

Handling, Mounting, Control, and Operation of High-power Pump Lasers

Overview

This technical note describes requirements for the assembly and operation of high-power pump laser modules to ensure maximum device performance and reliable operation over life. Topics addressed in this technical note include handling the pump module, mounting the pump module, and safe operation of the pump module.

The actual operational configuration for pump modules and their reliability requirements are highly dependant upon the customer-specific amplifier application. As a result of the variation in environmental and mechanical specifications at the system level, JDSU does not guarantee the reliability of the module attachment or control method within customer-specific applications, and can only recommend good engineering practices. The end-user must confirm the final reliability and quality of any system using a pump attachment and control architecture based on JDSU pumps meeting component level qualification and reliability criteria.

Introduction

JDSU is a leading manufacturer of high-power pump modules for high-reliability applications. Through the course of high-power pump evolution, JDSU has developed standard practices for the safe operation of these pumps. This technical note summarizes these recommended procedures for proper high-power pump mounting, control, operation, and handling to avoid damaging the pump module or system, as well as to avoid safety hazards for the end user. While the scope of this technical note is to describe specific requirements for high-power pump lasers, general requirements for safe pump laser operation should also be followed.

Safety Precaution

Note that the ex-fiber-coupled power offered by JDSU pump lasers represents significant optical power in the infrared region. Be sure to follow standard eye and skin safety protocol for Class IV IR lasers.

Electrostatic Discharge (ESD) Precautions

ESD damage to a diode laser is induced from the rapid flow of electrical charge between two bodies at different potentials, either through direct contact or through an induced electric field. ESD can cause catastrophic or latent damage, and is of particular concern for the pump module's diode laser and MPD.

Latent ESD damage, which occurs when the energy of an ESD event is below the critical level required to produce a catastrophic failure, can result in defects that propagate during module deployment and result in catastrophic failure over time.

A human body model (HBM) ESD test is used to determine the damage threshold of the pump module and pump modules are tested in accordance with GR-468-CORE section 5.22 (MIL-STD-883, method 3015.7). Refer to pump module specifications for ESD voltage limits. A number of industry specifications are available to make the work area ESD safe (e.g. EIA-625, JEDEC 108-A).

Below are common recommended guidelines for preventing ESD damage to the pump modules:

- Refer to the pump module specification sheet for ESD voltage ratings
- Use the provided shorting clips on 14-pin butterfly packages when the modules are disconnected from the operational circuit
- Ground operators, equipment, WIP transport carts/trays, pump modules or systems, and work surface to eliminate static electricity
- Only use confirmed ESD dissipative coatings/surface finishes on fixtures/tooling used to assemble the pump modules
- When manipulating pump modules, use ESD protective smocks, gloves and shoes/covers, dissipative bench-top mats, and ESD protective flooring or matting
- Remove or control static generating sources to voltages below the specified maximum for safe ESD handling
- Install air ionizers as necessary for additional environmental control
- Use electrically grounded soldering irons for soldering the pump module to the mounting surface
- Use electrostatic shielding containers and antistatic or dissipative carriers.

Pump Module Power Supply and Control

General diode laser (DL) power supply design requirements are applicable to high-power pump modules. Failure to follow these requirements may result in pump module degradation or failure. When designing or using an DL power supply, designers should refer to the specified absolute maximum ratings, specified for each series of high-power pump lasers.

Electrical overstress (EOS) damage occurs when a pump module is subjected to voltage or current levels beyond its surge-absorbing capacity. The location and degree of damage depends on the magnitude and duration of the voltage, current, total energy, polarity, and waveform of the electrical overstress.

