Recent Issues in Laser Diode Packaging for High Reliability Applications

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Outline

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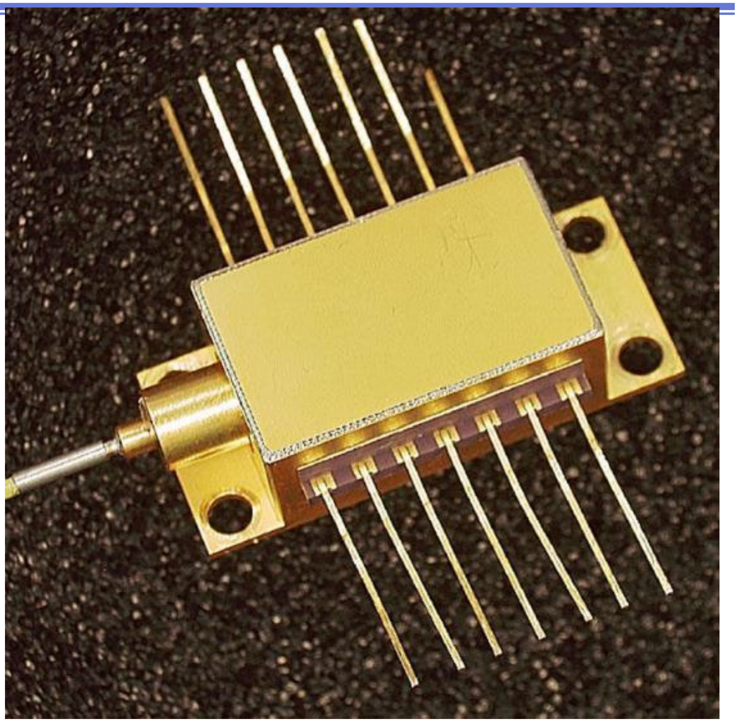
Summary

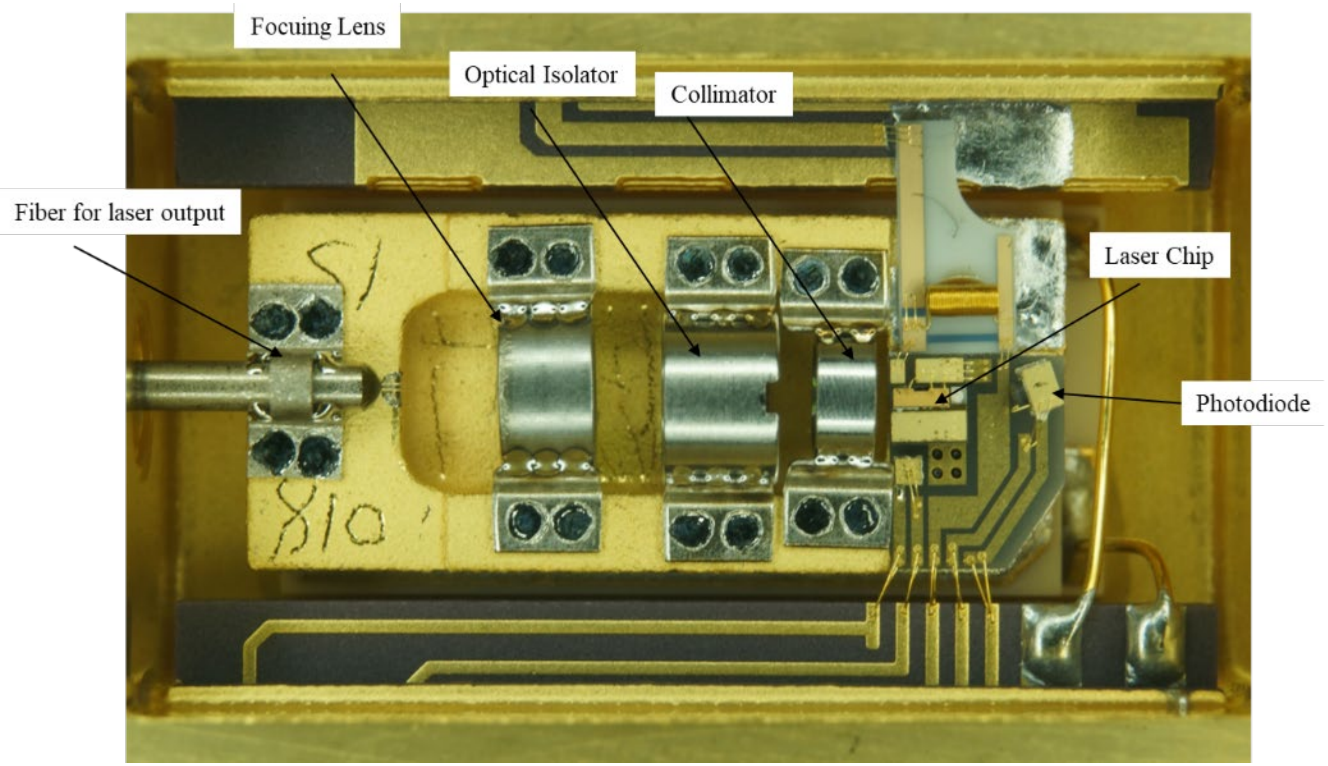
- There's a growing demand for butterfly laser diodes and two pin high power laser diodes as LIDAR and fiber laser systems continue to advance.
- As part of the screening and qualification testing of optoelectronic devices, construction analysis and precap inspections are performed.
- This presentation provides a brief overview of the various types of common laser diode internal packaging and issues observed during precap and construction analysis across various past and present programs.
- The presentation is not intended to show specific issues with specific vendors, but instead to provide a high-level overview of the different types of issues observed. In many cases, vendors have been willing to work with us to resolve these issues for our flight lot of laser diodes. In the case of precap inspections, parts can be corrected or rejected prior to delivery to NASA.
- This presentation is by no means comprehensive of all the issues seen with these types of devices. Common issues with EEE parts (like Indium/Gold interfaces and pure tin solders are not covered), instead focusing on issues related to the unique hybrid optical/electrical nature of these devices.



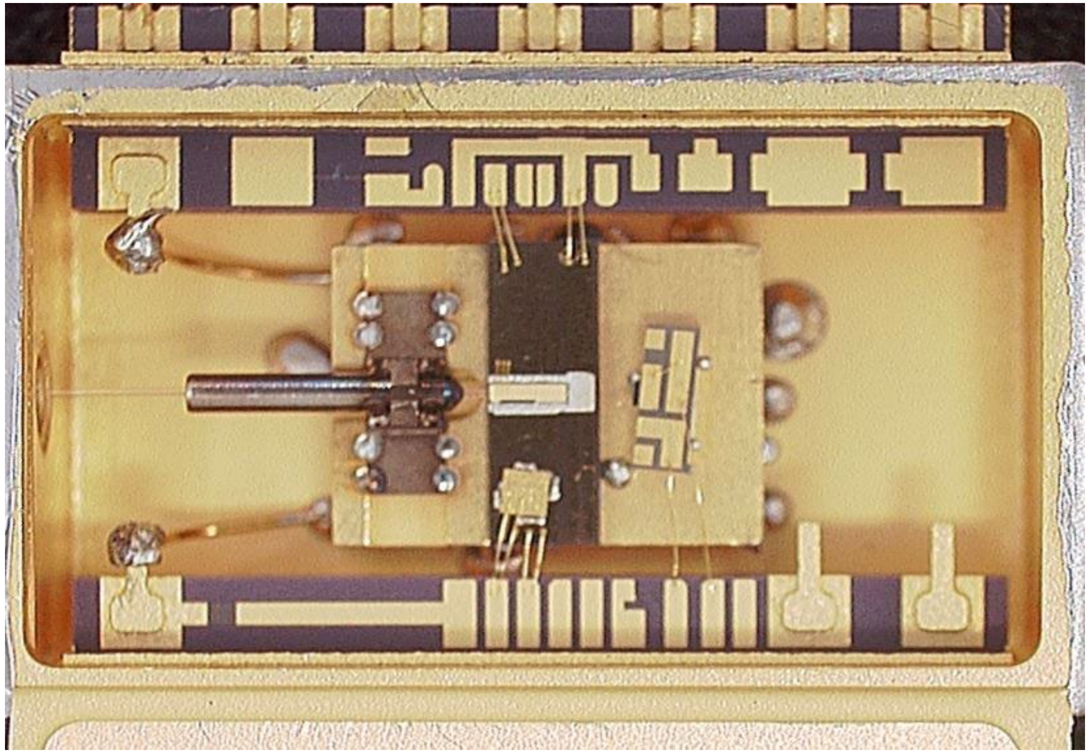
Examples of Fiber Coupled Laser Diodes

Distributed Feedback Laser Diode

A **Distributed Feedback (DFB) laser** contains a periodically structured element or diffraction grating in the active region of the device to stabilize and lock the laser wavelength. It provides high wavelength stability and narrow linewidth.



