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Clean Assembly Practices to Prevent Contamination and Damage to Optics

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ABSTRACT

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A key lesson learned from the earliest optics installed in the National Ignition Facility (NIF) was that the traditional approach for maintaining cleanliness, such as the use of cleanrooms and associated garments and protocols, is inadequate. Assembly activities often negate the benefits provided by cleanrooms, and in fact generate contamination with high damage potential. As a result, NIF introduced "clean assembly protocols" and related practices to supplement the traditional clean room protocols. These new protocols included "clean-as-you-go" activities and regular bright light inspections. Introduction of these new protocols has greatly reduced the particle contamination found on more recently installed optics. In this paper we will describe the contamination mechanisms we have observed and the details of the clean assembly protocols we have successfully introduced to mitigate them.

Keywords: Contamination, particles, assembly, damage, cleanroom, cleanliness

1. Introduction

High power laser facilities invest an appreciable amount of time and effort to minimize the amount of contamination on the laser optics because such contamination may damage optical surfaces when exposed to intense laser light (Figure 1). Furthermore, obscuration of the laser light by surface debris (Figure 2) must kept as small as possible to assure high transmission efficiency and diagnostic effectiveness. Abrasion sources were identified as a major potential contributor of particle contamination during a "lessons learned" review of the first operational beampaths installed in the NIF.

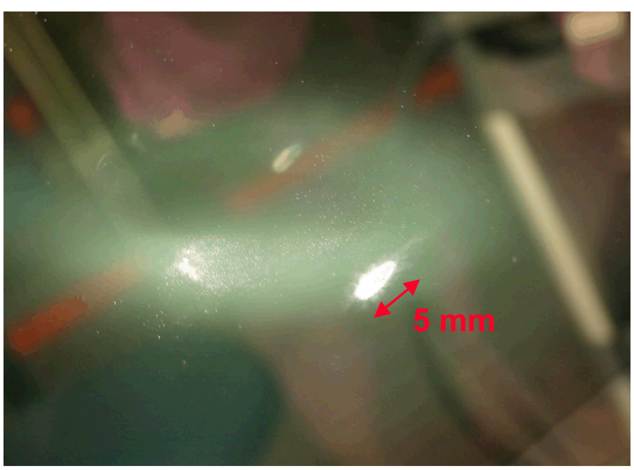


Figure 1. Contamination induced damage to transport mirror exposed to ~15 joule/cm^2 1ω beam.

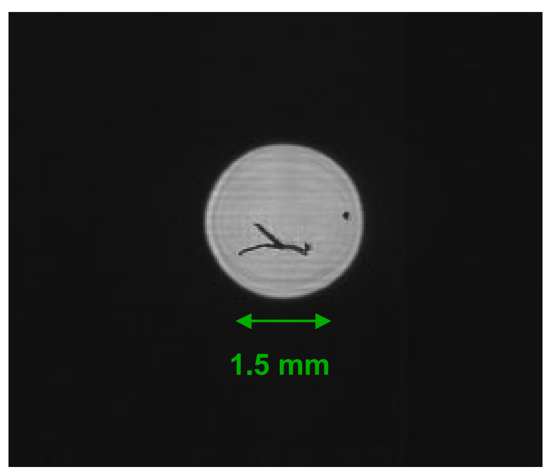


Figure 2. Fiber obstruction on laser system Front End diagnostic optic.

This is of particular concern because abrasion products, such as metal chips, can pose the greatest damage threat to optics[1]. Ironically, much of the work that produced this abrasion contamination was performed in clean rooms.

Working in a clean room can give one a false sense of security regarding contamination. First, laminar air flow will not entrain dense abrasion products, which will therefore not be detected by particle counters. As such, the NIF project introduced practices that expanded upon those commonly used for clean room work. This effort and related testing revealed that materials associated with clean rooms, such as clean room gloves, can also be potential contributors of contamination. The following sections discuss the results of our studies and methods that have been introduced on the NIF to control and mitigate contamination.