Power supplies, and test equipment can induce EOS. Some recommended guidelines for preventing EOS of pump module are:

- Transient electrical stress to the pump module should be avoided or minimized through operational life. The maximum specified transient current time for a pump module should never be exceeded while operating a LD; refer to the absolute maximum ratings specified within pump module specifications.
- Use transient suppression for power supplies
- Use over-voltage protection for power supplies and fuses at critical locations
- Confirm modules are mounted with the correct electrical pin configuration as specified
- Ensure that all operational and assembly equipment is properly grounded with no loose connections (which can lead to intermittent connections)
- Always ensure the TEC controller is enabled and that the pump module is being actively cooled prior to turning on the laser diode controller. Allow the internal temperature of the pump module to stabilize at the target operating temperature of $25\pm 2^{\circ}\text{C}$ (or $45\pm 2^{\circ}\text{C}$ for 2745 Series devices) before turning on the LD.

High Power Pump Laser TEC Control and Operation

Large capacity thermoelectric coolers (TECs) are used to control cooled pump module temperature for high power operation. Proper operational procedures for the TEC are critical for reliable performance of the modules during their lifetime. Pump module TECs typically are operated with closed-loop temperature controllers/power supply circuits. Closed-loop circuits allow maintaining internal temperatures of the pump modules at the target pump temperature 25°C or 45°C (nominally) depending on the product specification. The TEC can be switched from a cooling mode to a heating mode by reversing the direction of current flow.

TEC Power Supply

The pump module TEC operates from a DC power source. An important criterion for reliable high-power pump module operation is to use a filtered DC current. DC ripple affects the TEC performance and, as a result, subsequent pump module performance during its lifetime.

The TEC power supply should be limited to the absolute maximum TEC current as specified for each model of pump module. The TEC can run at the absolute maximum TEC current for a very limited duration without impacting module reliability.

When the pump module is first turned on, there will be a transient current supplied to the TEC as it stabilizes via the feedback circuit. It is also important to note that the absolute maximum TEC current is different from the maximum operating current. The maximum operating current is the current at which a TEC can operate at for an unlimited time throughout the lifetime of the module. The end-of-life (EOL) TEC operating current should not exceed 70 percent of absolute maximum current. The maximum operating current is specified for each series of pump modules.

In summary:

- Limit TEC power supply ripple factor to less than 10 percent
- Limit the TEC controller power supply to the absolute maximum TEC current rating
- Do not operate the TEC at its rated maximum current except as transient applied current during module start-up
- Limit the TEC operating current to 70 percent of the specified TEC maximum current
- Operate the TEC in constant temperature mode rather than in constant current mode, using temperature feedback from the module thermistor.

Temperature Controller

Pump module TECs operate with closed-loop temperature controller/power supply circuits. A thermistor is used to control the DL temperature within the pump module to 25°C or 45°C through the specified operational ambient temperature range.

It is important to note that if the 14-pin butterfly package thermistor leads do not have electrical contact when the package is mounted and operated, the temperature controller/power supply loop will be open. An open loop TEC will run at its maximum available power supply current and can result in permanent module damage. This situation can arise by placing a pump module into an active TEC-powered circuit board, with pins 1 and 14 on the BF package placed first.

- Make sure that the electrical circuit connected to the pump module has the correct orientation for mounting the 14-pin butterfly package, as the pump module is symmetrical; it is possible to connect it backwards by 180-degrees (see Figure 1 for an example mechanical and electrical schematic).
- Make sure that all 14-pin butterfly package leads have electrical contacts to avoid controller/power supply open circuits
- Ensure the TEC leads are connected to the proper electrical polarity, and ensure that the TEC power supply is turned off prior to mounting or un-mounting the pump module
- Wait until the internal temperature has stabilized to $25\pm 2^\circ\text{C}$ (or $45\pm 2^\circ\text{C}$ for 2745 Series devices) after turning the DL on before making any TEC control changes
- Do not leave a module operating without making sure that the internal laser temperature is at $25\pm 2^\circ\text{C}$ (or $45\pm 2^\circ\text{C}$ for 2745 Series devices).