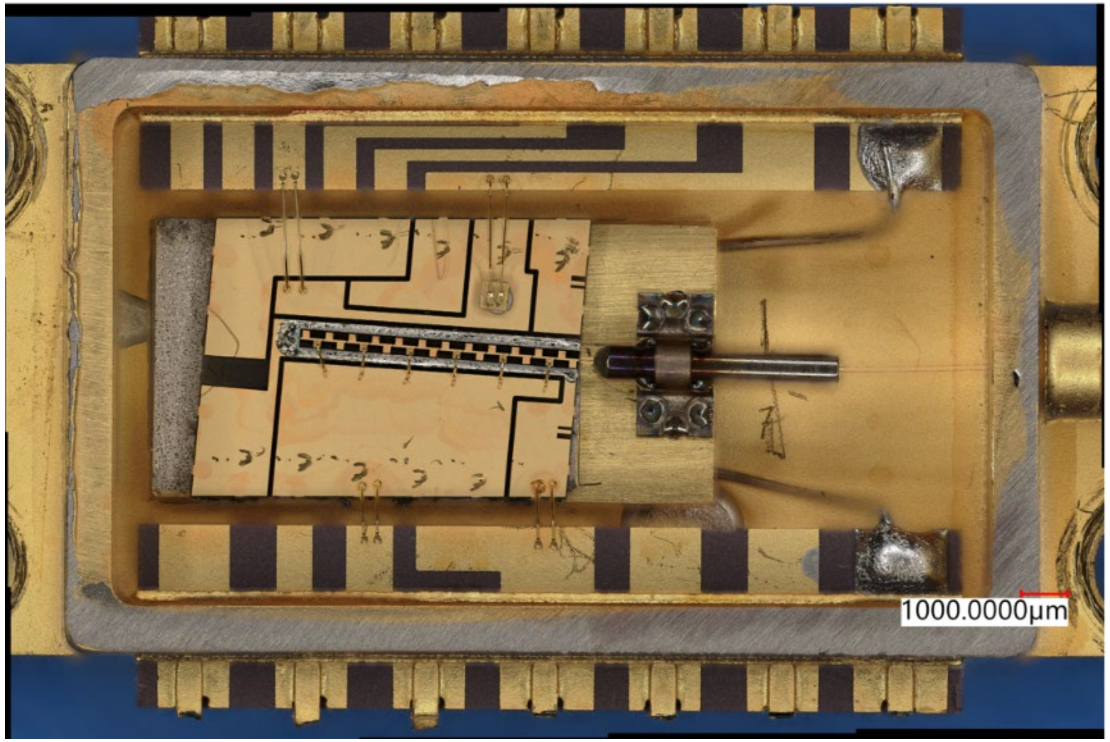
Example of a DFB laser diode containing bulk optics inside laser diode package

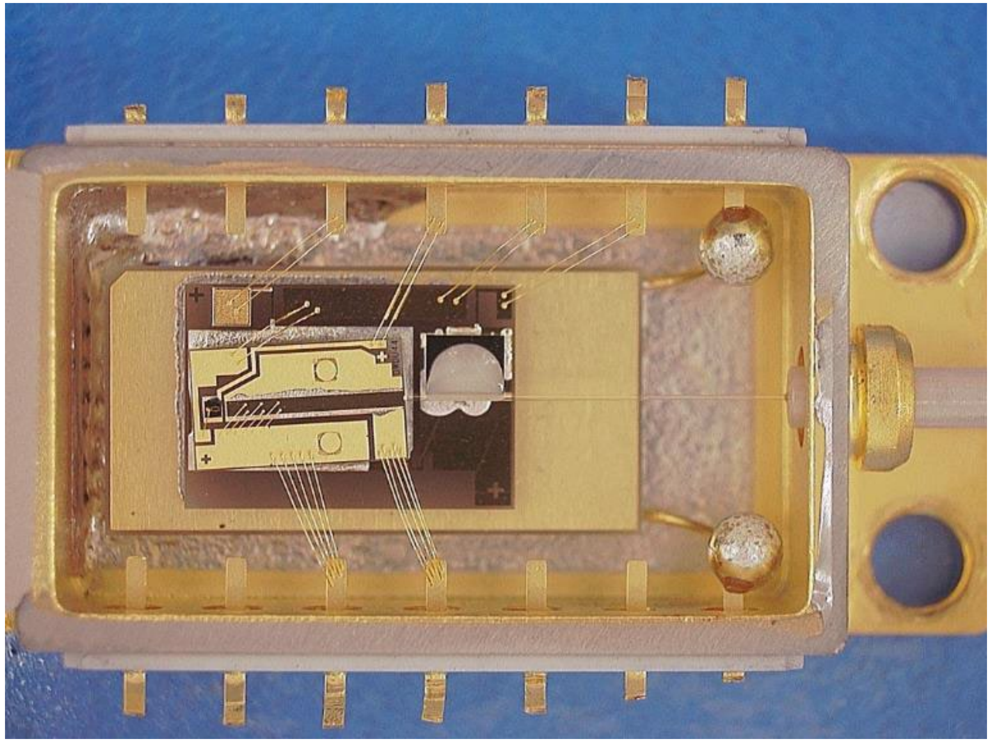


Example of a DFB laser diode with no bulk optics

Fiber Bragg Grating Laser Diode

A **Fiber Bragg Grating (FBG) laser** achieves wavelength stabilization using a Fiber Bragg Grating in the fiber instead of the laser diode active material. Recent work with FBG lasers has shown reduced stimulated Brillouin scattering (SBS) when amplifying compared to the DFB laser.



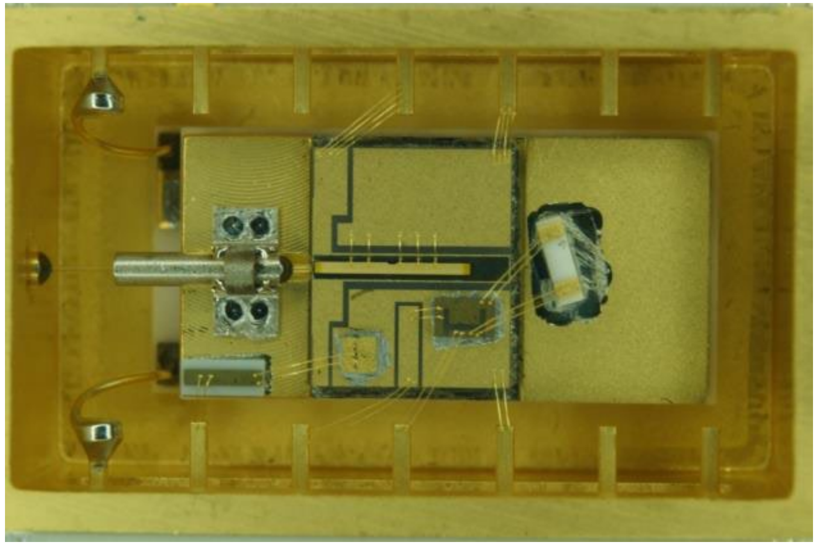


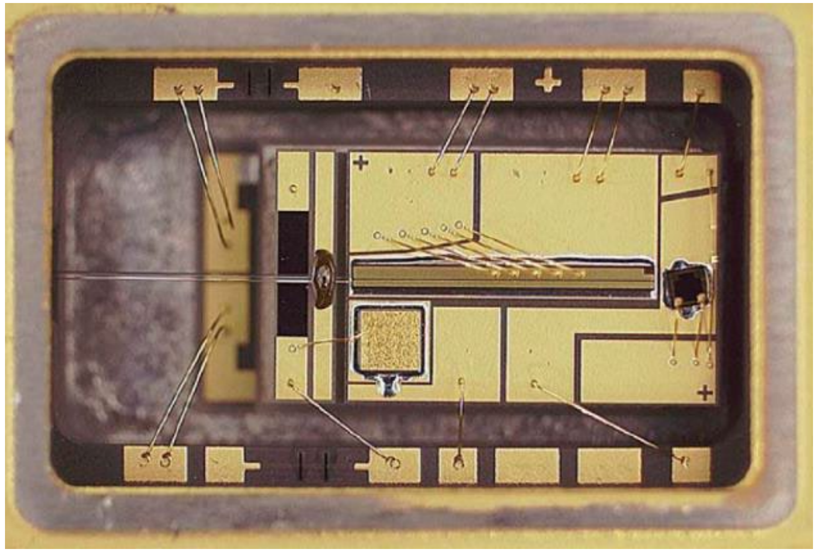
Spectrum Stabilized Single Frequency Laser Diode

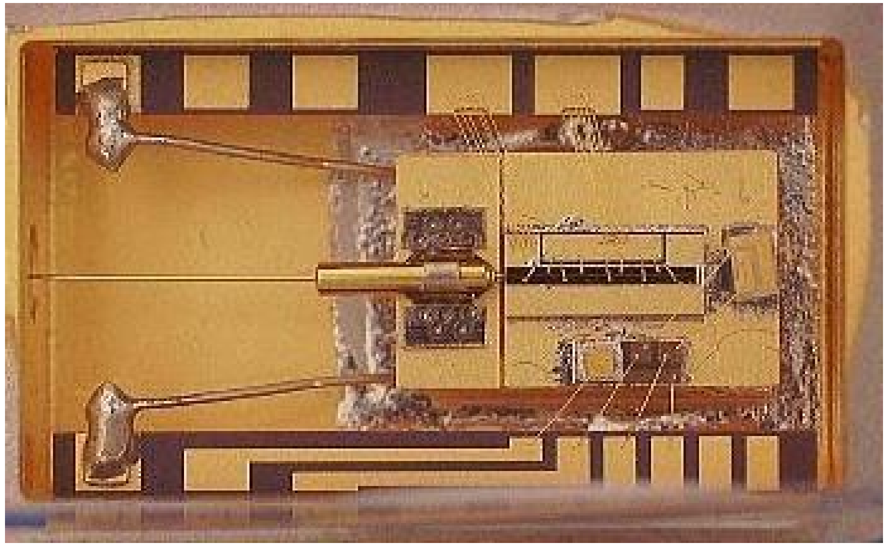
A **Spectrum Stabilized Single Frequency Laser** achieves wavelength stabilization using a transmission grating in front of the laser diode output. This allows for the optic to be thermally decoupled from the diode itself.

Single Mode Pump Laser Diode

A **Single Mode Pump Laser Diode** controls the wavelength stability of the output beam using precise temperature control. The laser features thermoelectric coolers under each part, thermal sensors, a monitoring photodiode, laser diode bar. Light is output to a single mode fiber hermetically sealed to the package. This is a lower powered part, and typically features a small number of bond wires.