2. Causes of Contamination and Corresponding Solutions

2.1 General

As with many complex systems, success in preventing contamination hinges on planning and foresight. Further more efforts to mitigate damage after the fact can cost many times that of preventive efforts. Efforts to preclude mechanisms that result in abrasion products and other uncommon sources of contamination needs to begin during design of the product, and continue through planning of the assembly stations and procurement of the clean room supplies.

2.2 Designing to minimize sources of contamination:

2.2.1 Abrasion products from sliding contact

Contamination sources, particularly abrasion, are often designed into a product. An example of this is aluminum-to-aluminum sliding contact of an optic guillotine frame in its mating groove (Figures 3a and 3b.). The frame and groove were tested for sliding contact during this prototype stage and were found to be satisfactory but the test setup did not faithfully represent all operational orientations and particle debris from abrasion became a problem. The addition of a smooth PEEK rail did not eliminate the abrasion as the hardness of the rail caused it to gouge the aluminum. The final solution was a change in the design concept which eliminated the sliding contact altogether.

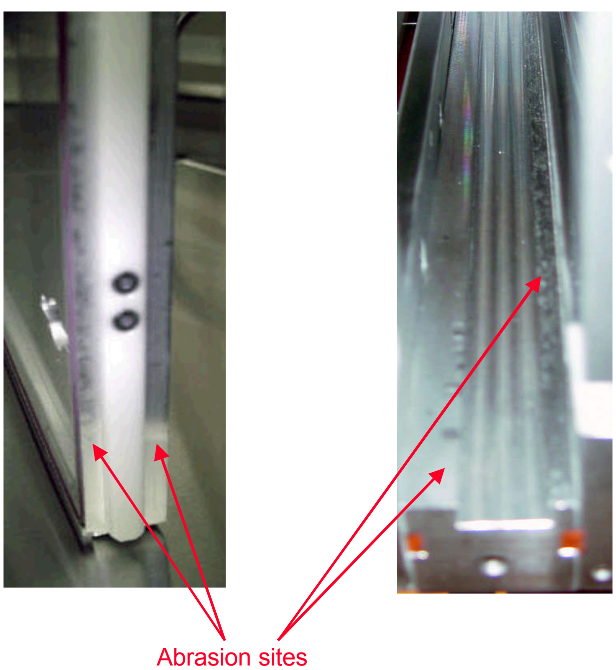


Figure 3a. Abrasion sites on optic guillotine and mating groove.

Figure 3b. Abrasion product adjacent to guillotine groove.

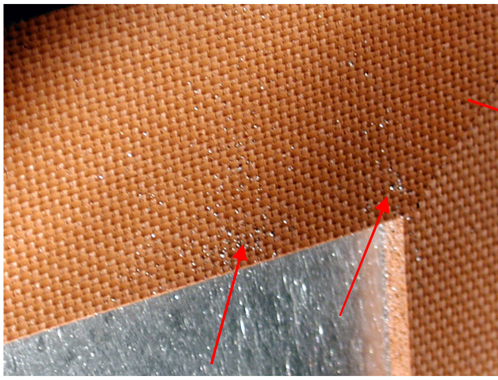


Figure 4a. Metal particles abraded from captured threaded steel fasteners.

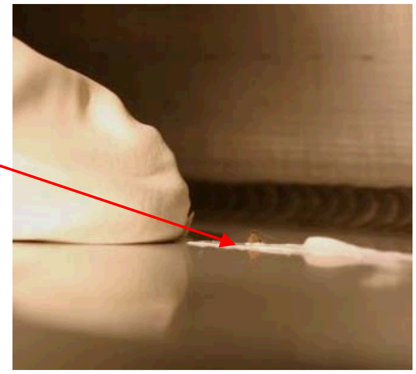


Figure 4b. Silicone rubber particle shedded from foam gasket shown in Figure 4a.