Butterfly Package Mounting

When mounting the 14-pin butterfly package, ensure that the butterfly pins have the right orientation (do not turn module by 180 degrees). See Figure 1 for module mechanical and electrical schematic. Follow all integrated circuit standard practices, including ESD prevention measures.

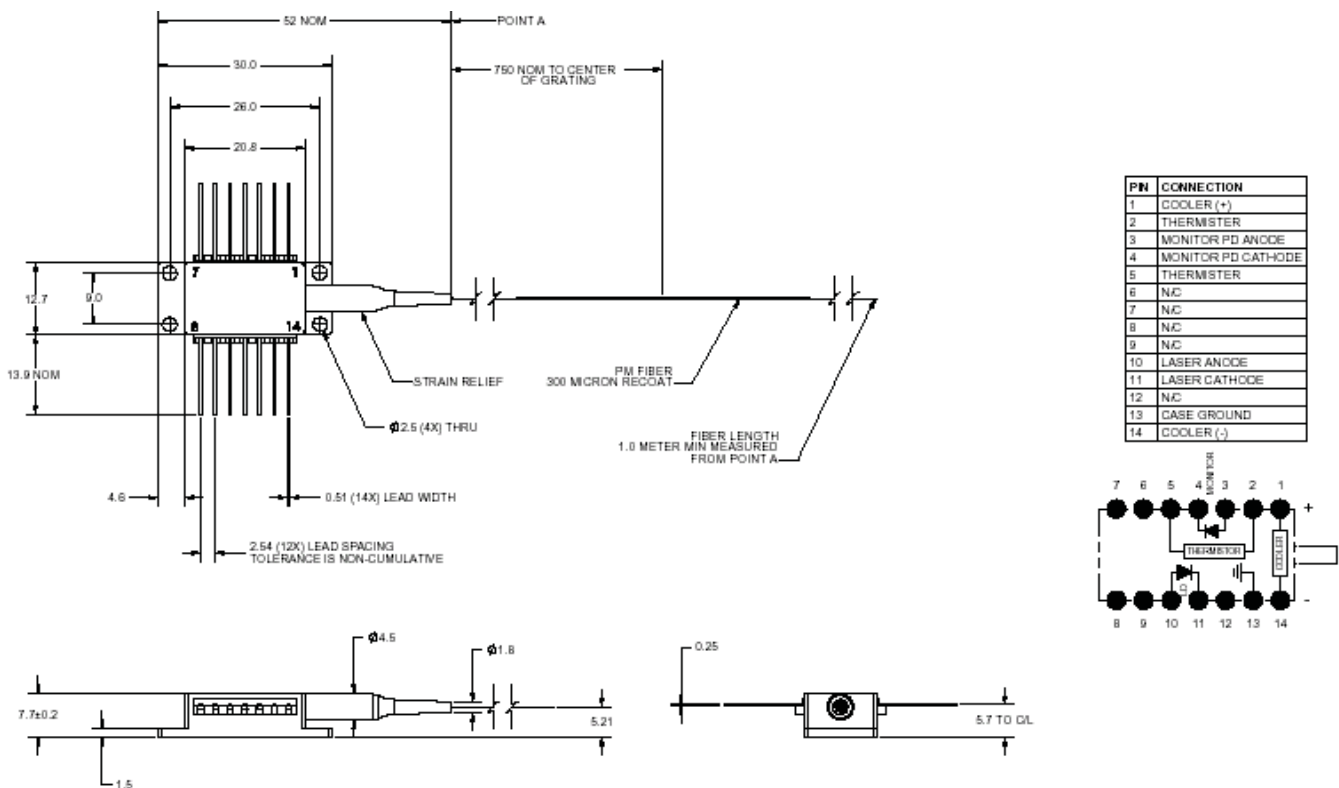


Figure 1. Example of mechanical and electrical schematic for a high-power pump module

Heat Sinks for High-power Pump Module Mounting

The design of the receiving heat sink, intended to dissipate the heat pumped by the TEC, is crucial to the overall pump module performance and reliability. All pump modules with a TEC to control DL temperature require heat sinks and will fail catastrophically if operated without one. The goal of the heat sink design is to dissipate the heat from package base with minimized thermal resistance.