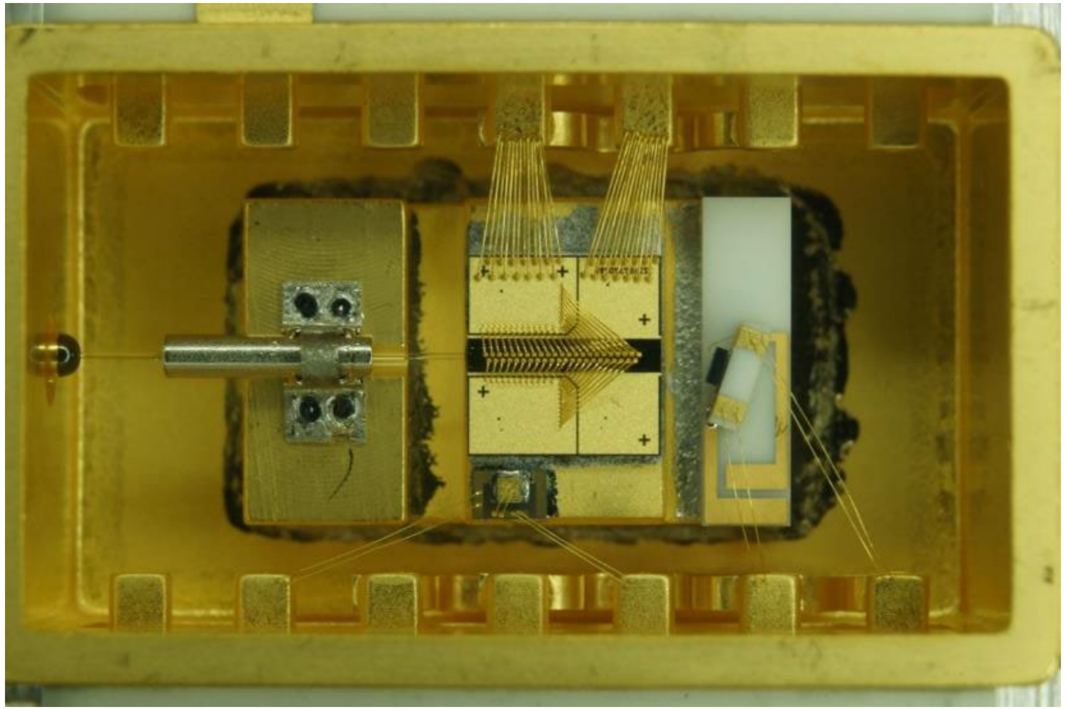






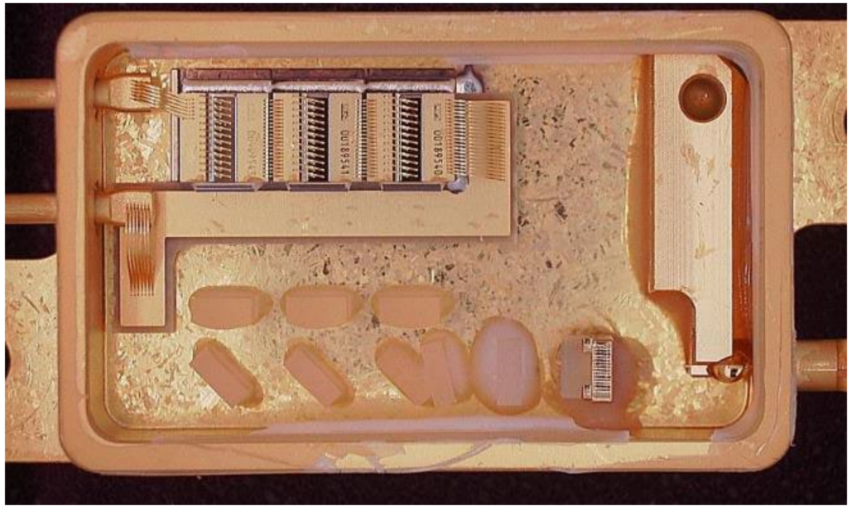
Multi Mode Pump Laser Diodes

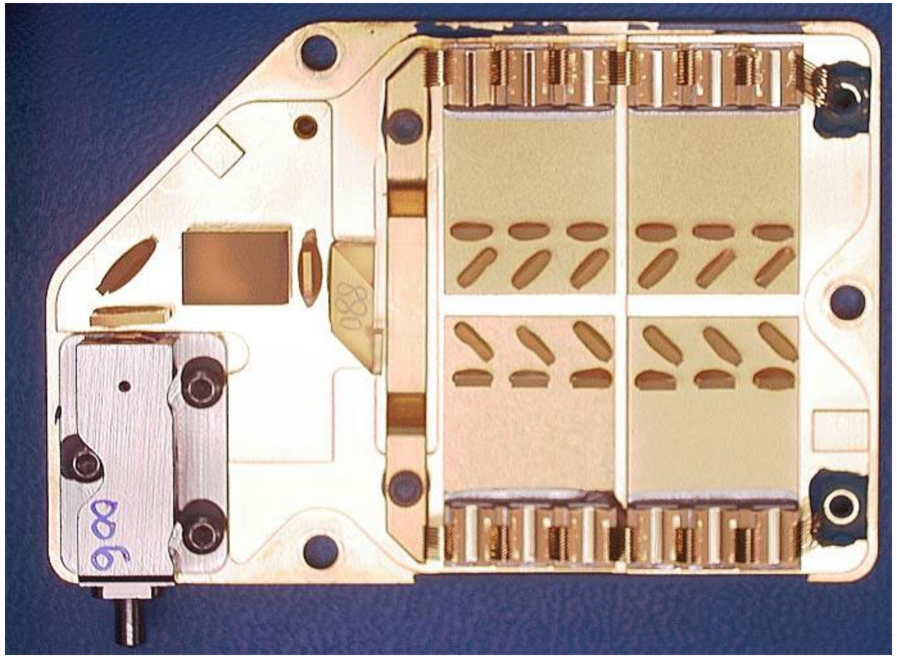
A **Multi Mode Pump Laser** is similar in construction to the single mode pump laser but note the much larger number of wire bonds to the laser bar for the higher current device.



High Power Laser Diodes

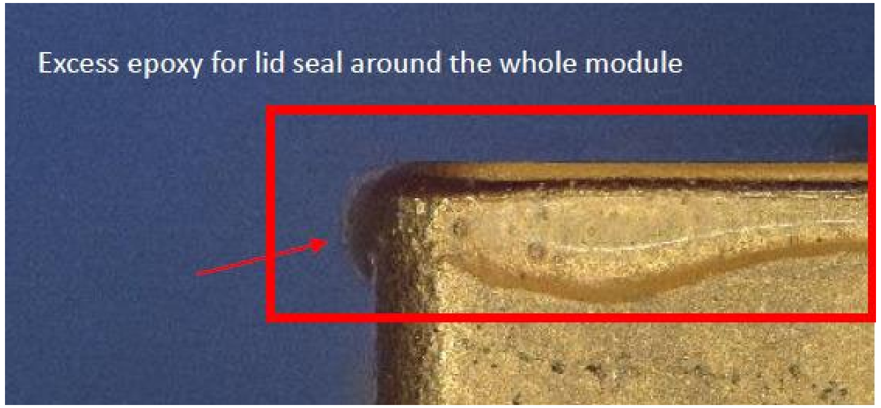
A **High Power Laser** utilizes bulk optics to collimate laser diode output in both axes, bulk grating for wavelength stabilization, and focusing lens for injecting light into fiber optic.

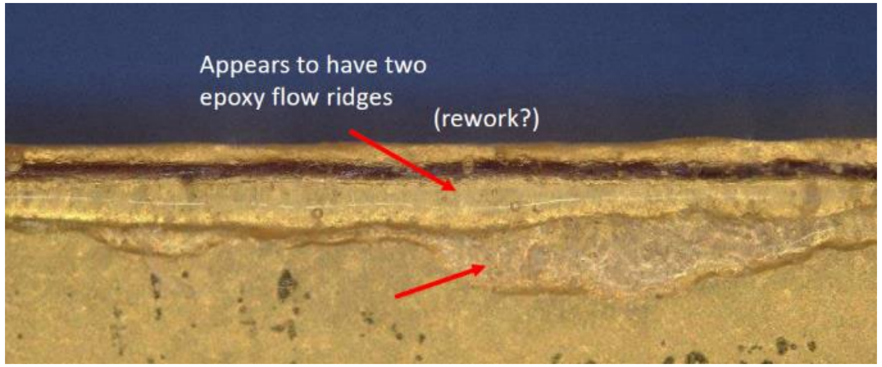


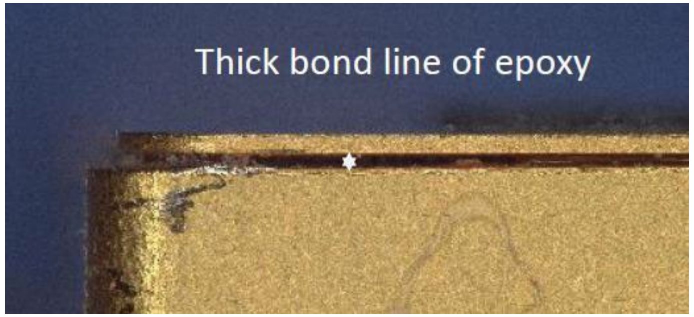


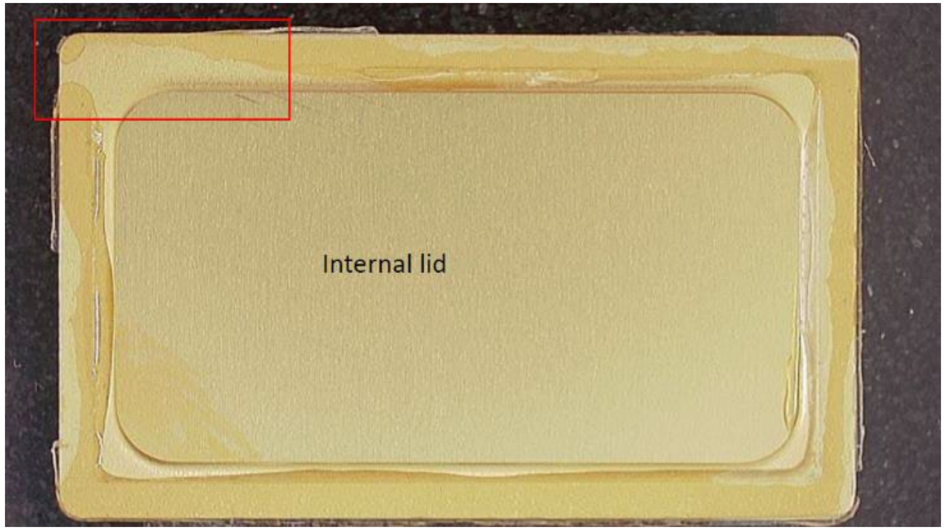
Recent Issues in Butterfly Packaged Laser Diodes

