Case Study

Key Findings

HIGH CLEANLINESS REQUIREMENTS

Particulate contamination initiates damage on both bare and coated optical surfaces in the presence of high intensity laser light. Flashlamp light is sufficient to create aerosols within laser amplifier cavities and these aerosol particles subsequently settle onto laser amplifier slabs and initiate pitting damage to the optical surface. Damage resulting from contaminants is estimated at between 6 to 8 times larger than the contaminant causing the damage.

High-intensity laser light is sufficient to dislodge particles from structural surfaces which forms an aerosol that transports particles from structural surfaces to nearby optical surface(s). If it were not for laser displacement of contaminants, most contaminants would remain tightly attached to structural surfaces and not transport onto optical surfaces.

NVR Cleanliness Level	Limit, NVR mg/ft2 (or µg/cm2)
A/100	0.01
A/50	0.02
A/20	0.05
A/10	0.1
A/5	0.2
A/2	0.5
A	1.0
B	2.0
C	3.0
D	4.0
E	5.0

Table 2: Thin-film (NVR) cleanliness Levels as defined in MIL-STD 1246. A/10 is equivalent to a single monolayer of contaminant.

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The NIF laser system is conceptually divided into small aperture front-end and large aperture high-fluence optics. The smaller front-end optics number over 20,000 and precondition the laser light before entering the 192 symmetric beam-lines.

Due to the large number of serially arranged optical components, it is necessary to achieve and maintain very high levels of surface cleanliness to essentially eliminate all surface scattering losses. Surface cleanliness is assigned as an integrated scatter loss budget of 0.1% for the front-end optics and an additional 0.2% for the large aperture optics. This results in a typical surface scatter loss budget, due to contaminants, of ≤ 2.5x10 (to -5) per surface. For comparison, the scatter loss per surface due to surface roughness is of a comparable value of 5.0 x 10 (to -5).

Large aperture optics on NIF have a cleanliness requirement of Level 50-A/10 as installed and will be removed for refinishing if dirt and damage cause obscuration exceeding 2.5x10 (to -4), or if a singularly damaged site reaches 2mm in size. The smaller front-end optics must be initially cleaned to Level 100-A and will be removed for refinishing if the accumulated dirt and damage cause obscuration exceeding 2.5x10(to -4), or if any singularly damaged site reaches 250µm in size.

Optical and structural surface cleanliness is further specified as initial cleanliness (immediately after cleaning), as-assembled cleanliness, and end-of-life cleanliness (see Table 1).

- The evolution of large lasers has necessitated the need for more cost-effective optical fabricated processes. One of these is the application of a thin solgel coating used as an anti-reflection coating on surfaces aligned normal to the laser.
- Solgel is a material of enormous surface area per gram of coating. It has the unfortunate property that it attracts organic molecules that may be in inert gases inside laser cavities.
- A few monolayers of organic material to the surface of a solgel coating can result in a change in the transmission of the coating of up to several percent.
- Solgel coated optical surfaces in vacuum (at 10 to -5 Torr) can loose transmission at the rate of up to 0.1% per day in the presence of an inert gas containing a very low concentration of mid-atomic-weight organic matter (organic matter with an atomic weight of 100-200amu appears to result in the most rapid change in solgel coating transmission).
- The rapid change in the transmission of solgel coatings in vacuum is exacerbated by large mean-free-path between gas molecules which allows molecules leaving a contaminated surface to be transported nearly ballistically to nearby solgel coated surfaces.
- At atmospheric pressure this transport mechanism is thwarted by the small mean-free-path of the gas molecules. However, the transport of mid-weight organic molecules appears to occur at atmospheric pressure, at a substantially lower rate.*

*Solgel coating remaining open and exposed to the air in a Class 100 cleanroom also suffers from degradation in transmission, with results repeatedly measuring a transmission change of 0.1% per month.