Heat sink performance is usually specified in terms of thermal resistance (Θ):

$$\Theta_s = (T_s - T_a)/Q$$

where:

- Θ_s = thermal resistance in degrees C per watt
- T_s = heat sink temperature in degrees C
- T_a = ambient or coolant temperature in degrees C
- Q = heat input to heat sink in watts

Each thermoelectric cooling application will have a unique heat sink requirement, and frequently there will be various mechanical constraints that may complicate the overall design. Because each case is different, there is no single heat sink configuration suitable for all situations.

A well-designed heat sink, in combination with a high-performance thermal interface material and package mounting technique, should guarantee that the pump module case temperature does not exceed the maximum temperature specified for each series (refer to the absolute maximum characteristics). Failure to keep a package base below the specified maximum temperature will lead the pump module to overheat and result in module damage.

The following general heat sink guidelines are recommended:

- Mount the butterfly pump module on a heat sink with flatness of 50 microns or less over the entire mating surface to the module
- Mount the pump module on a heat sink with a surface finish of 0.8 micron or less
- The heat sink should be designed to handle at least the maximum module heat dissipation throughout the life of the product. For total module power dissipation, refer to the module specifications. Maximum module heat dissipation is approximately equal to total module power consumption (DL and TEC) minus the ex-fiber optical power.
- Design a heat sink that is capable of keeping the pump module case temperature below the maximum rated temperature for all operating conditions. For maximum package base temperature, refer to the pump module specification.

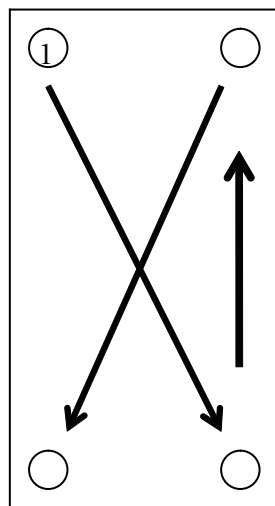
Thermal Interface Materials

Ideally, thermally conductive materials are used as an interface between a pump module and the heat sink to account for any flatness/smoothness discrepancies between the two parts. Suitable thermally conductive materials include phase change materials, greases, thermal compounds, elastomers and adhesive films. All are designed to conform to surface irregularities, thereby eliminating air voids to improve heat flow between thermal interfaces.

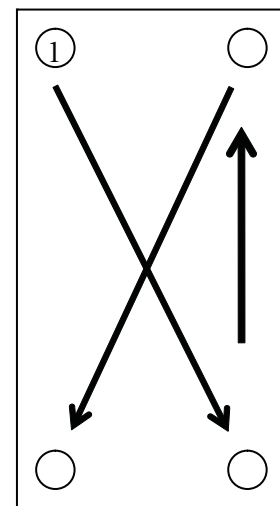
The specific choice and implementation of a thermal interface material is highly dependant upon the customer-specific applications and reliability considerations.

Failure to follow a proper pump module mounting procedures to a properly prepared heat sink can result in high thermal resistances and module warpage, both of which can impact performance and may lead to catastrophic failure.

- Use a thermal interface material with a thickness sufficient to compensate for a maximum nonplanarity of 100 μ between the pump module base and the heat sink mounting surface
- Use a thermal interface material with a thermal conductivity of 3 W/mK or better
- Prevent contaminating the pump module's fiber strain relief (black boot) and fiber buffer with any thermal interface materials
- Follow a X-style bolt pattern when mounting the pump module (see Figure 2)
- Bolt down the pump module to the heat sink in a X-style fashion, with the initial torque set to 0.75 in-lb and a final X-style bolt-down at 1.5 in-lb.



Initial torque to ~0.75 in.lb.