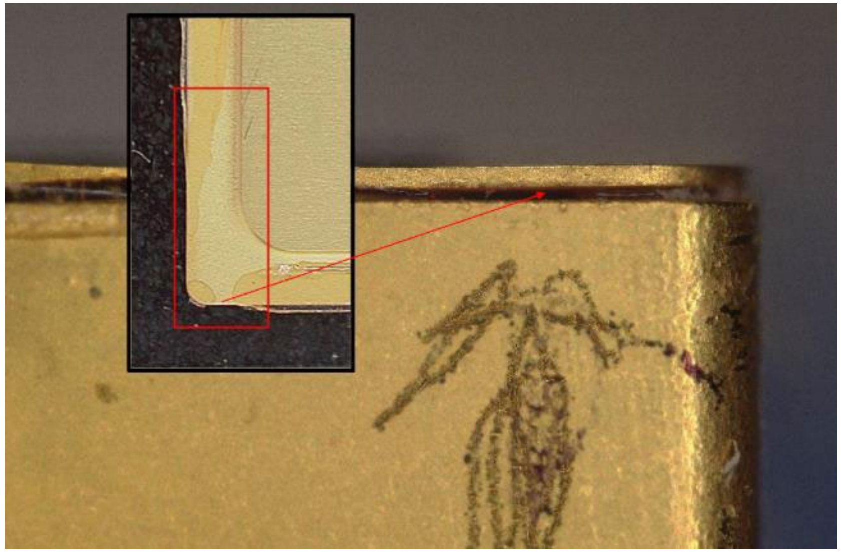
Lid Sealing Issues: Epoxy











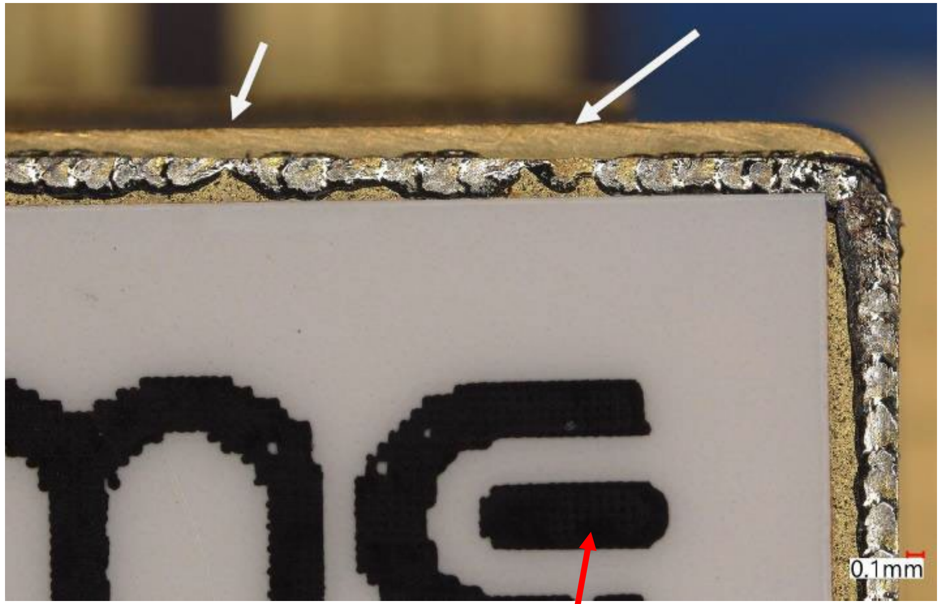
Epoxy seals are not typically recommended for hermetic packages but can be used to reduce contamination risk.

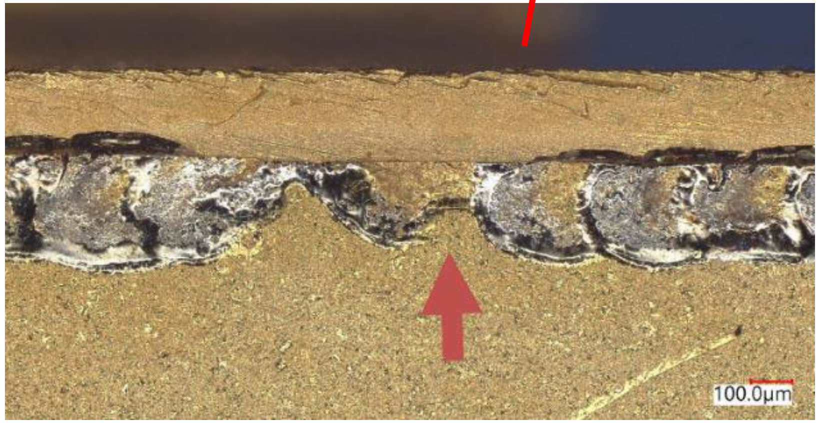
Lid sealing issues due to improper epoxy application are common in COTS parts. Close examination of the epoxy bond line should be made for high reliability functions.

In vacuum applications, epoxy used should be tested for outgassing.

Lid Sealing Issues: Weld

Inconsistent weld in lid seal

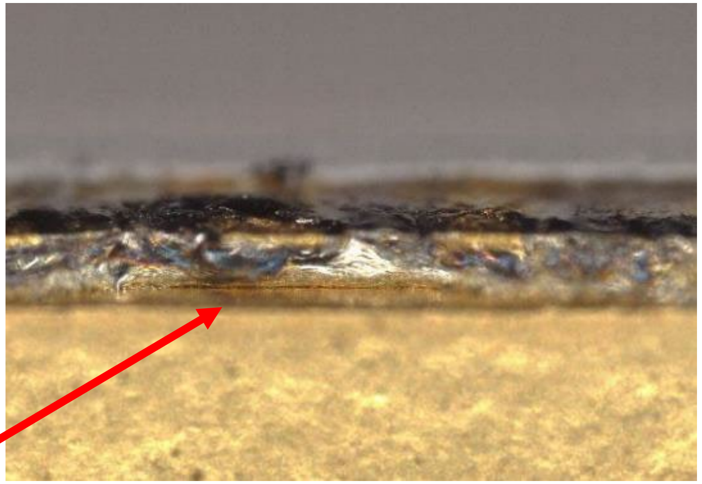




Weld seals are recommended for hermetic laser diode packaging.

The package shown on the left was caught as having a suspected bad weld seal during incoming inspection of the part. The part failed hermeticity testing.

It is recommended that all parts with a hermetic requirement be tested individually.