2.2.2 Abrasion Products from Threaded Fasteners

Threaded fasteners, the other major contributor to abrasion products (Figure 4a.), required more complex mitigation strategies because their applications varied. The fact that organic lubricants could not be used because of out-gassing and other contamination concerns was an additional complication. Threaded fasteners are widely used for enclosure covers that must be regularly and frequently removed and replaced. Frequent removal aggravates particle contamination because extraction of a threaded fastener can produce copious debris. Often in these situations the threaded fasteners are silver plated to prevent galling, which in itself can become an abrasion product. The “dry” lubricant fastener coatings Dicronite ™ and molydysulfide were tested. Though they may have eased the effort for inserting and extracting the fastener, they also increased the amount of abrasion products. It became obvious that the solution was not in the threaded fasteners themselves, but in a broader design philosophy change. The test results and observations for various fastener designs and coatings showed that quarter turn fasteners (Figure 5) were the most benign with regards to abrasion. Unfortunately, quarter-turn fasteners are good for only low stress applications. Generally two approaches were developed for future designs. One was for applications in which threaded fasteners were essential and a second for applications where they were not.

Figure 5. Quarter turn fastener

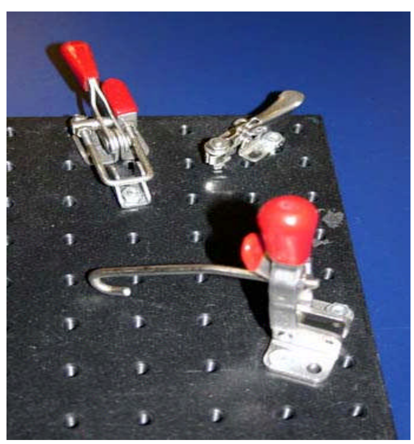


Figure 6. Samples of toggle clamps

Figure 7. External pin connections

Threaded fasteners were determined to be necessary for retaining covers on vacuum enclosures. In such cases rather than a threaded bolt, a stud with the retaining nut external to the cover was used. With this modification abrasion products would, for the most part, be produced external to the enclosure and the optics it contained. Guide pins could be added to preclude the cover from sliding on the stud threads during placement or removal. For less robust applications the quarter turn fasteners were recommended. As an alternative, fasteners that are fully external to the enclosure such as toggle clamps (Figure 6) or pinned connections (Figure 7) can be used. However, these fasteners often require more space than was available.

2.2.3 Other Design Related Contamination Sources

Several other sources of particle contamination were addressed in addition to the primary sources discussed above. Silicone rubber foam gaskets, for example, had a tendency to shed particles (Figure 4b.). To eliminate this problem these were replaced with a closed cell foam polyethylene gasket material (which also proved to be significantly less expensive). Electromechanical devices such as pumps (Figure 8) and actuators were also sources of abrasion products. For such devices cycle tests were run to screen out those with a tendency to produce particles.

A design feature that was not a source per se but a collector of particle contamination, was the gap at the top of enclosure cover gaskets (Figure 9) that trapped particles from the less clean building environment for transport into the optic enclosure when the cover is removed. This "crud catcher" was eliminated by the introduction of gaskets that extended to the top of the cover.

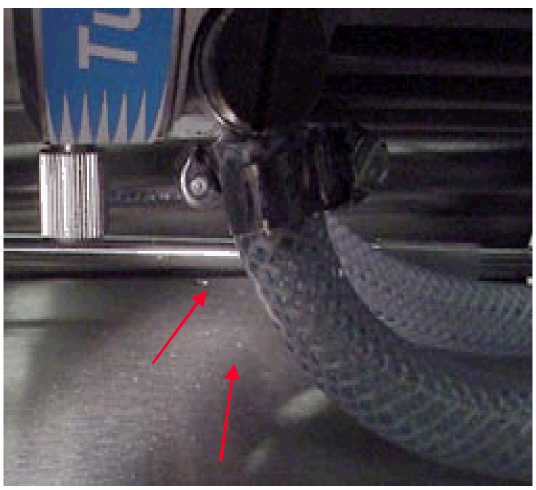


Figure 8. Metal particles abraded during operation of vacuum pump.