Final torque to 1.5 in.lb.

Figure 2. Bolting pattern and torque specifications for mounting a butterfly module

Soldering Pump Module Package Leads

The pump module leads can be soldered to mounting surface using localized solder reflow techniques. A handheld iron can be used that meets the requirements of the solder temperature dwell time, maximum temperature, and force applied at the joint area.

- Use handheld iron with a tip small enough to achieve reflow in less than three seconds to prevent module components damage
- Do not exceed a lead temperature of 260°C during the soldering operation
- Allow the module to cool down to ambient temperatures after the pump module leads are soldered to the mounting surface.

Ensure that during any soldering operation, that the fiber temperature does not exceed 85°C (either through exposure to the soldering iron or other hot surfaces). A fiber-coupled pump module is easily damaged if a hot solder iron touches the fiber. While this may not immediately break the fiber, it will increase loss due to local stresses, and it will compromise the physical strength of the fiber and integrity of the recoat buffer. A fiber damaged by a hot soldering iron is no longer a reliable device and should be replaced.

- Prevent fiber heating above 85°C when performing any lead soldering operation

Fiber Fusion Splice

Splice losses have a profound impact on the quality of system performance and long-term reliability. Pump modules spliced with a high loss dissipate more heat to the local surrounding, which may cause fiber buffer temperature increase or damage to the secondary surroundings. Fiber temperature increases can lead to catastrophic damage of the fiber or to long-term reliability considerations.

- Splice loss greater than 0.25 dB should be avoided

Fiber Handling

Both the fiber buffer and grating section are heat sensitive, as well as susceptible to buffer damage. Care must be taken during the set up and qualification of any process used in the handling and assembly of pump modules, as the buffer is readily susceptible to damage—even, for example, by coiling the fiber during product assembly and securing the coil with sections of solder or wire. This practice is commonly seen and is known to cause compression and delamination damage to the optical buffer.

Maximum storage and exposure temperatures for optical buffer are 85°C as recommended by fiber manufacturers. Exposure of the buffer to temperatures above 85°C will likely cause permanent damage to the pigtail. If temperature exposure beyond 85°C is required, it is critical to understand the risk associated with the optical fiber reliability.

The optical buffer is susceptible to damage to the buffer, and the damage is typically classified under 10 – 40 times magnifications as:

- M0: contamination of the surface of the fiber (debris or epoxy)—this contamination should not be removed by solvents or mechanical force; it can be removed by gentle swabbing with a foam-tipped probe.

- M1: Delamination of the buffer from the glass fiber, but no compromise in the buffer integrity and the buffer diameter remains fixed. Delamination is typical caused by compression of the optical fiber, and although small sections of delamination (mm long) do not introduce reliability risks, they do imply over-handling or processing where potential damage can be incurred to the buffer.
- M2: Compression of the buffer occurs when the physical diameter of the buffer has been reduced due to a force on the fiber. This will typically appear as an indentation or 'dent' in the buffer and may be accompanied by delamination. A compression defect again has no breach of integrity of the buffer and presents no immediate reliability risk, but does again imply a concern with regards to processing and handling the pump module.
- M3: Cracked acrylate sections of the buffer occur when damage to the buffer causes it to crack. While there may not be any evidence of directly exposed glass fiber, the buffer integrity is compromised and presents a reliability hazard. JDSU screens for this type of defect prior to module shipment due to the reliability risk it poses.
- M4: Exposed glass sections of the fiber are the highest reliability risk, and pose severe reductions to the inherent proof-test strength of the optical fiber. JDSU also screens for this type of damage due to its reliability hazard.