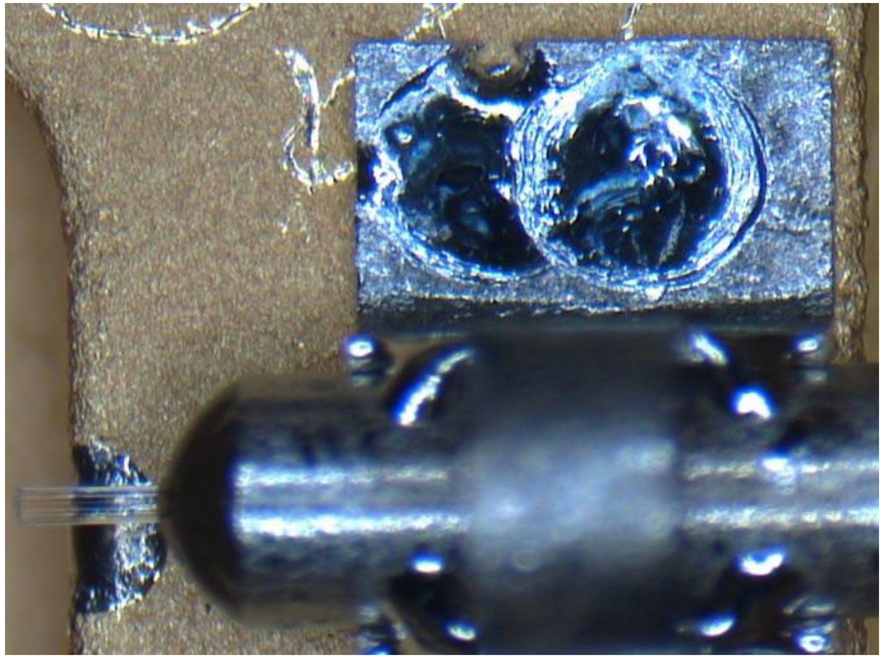


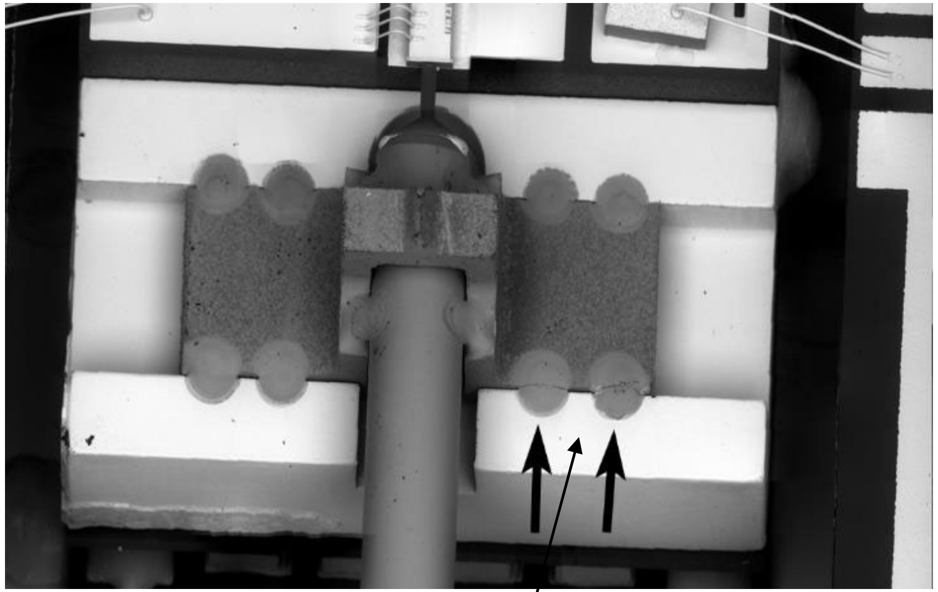
Welded Joint Issues

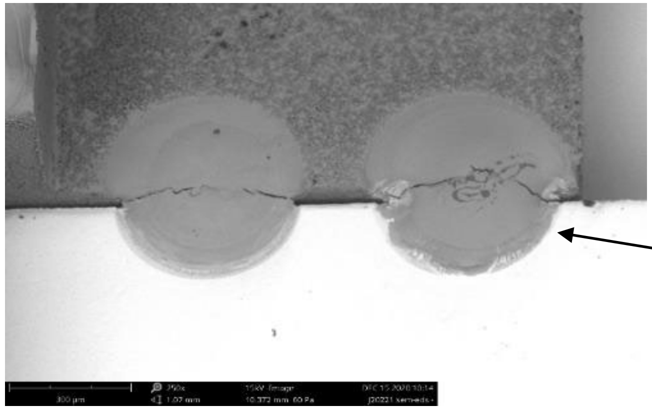
In some applications welded joints are used to hold the housing for the optics and fiber ferrule in place.

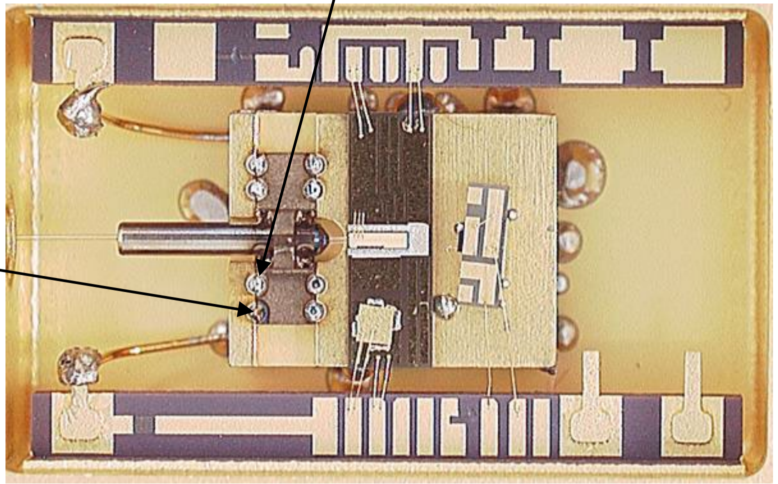
Cracked or insufficient joints can cause the optics or fiber to shift during vibration and/or temperature cycling.

Issues with the welded joints can typically only be seen during pre-cap inspection of the part. Welded joints can sometimes be seen during X-ray depending on the package construction.







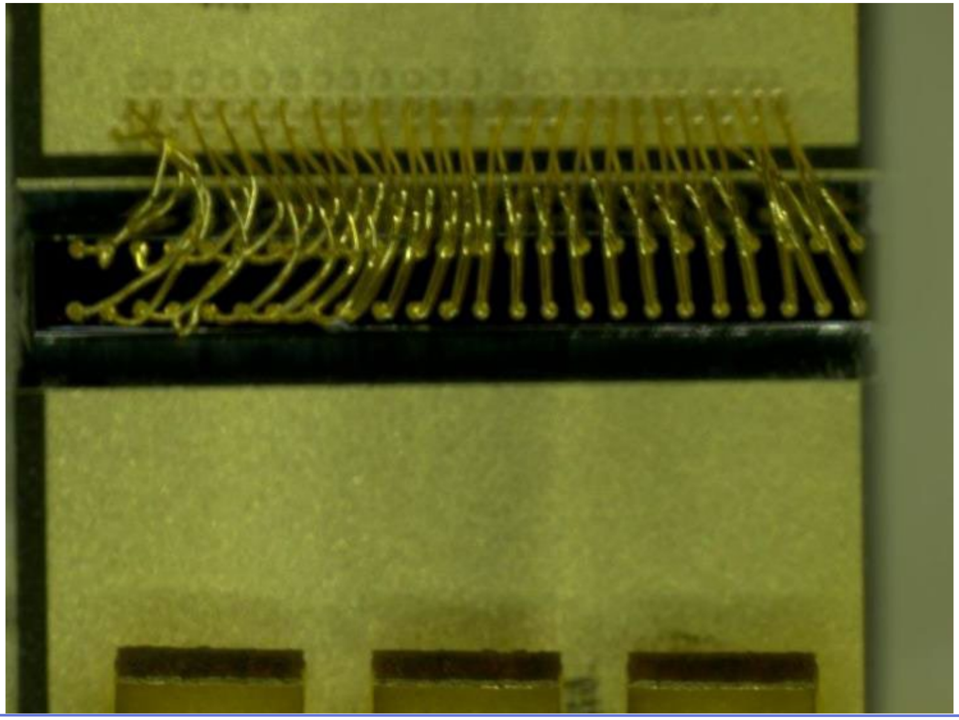


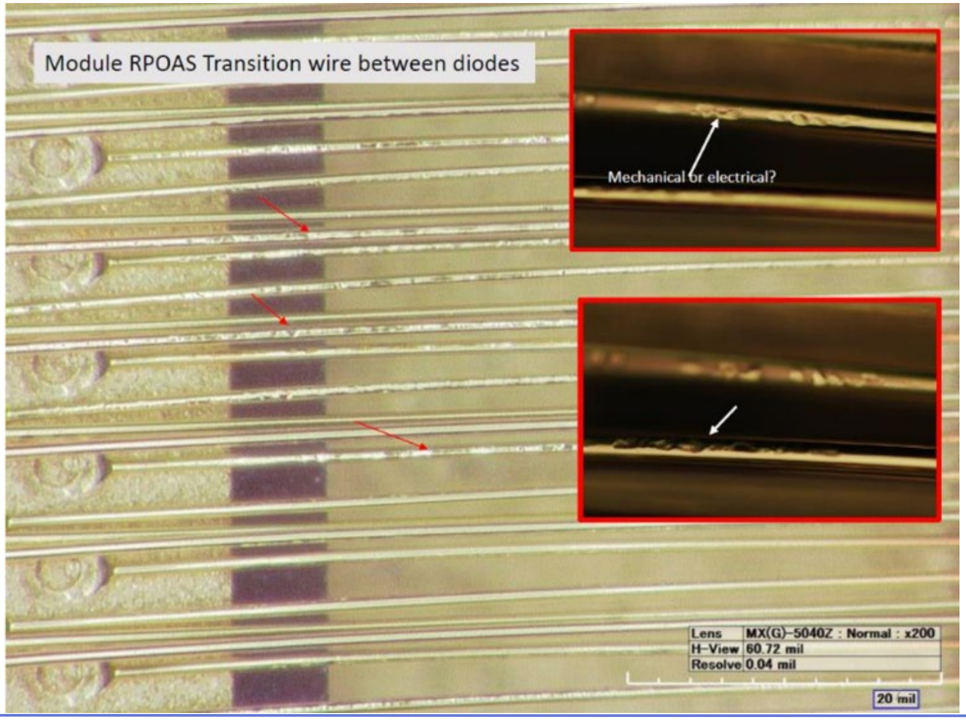
SEM image shows cracked welds at the fiber mounting structure.

Wire Bond Issues

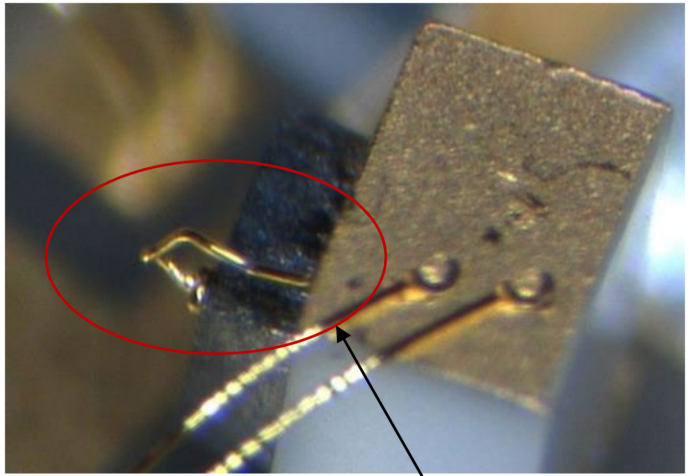
Wire bonds are commonly used within butterfly packaged laser diodes with lower current applications. Criteria for rejecting the part is based on the number of damaged wire bonds, current being carried/size and the number and redundancy of the wire bonds, and possibility of wire coming completely off.

- Disturbed wire bonds, seen on the bottom left, are typically seen when part has been reworked or when the manufacturer performed an intermediate testing step that required probing the part during assembly.
- Damaged wire, seen on the bottom right, can either be an issue with the lot of wire, caused by mishandling of the wire during installation or a tooling issue, or overdriving the part.