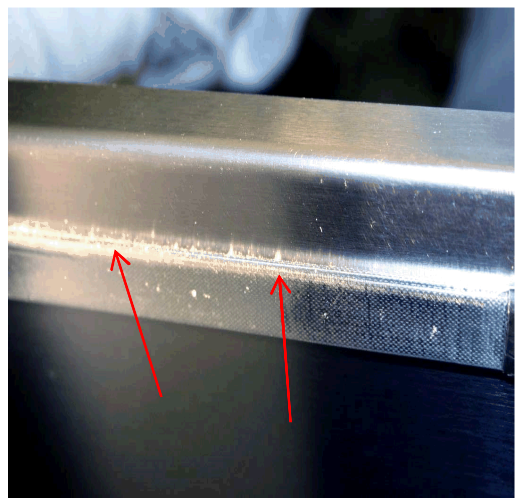


Figure 9. Particles trapped on gasket between cover and enclosure.

2.2.4 Designing Optic Assembly work Stations

Work areas and optic assembly stations in clean rooms need to be designed with the same discipline as products to assure that abrasion and other particles are not produced or collected developed during use. Experience has shown that mechanical aids used in clean rooms, for example a diagnostic connector (Figure 10a and 10b), are prone to the same abrasion mechanisms as discussed above for product designs. Unfortunately, particle contamination from these aids can be transferred to clean surfaces during transport after final, cleaning and assembly, thereby avoiding prompt detection.

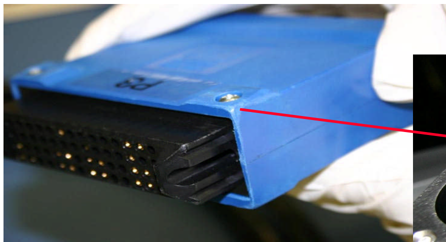


Figure 10a. Abraded corner of test connector

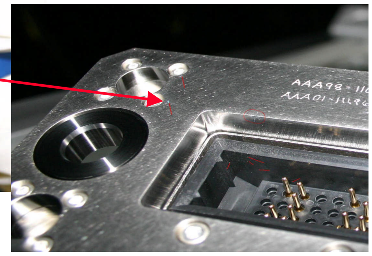


Figure 10b. Abrasion particles from test connector

2.3 Introduction of Clean Assembly Protocols:

2.3.1 Utilize "clean-as-you-go" philosophy

Even with the best design strategy not all abrasion and other particle sources can be eliminated. For example, threaded fasteners are inherent in many off-the-shelf optical components. Furthermore cleaning of a completed optics assembly may be incomplete because contamination can accumulate in inaccessible areas. An assembly leaves a clean room apparently clean, may reach its destination covered with a myriad of particles that were shaken loose during transport (Figures 11a. and 11b.) such particles may continue to appear after re-cleaning. A solution to this dilemma is a "clean-as-you-go" philosophy documented in NIF cleanliness procedures[2].