Follow the proper procedure of fiber handling to avoid catastrophic damage to the fiber in high-power pump lasers:

- Do not expose fiber to temperature higher than 85°C
- Always wear finger cots or gloves when handling fiber to avoid contamination.
- Whenever possible, handle fiber in loops to prevent fiber damage
- Do not drag fiber over equipment to avoid fiber damage
- Avoid fiber contact with any sharp object
- Never use the fiber to pick up or support the weight of the laser pump. Always handle modules with two hands, one holding a package and the other handling the fiber coil to avoid fiber damage
- Do not allow kinks or knots to develop in the fiber. Carefully work out any tangles; pulling on the fiber will cause any kinks or curls to tighten and exceed the minimum bend radius
- Do not bend a fiber with a radius smaller than specified as minimum bending radius for each specific pump module series (refer to the module specification for a value).

Bending the fiber to a smaller than specified minimum radius can result in increased fiber temperature due to a bend loss and subsequent optical absorption by the fiber and its buffer. Catastrophic damage of the fiber can occur due to a crack growth induced by temperature increase. In less severe bend situations, a temperature increase can lead to degradation of the coating, and as a result, to long-term reliability issues.

Fiber Lay Sensitivity—Polarization Effects

Wavelength stabilization of pump modules is realized by writing a slightly reflective, narrow-band fiber Bragg grating (FBG) into the module pigtail, roughly one meter away from the butterfly package. The majority of the pump laser light passes through the FBG, but a small percentage (less than five percent) reflects back into the DL providing optical feedback. If the amount of reflected light is adequate, the optical feedback ensures that the laser operates only at the FBG wavelength, even if the drive current or temperature varies widely.

The key to effective wavelength stabilization is maintaining adequate optical feedback into the DL cavity. The laser chip is, however, a polarized light source, producing a fundamental TE-polarized lateral mode pattern. Consequently, only the TE-polarized component of the FBG feedback can influence the diode laser. Any birefringence in the round-trip optical path from the DL to the FBG reduces the amount of reflected light providing the optical feedback. If birefringence produces a polarization rotation near 90 degrees, then there is little or no effective optical feedback, and the diode laser is decoupled from the FBG.

Birefringence in the pump module pigtail must be minimized by the EDFA assembler through proper fiber handling techniques and production controls. Birefringence can arise if the pigtail is twisted during spooling, bent to too tight a radius, or if the method of securing the pigtail places any stress on the fiber or allows the fiber to move during pump laser operation. NOTE: JDSU recommends that customers spool the pump module pigtail to a radius above the specified 16 mm minimum, taking care that axial rotation of the fiber is minimized during the process. Once spooling is complete, the pigtail must be secured in place with the proper method, ensuring a fiber bending radius with the specified 16 mm minimum.

Following these guidelines will minimize birefringence and optimize the spectral performance of the pump module. If poor spectral performance is observed subsequent to the original spooling of the fiber, the spooling process should be repeated.

Fiber Contamination

Fiber contamination is a key consideration for high-power pump modules. The optical power from pump modules that is not coupled into the fiber core is propagated by the fiber cladding layer a short distance from the module. Fiber contamination, especially contamination with dark color, will cause a local temperature increase as it absorbs the dissipated cladding modes. Wear gloves when handling fiber:

- Avoid any contamination of fiber
- Clean a fiber if contamination occurred, being especially considerate of the first ~2' of buffer
- No dark color contamination with area larger than 100 μm is allowed within the first ~2' of buffer, and should be avoided along the entire length of fiber.

Fiber cleaning materials and procedures shown below are for informational purposes only and are not meant to recommend, endorse, or discredit any existing procedures. It is recommended that users evaluate any procedure or product before using it in applications where damage or failure could result. As always, safety precautions must be exercised at all times when using glass, chemicals, and lasers.

There are many materials commercially available for fiber optic cleaning. Some are marketed specifically for the fiber optic industry, while others are considered "raw materials," or generic in nature, but can be used for the same purpose.

Swabs

There are applications for each type of swab. Choose the proper type of swab after experimenting with its results. Manufacturers sometimes recommend multiple uses of swabs. In some applications this may be suitable, but in others, only a single use prior to disposal is suggested.