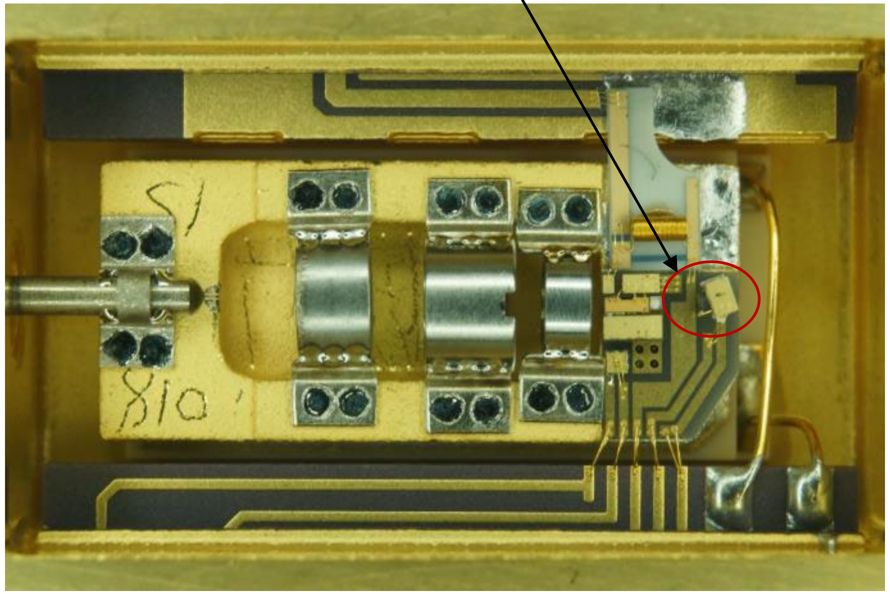


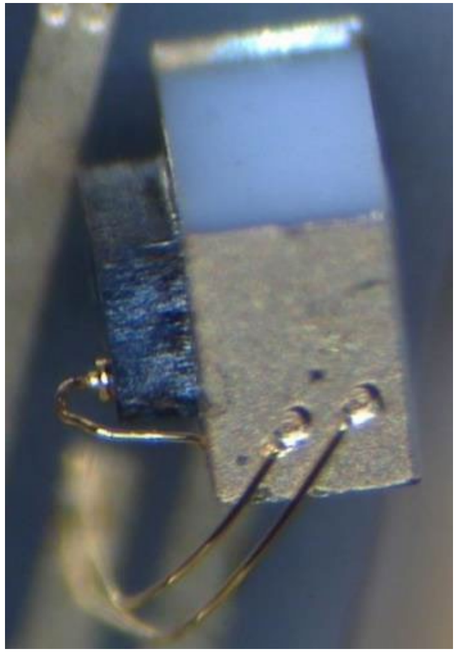
Wire Bond Issues
Example on Photodiode



The images shown are from the same laser diode and show an abnormal bend on a wire bond on the photodiode of the part. The bend was noted but was not adjusted. This diode was removed from flight candidacy but was used for life test purposes.

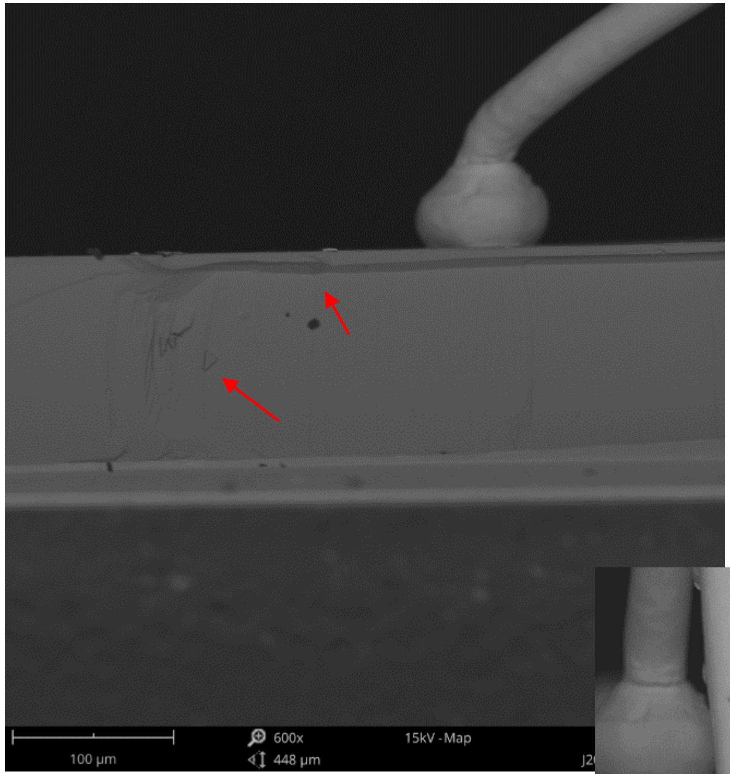
A bend like the one shown could be an issue with workmanship or damage during manipulation or installation of the photodiode into the next higher assembly.

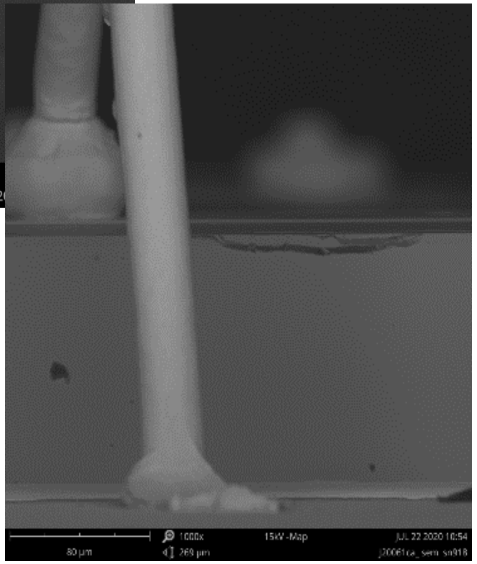




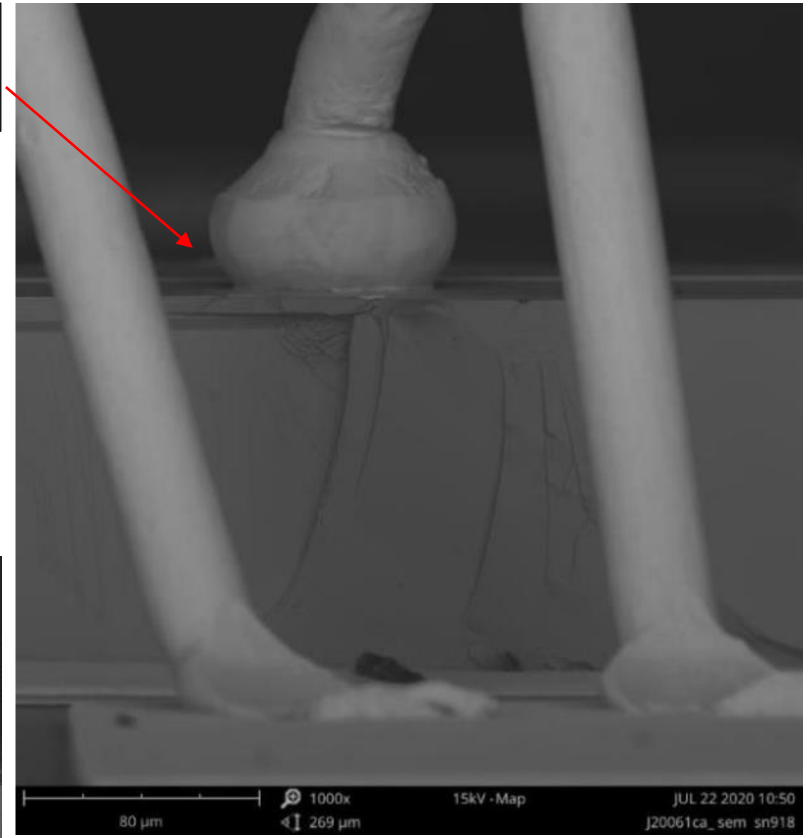
Wire Bond Issue:

Laser Bar Damage





Compression damage to the GaAs due to bonding pressure



Chip damage due to excessive bond force.

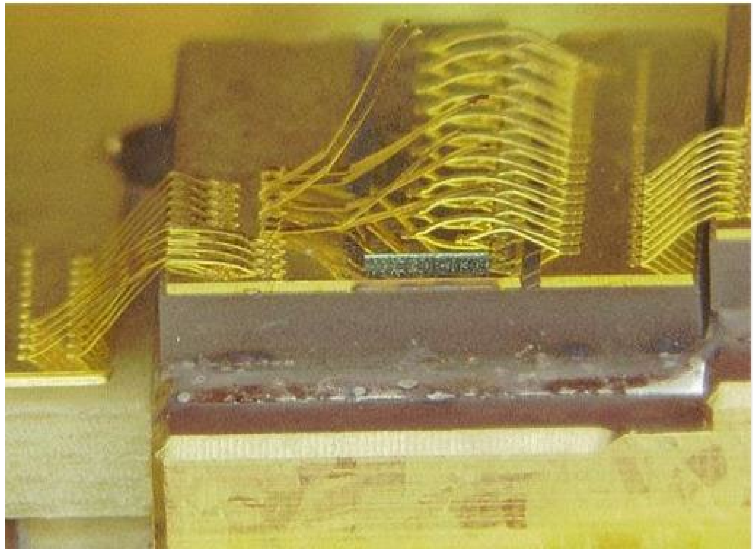
Images show damage to the laser bar of a high power laser diode due to excessive force of the bond.