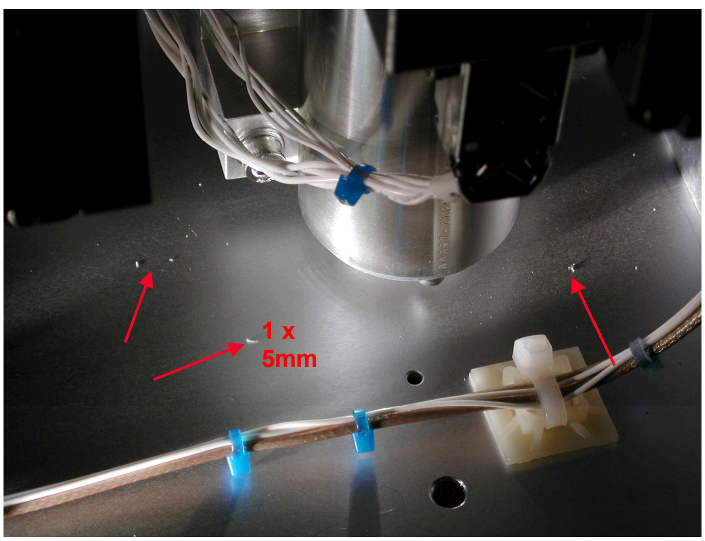


Figure 11a. Particle contamination found in an optical assembly upon delivery, left the vendor apparently "clean".

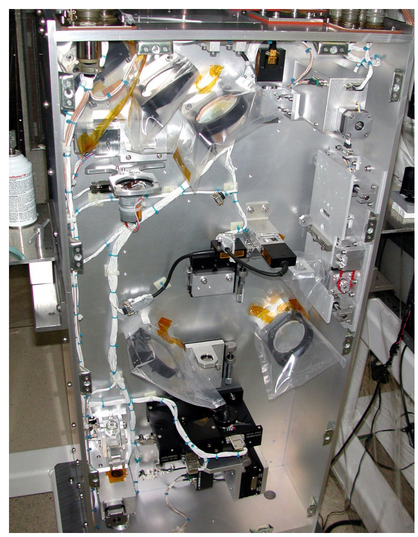


Figure 11b. Overall view of the assembly from which photo 11a. was taken. Note the number and variety of places for particles to hide.

"Clean-as-you-go", practices such as daily vacuuming and other regular cleaning activities are often performed during the construction of clean rooms. The goal is to preclude the build up of dirt and dust behind walls and other soon-to-be inaccessible areas which later escape into the clean room during operation. The same notions must to be applied when constructing optical assemblies. Regular cleaning during assembly activities, such as at the end of each shift, includes vacuuming (Figure 12[a]), dry wiping (which has typically proven to be more affective at removing particles than wet

[a] Nilfisk Advance America Inc., www.pa.nilfisk-advance.com, (800) NILFISK

wiping) and judicious use of ultra-clean gas blow off. To aid in this activity “bright lights” should be utilized (Figure 13[b]) to highlight surface debris. The combination of the sensitivity of the human eye and the contrast provided by bright lights provides an extraordinary ability to see particles as small as tens of microns depending on the particle and background (Figures 14a. and 14b.). We recommend that bright lights be utilized often to determine which assembly practices are “dirty” (we uncovered an abrading bearing by seeing the abrasion particles in flight with these lights). After studying the primary sources and frequency of particle generation, a routine can be established for inspection, including bright light inspection, and cleaning.

Figure 12. Nilfisk clean room backpack vacuum (“back vacuum”) with mini attachment for tight spaces.

Figure 13. SteamLight UltraStinger (75,000 candlepower) and PolyStinger (for tight spaces)”bright light” flashlights.

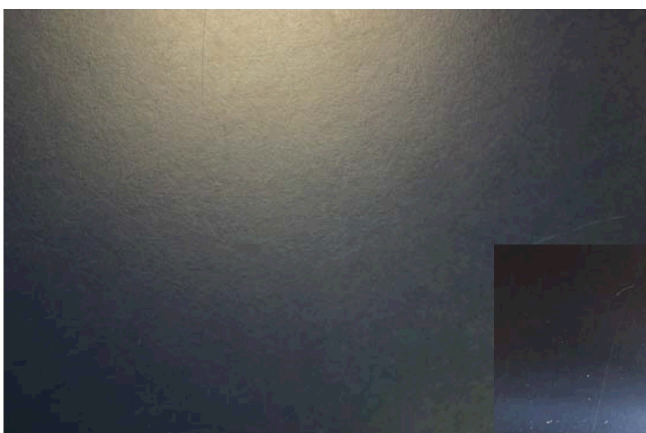


Figure 14a. Tabletop in ambient room light.

