SS
- Seal material: Viton V0747-75
Inserting the GCC into the laser bay proved to be challenging

- Seven 10-ft lengths of the 15-ft × 15-ft chamber sections were delivered from California to New York
The GCC must be maintained at high vacuum to prevent ionizing the air and degrading the laser-beam wavefront during compression, which could lead to focusing problems.

- Two roughing pumps: Edwards GV600 industrial dry pump [with EH2600 and EH4200 mechanical booster providing over 2600 liters/s (maximum pump speed)]
- Three 20-in. cryogenic pumps: CVI Model TM500. There is a fourth port if needed.
- Operating pressure <1 × 10⁻⁵ Torr
- Base pressure measured with an empty chamber: 8.7 × 10⁻⁷ Torr in 3.5 h
The GCC contains critical optics for the success of the OMEGA EP project

- 14 custom-fabricated optical tables
- >100 individual optics
- 32 critical beamline optics
- 8 multilayer-dielectric-grating assemblies (4 per beamline)

The optics and chamber are a challenge to clean and keep clean to LLE specifications.
All components are cleaned and tested before being deployed into the OMEGA EP system.

- **Incoming part**
  - Component electropolished, pasivated, or plated NO
  - Spot/local passivation? NO
  - Size dependent
  - IPA wipedown for bay entry
    - Precision wipedown
    - Size dependent
      - Precision ultrasonic wash (OAA)
        - Precision pressure wash
          - PASSED
            - Release for installation
          - NVR
            - FAILED
    - Citrisurf component
      - LaCave ultrasonic cleaning
        - IPA wipe for bay entry
          - High-pressure wash
            - NO
              - IPA wipedown for bay entry
                - Precision wipedown
                  - Size dependent
                    - Precision ultrasonic wash (OAA)
                      - Precision pressure wash
                        - PASSED
                          - Release for installation
                        - NVR
                          - FAILED
Internal GCC components and structures were cleaned to meet the IEST-STD-CC1246D cleanliness and NVR standards

- All components were cleaned using either high-pressure cleaning methods or ultrasonic cleaning methods

- Components (i.e., optical tables) that were too large for a cleaning tool were cleaned using a high-pressure, high-temperature spray of 5% surfactant solution in DI water followed by an IPA clean and filtered N₂ dry

- Most other components were cleaned in a cleaning tool that used 5% surfactant in DI water at 150°F with ultrasonic energy at 40 kHz

- NVR analysis was performed after the clean to verify that the components met the A/10 (<0.10 mg/m²) specification
Individual materials were tested for compatibility using a GC-MS before they were accepted for deployment in the GCC

- HP 5988A GC-MS system supports contamination identification/control activities.
- Direct-insertion probe mass spectrometry is used to detect vacuum outgassing.

Ion source: electron impact (EI)
- Mass filter: single quadrupole
- Mass range: 10 to 1000 amu
- Mass accuracy: ±0.13 amu
- Dynamic range: $2 \times 10^6$
- Detection limit: 500 picograms
- Scan speed: 2000 amu/s
Components were tested for vacuum compatibility before they were accepted for deployment in the GCC

- Components were tested for vacuum material outgassing
- A Hiden Analytical quadrupole mass spectrometer was used to qualitatively understand outgassing materials
- Samples were heated and analyzed for 24 h or longer
- Samples were examined after 24 h for significant peaks greater than the background
- Samples exhibiting peaks after 24 h were re-run with a witness grating, samples were subsequently tested for laser-damage resistance
Grating-damage-threshold degradation from exposure to the GCC environment is a serious concern.

- A multistep experiment was performed to sample the environmental effects of the GCC with one set of optical tables installed.
- Four sets of small MLD gratings were damage tested before and after vacuum pumpdown.
- Silica getters (Sigma-Aldrich grade 03 silica gel) were also placed next to one group of grating samples during the initial test.

Results of the first test were positive with no significant damage-threshold degradation. Getters will be placed next to all four grating assemblies.
Issues

Non-vacuum compatible materials were used on some components

Rulan 123 pads were not vacuum compatible, and the adhesive outgassed

GCC piers had fabricating cutting fluids leaching out of the seams during the vacuum outgassing test, causing them to fail.

Some components had to be re-fabricated to meet our vacuum cleanliness and compatibility specifications.
Failed NVR or outgassing components were either replaced or recleaned

- Hydrocarbon signature during outgassing test
- Sample was recleaned to remove residual contaminant from the clean process.

- Component was re-cleaned twice, then analyzed again.
- The hydrocarbon signature was gone.
Continuous contamination control is needed to minimize long-term contamination of the MLD gratings

• Utilize a “clean-as-you-go” philosophy
• Daily/weekly cleaning of all internal chamber surfaces
• Protocols in place for items permitted within the GCC
• Special protocols for personnel entering and exiting the GCC
• Getters will be used to help “protect” the gratings
• Future components will undergo cleaning and vacuum compatibility tests
• Sample gratings will be placed within the GCC for periodic testing of damage-threshold degradation
Systematic approaches to minimize contamination of MLD gratings within the large GCC vacuum system have been implemented.

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- Numerous protocols have been developed and implemented at LLE to minimize MLD grating contamination.
- Vacuum surfaces and components are cleaned through multiple qualified cleaning procedures.
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Keeping the GCC and MLD gratings clean is critical as the OMEGA EP Laser System becomes operational.
The GCC is expected to be operational by 2008