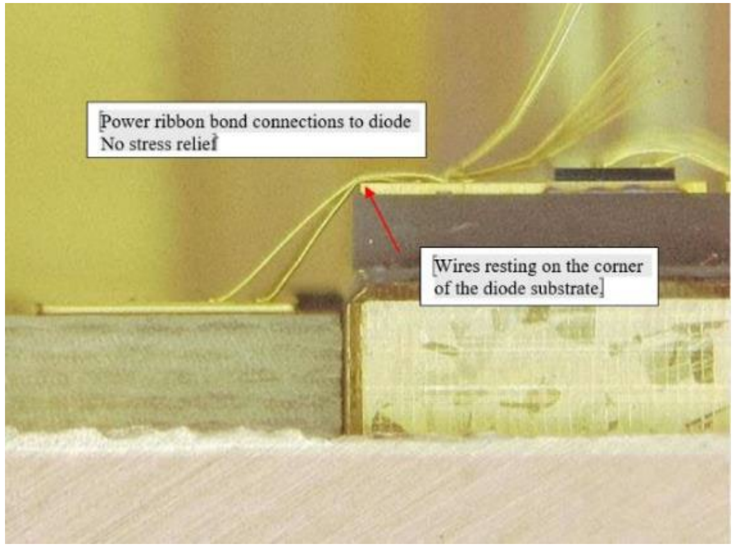
Ribbon Bond Issues

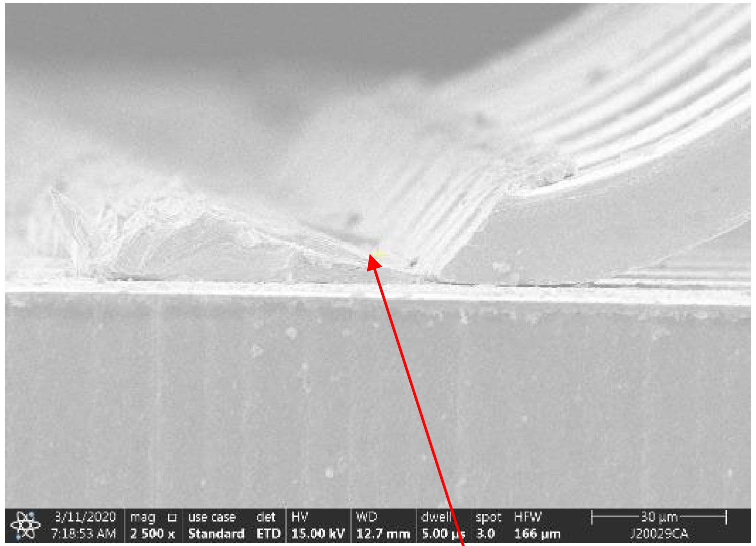
Ribbon Bonds are used in high current applications for high power laser diodes.

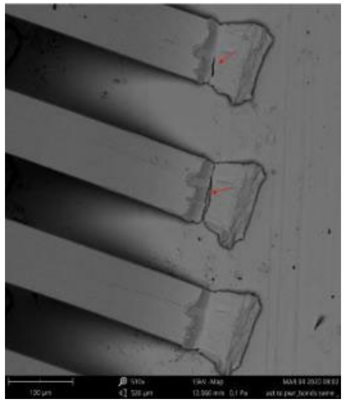
Close-up images of ribbon bonds of the part show anomalous bonds containing cracks and gaps in the ribbon weld. These were caused by the vendor’s ribbon bonder putting too much force during the application.

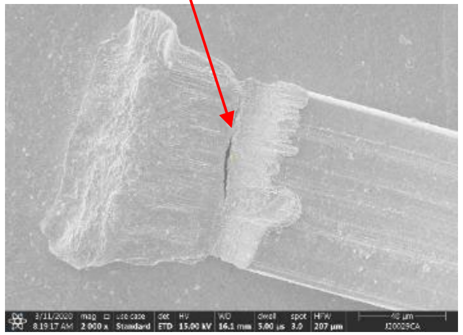
Inspection also found improper strain relief on the ribbon bond during transition over the substrate corner (2nd image from left). Both issues were corrected with the vendor prior to the final flight lot.



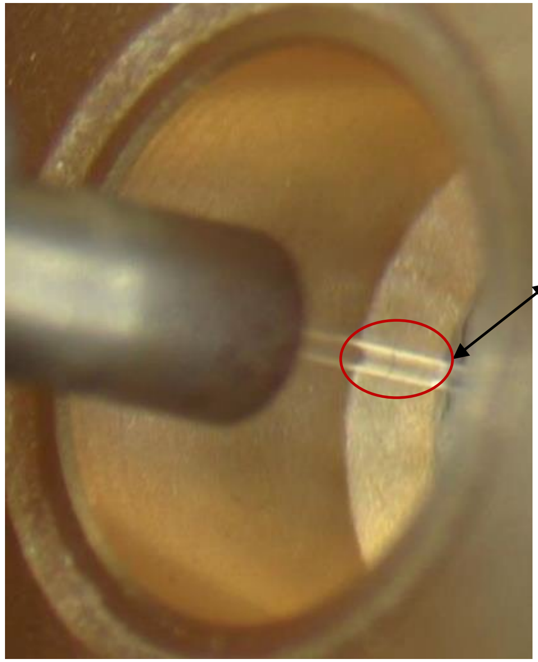


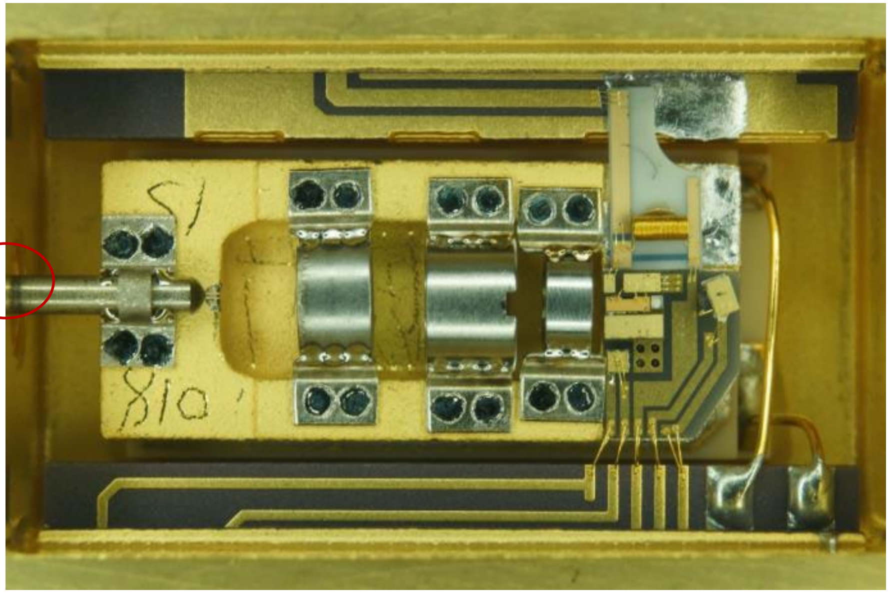






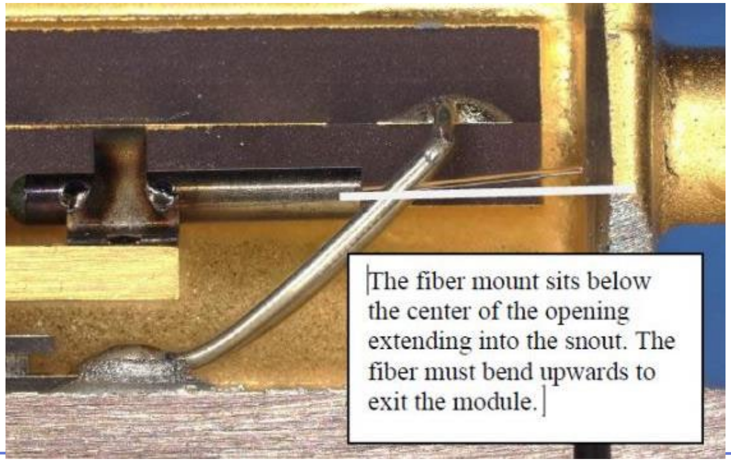
Defects in Fiber Optic Output

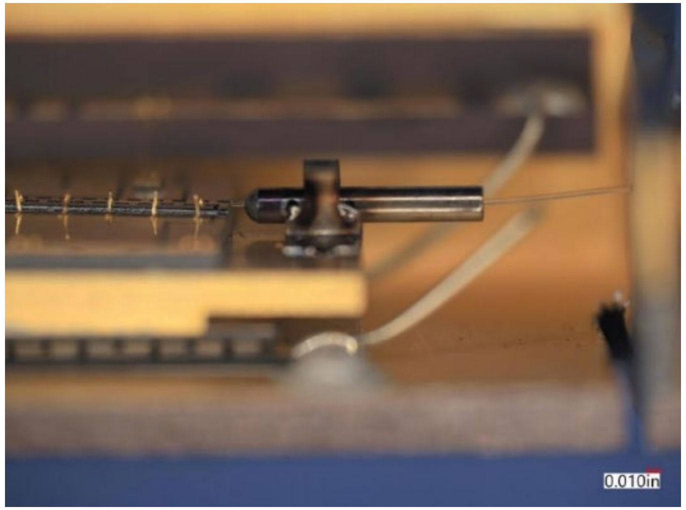




The fiber optic output is critical to the output stability of the laser diode in addition to providing the hermetic seal of high reliability parts.

This part in the top two images had a line across the fiber in the “snout”. Fiber optics need to be carefully inspected during precap for any abnormalities.





The bottom two images show potential strain on the fiber caused by the fibers not sitting in plane with the output. When the fiber mount sits below the opening in the package wall, it forces the fiber to bend upward to enter the snout.