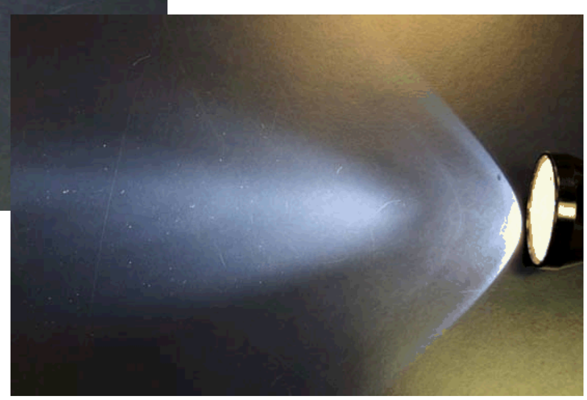


Figure 14b. Tabletop under “bright light”

2.3.2 Discipline when working with small parts

Leaving behind small parts that were being installed or removed during assembly activities is not uncommon (Figures 15 and 16). Such events can obviously have a profound effect if such parts fall directly on an optic,

[b] StreamLight; www.streamlight-flashlight.com, (800) 666-6200

particulate when exposed to laser light or form a large obstruction. Several rules need to be observed to minimize such occurrences.

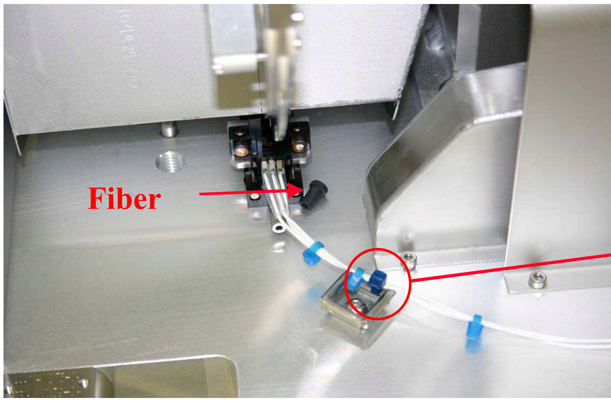


Figure 15. Fiber optic cap removed during fiber installation; dropped or otherwise left behind (found during cleanliness inspection).

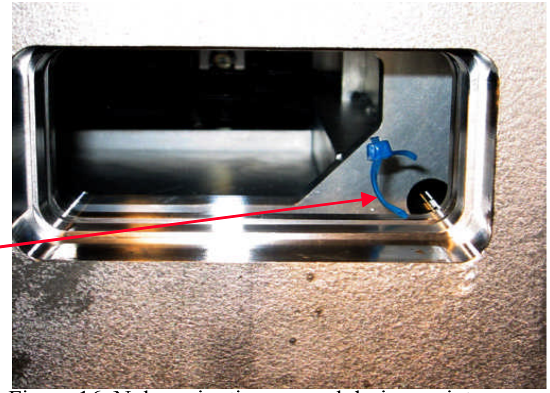
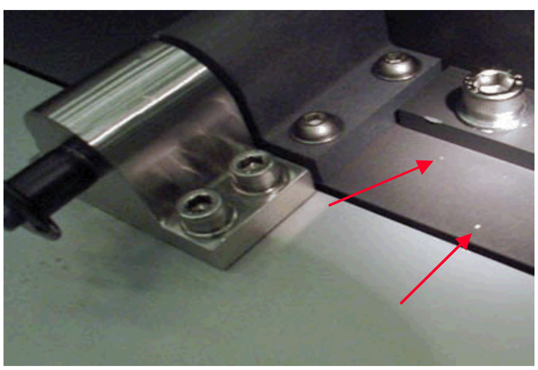