Cotton tipped—Various sizes are available, with different materials and lengths of sticks. Used dry or dampened with your choice of cleaning fluid, these are not the best in tight or unseen areas as cotton fibers may come off of the swab and adhere to connectors or become lodged in small openings.

Foam tipped—These are designed to be used with different cleaning fluids. They come in various sized tips, with different materials and lengths of sticks. Care should be taken to properly moisten and dry the freshly cleaned surface.

Felt-style tipped—Similar to the foam tipped, except the tip is stiffer. A hard felt-type tip softens and swells with moisture. Care should be taken to properly wet and dry the freshly cleaned surface.

Film—This is probably the newest style of cleaning material or fabric. This swab uses a woven film similar to the tape and reel cleaners (see Wipes). The woven material is wrapped to the end of a stick and can be used both wet and dry. The film removes both particles and oils.

Alcohol

Isopropyl alcohol is the most commonly used of the alcohols in fiber optic cleaning, due to its low cost and safety qualities (toxicity, flammability, environmental/disposal). Alcohol will loosen particular contaminants and aid in removing oils. It is used on swabs and wipes, by directly spraying, in soaking tubs, and in ultrasonic cleaners. The better alcohols are have a higher alcohol concentration (lower water content), and 99 percent is readily available in bulk, small bottles, and pressurized spray cans with nozzle extensions.

As a general consideration, always replace the cap on bottles or the concentration will degrade because of humidity absorption. Do not 're-dip' a wipe into the same volume of alcohol for multiple cleanings. Degradation also results when storing a bottle with little fluid and more air space for the same consideration of water absorption. If a previously opened bottle is not used in a generally short amount of storage time, it should be disposed of. Spotting on a cleaned surface will indicate degradation due to moisture absorption.

Wipes

Natural fiber—Cotton wipes in various weaves are available, as well as different absorbency, thicknesses, and pad sizes.

Synthetic—Similar to cotton wipes, but stiffer and sometimes less absorbent.

Moist—Premoistened wipes are available in tubs (tear off) and individually prepackaged. The tubs should be closed after each use to keep the wipes from drying out. The individually packaged wipes are single-use only. These tend to come with a lower concentration of alcohol (40 – 60 percent).

Dry film—Woven film similar to the tape and reel cleaners (see Wipes section) is used in a card style, designed for single wipe-and-clean of connector tips or faces. This allows for removal of both particle and oil contamination.

Adhesive

Adhesive-type cleaners are used to remove particle contamination. It is important to select an adhesive in-line with the particular application so that the adhesive itself does not create a new source of contamination or damage (the adhesive itself may adhere to a surface, or a contaminant that was on the adhesive prior to cleaning may cause cross-contamination, or scratching, and dig-type damage).

Tape—A high-quality common adhesive tape can be used. Tapes should be used as referenced in MIL standards.

Pads and Sheet—Available in a pocket-sized sheet, this product has individual pads for single-use tip or end face cleaning. Keep the adhesive pads covered or contamination will result.

Air

Air is used for drying and clearing surfaces and areas of contaminants separately, or after cleaning with a fluid or wipe. Open air-drying is sometimes done but can be problematic as it allows for water spotting on surfaces.

All air used in fiber optics must be free of particulates and oil contaminants, and should not generate increased susceptibility to ESD. Testing should be done when selecting a canned air to ensure cleanliness, and detect any residual film problems. Proper filters must be used when using house air. Canned air is most commonly used because of its portability and reliability of cleanliness.

System or house air—Pressurized air that is piped through the lab or building supplied through a compressor. Proper filters and testing are required to certify that the air is free of particles and oil contaminants.

Canned air—Choose a high-quality canned pressurized air that, when tested on a dark glass or shiny plastic surface, leaves no residual film or oil. Do not spray from a can that has been shaken or inverted within the last half hour as some propellant may be sprayed out and possibly contaminate the surface being cleaned.