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AIRBORNE CLEANLINESS SPECIFICATIONS

The NIF laser bay, switchyard and target bays are designated Class 10,000. The cleanrooms that perform precision cleaning are designated as Class 100, and supporting facilities are designated Class 1,000. In contrast, the inside of the laser cavity is designated ≤ Class 1.

Airborne cleanliness is designated by "class" which is a measure of the number of particles/ft3 of a size ≥ 0.5µm diameter. Details of the metric equivalent classifications can be found in FED-STD-209E *Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zone.* Interestingly, the choice of 0.5µm for the definition of Class is based on the observation that High Efficiency Particulate Air (HEPA) filters have their lowest filtration efficiency at or near 0.5µm because this is the cross-over point between two different particle capture mechanisms within the filter. These filters become more efficient both above and below this cross-over point. Designating filter efficiency at this point represents a conservative design philosophy.

Final Optics Assemblies (FOAs)

	Surface cleanliness Level as-cleaned	Surface cleanliness Level as-assembled	Surface cleanliness Level at end-of-life
Large optical surfaces	≤ Level 50–A/10	Level 50-A/10	≤ 1 damage site of 2-mm size per surface or per surface obscuration of $2.5x10^{-4}$
Small optical surfaces	≤ Level 100-A	Level 100-A	≤ 1 damage site of 250 µm size per surface or obscuration of $2.5x10^{-4}$
Structural surfaces enclosing large optics	≤ Level 83-A/10	Level 100-A/10	Level 100-A/10
Structural surfaces enclosing small optics	≤ Level 300-A	Level 300-A	Level 500 (visibly dirty)

Table 1 Cleanliness Levels in the as-cleaned, as-assembled, and end-of-life conditions for small/large optics, and structural surfaces.

Relationship between Airborne and Surface Cleanliness

Under no circumstances should the designations 'Class' and 'Level' be used interchangeably. Class refers to the maximum expected particle concentration in a volume of gas whereas Level refers to the maximum particle concentration on a surface. A Class 100 cleanroom is not required to achieve or maintain a Level 100 surface; maintaining a Level 100 surface as a Class 100 cleanroom is dependent on several variables, the most important being the time of exposure to the air in the cleanroom. The only way to guarantee the maintenance of a Level 100 surface in a cleanroom is to cover it or to place the critical component within a container with an even lower airborne particle concentration or Class.

For example: A perfectly clean metallic surface is placed horizontally in a cleanroom designated as Class 100 and which is operating at 100 particles/ft3 ≥ 0.5 µm due to a high population of personnel. The particle settling rate in any room is highly dependent on airflow patterns and electrostatic effects but is dominated by the particle settling velocity (Stoke's velocity) of particles greater than 1 µm in size. The Stoke's velocity v. of 5.0 µm particles with a density of 1 g/cm3 is 0.12 ft/s. The surface accumulation rate is dependent on the airborne concentration of 5.0 µm particles and the amount of time that the surface remains in the Class 100 environment. The surface accumulation rate is given as the product of the airborne concentration [P/ft3] times the Stoke's velocity [V.]. Furthermore the total accumulation is the accumulation rate times the exposure time. For our example, the concentration of 5.0 µm particles in a Class 100 cleanroom is not 100/ft3 but can be found by extrapolating the Class 100 line in Figure 2 (page 5) to the concentration corresponding to the 5.0 µm size particles, which yields a concentration of only 0.63 particles/ft3. Multiplying this by the particles Stoke's velocity of 0.12 ft/min results in an accumulation rate of only 0.076 particles/ft2-min. However, after 24 hours of exposure, the accumulation reached 109 particles/ft2 ≥ 5.0 µm or a surface cleanliness of Level 44. If the cleanroom had been operating at Class 1,000, then the 24 hour accumulation would have been an estimated 1,090 particles/ft2 ≥ 5.0 µm or a surface cleanliness of Level 87.

CONCLUSION

As shown in Table 1, Level 83 is the desired cleanliness Level of laser cavity surfaces and by simply leaving a "clean" part for 24-hours in a Class 1,000 cleanroom we would expect it to exceed the specified surface cleanliness requirement.