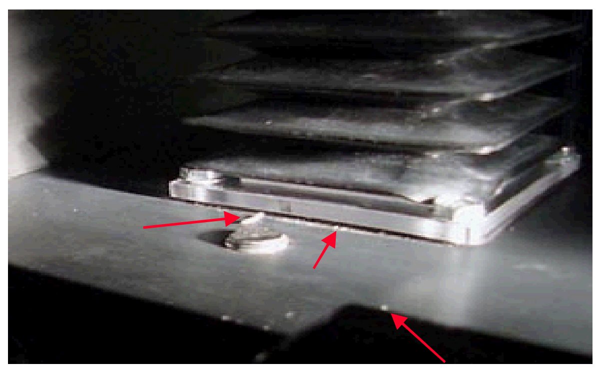
Figure 16. Nylon wire tie removed during maintenance activity resting on alignment window (not found during cleanliness inspection. Fortunately the window was no longer in use).

The first rule is that small parts should be kept in containers such as stainless steel pans, and are not to be set on the assembly, even "for just a few minutes." Second, when removing parts, immediately put them in a container. Do not wait until completion of the work or shift. Finally, if entering large vessels, track tools and items taken in, and then check them off upon removal.

2.3.3 Apply philosophy to optic work stations

As with design discipline discussed under section 2.2, the "clean-as-you-go" philosophy with bright light inspections should be applied to optic work stations as well as assemblies themselves. Work stations are exposed to many of the same particle generating mechanisms as product assemblies (Figures 17a. and 17b.).   Bright light inspections readily reveal such contamination.





Figures 17a.and 17b. Abrasion products and other particle contamination found at optic assembly work stations in Class 100 clean room.

2.4 Use of "Clean" clean room supplies and tools

Just as cleanroom air cannot be relied upon to eliminate particle contamination, not all clean room supplies can be relied upon to be "clean" for all applications. For example wipers designated as "high absorbency" were easily shredded when used on mildly rough or snagging surfaces such as a fastener threads and optic mount clips (Figure 18). Unless the wiping is to be performed on smooth surfaces, it is recommended that less absorbent but more robust continuous weave wipers used. Similarly, some "cleanroom" gloves advertised for use in class 100 clean rooms were found to be to the source of smudges and particles (Figure 19). After comparison studies we found a very clean (and very comfortable) clean room glove.

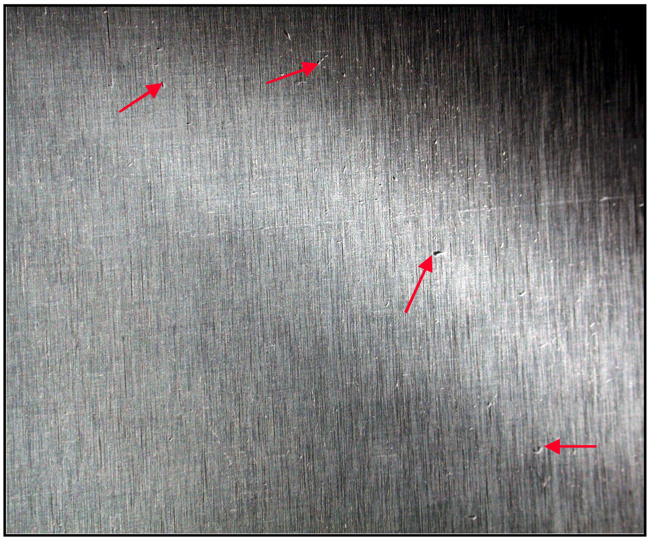


Figure 18. Fibers shed from soft clean room wiper onto door panel.

Figure 19. Smudges and particles on black glass caused by tapping and rubbing with a "clean room" glove that was not as clean as desired.

3.0 Summary

Practices need to be added to the traditional clean room protocols if contamination of optics during assembly activities is to be minimized. These include designing the product to eliminate abrasion and other sources of particles and the introduction of "clean-as-you-go" protocols. These practices need to be extended to the design and operation of clean room apparatus.

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