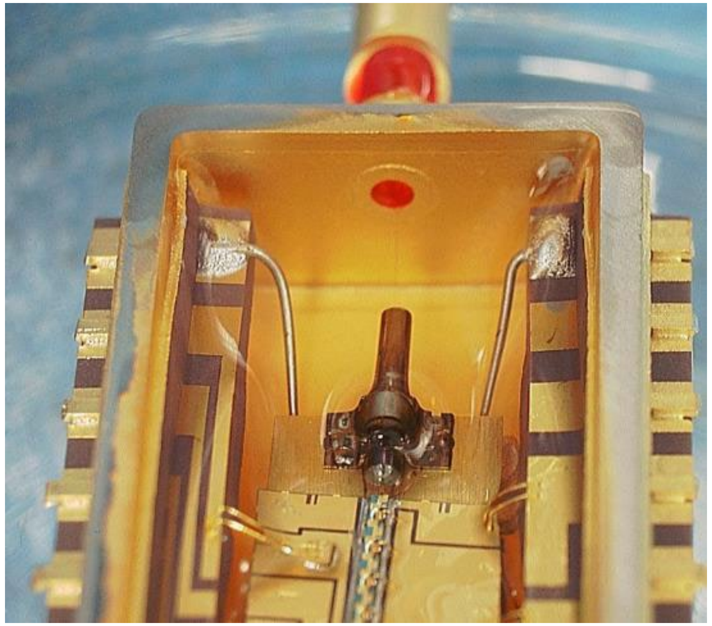
Possible long term reliability concern depending on mission requirements (temperature ranges, number of temperature cycles, vibration, etc.)

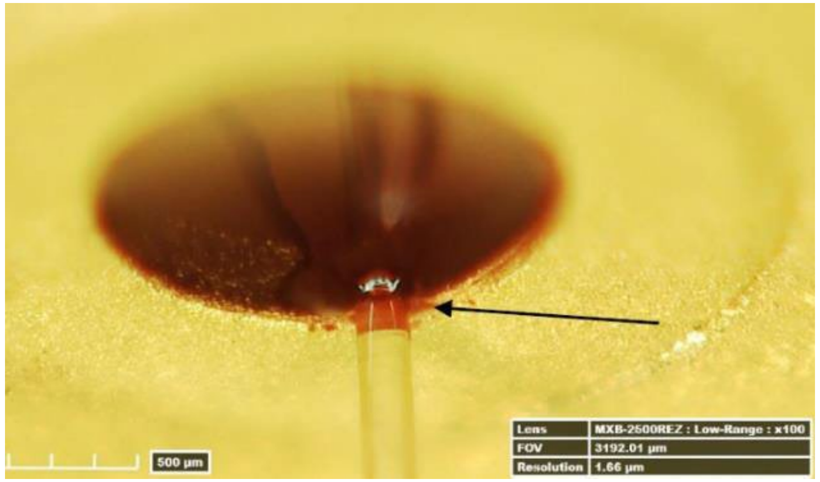
Fiber Optic Inspection Continued

In hermetic packages, a glass seal is preferred over an epoxy seal. Epoxy seals can have shrinkage and cracking over time which could cause a failure in hermeticity or a strain on the fiber output.

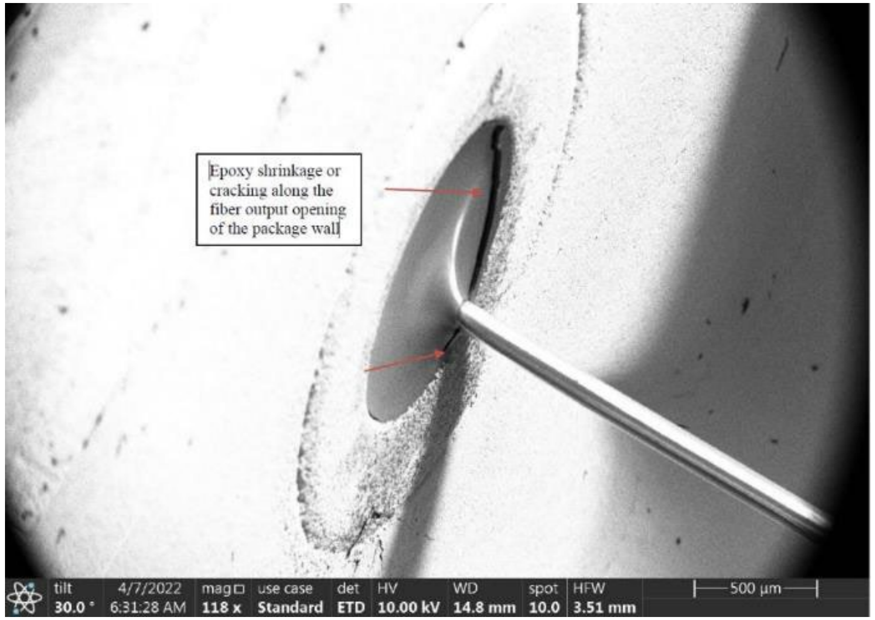
It is also recommended to keep the fiber optic centered within the snout opening of the laser diode for long term reliability and stability.

Images below show some examples of a cracked epoxy seal within a laser diode package.

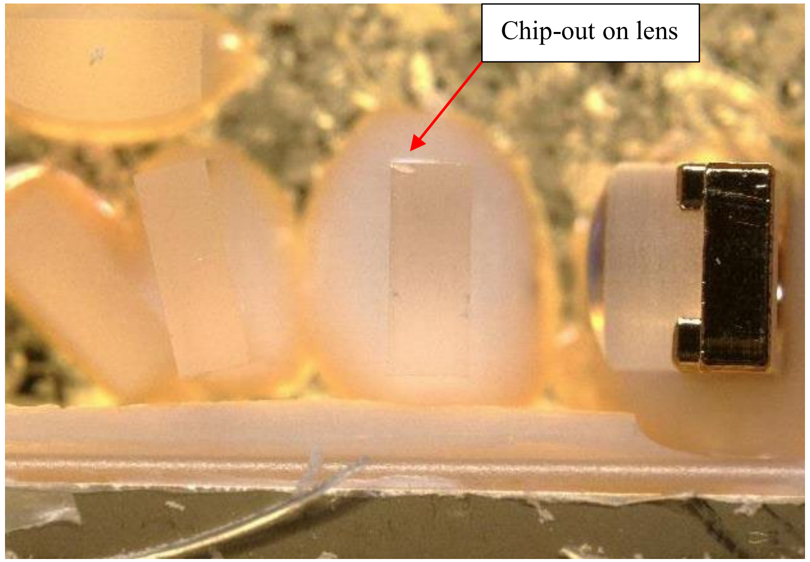


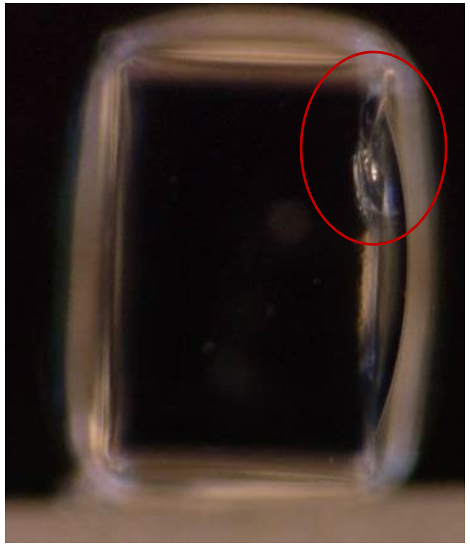


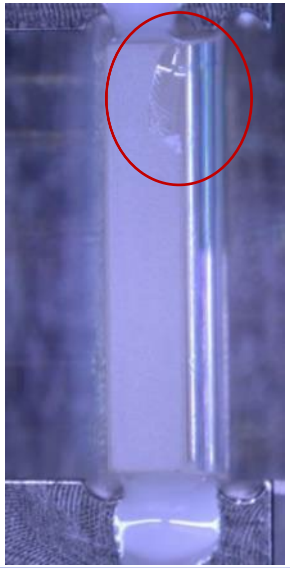
The fiber is positioned on the bottom of the snout opening in the package wall.



Optical Chips and Cracks

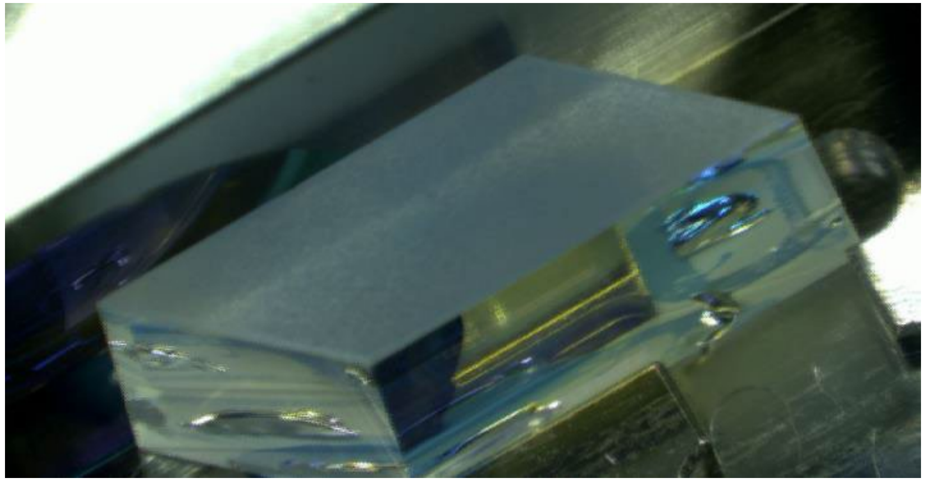


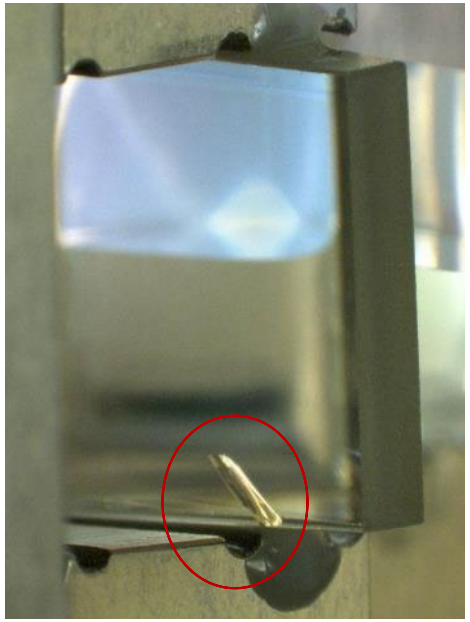


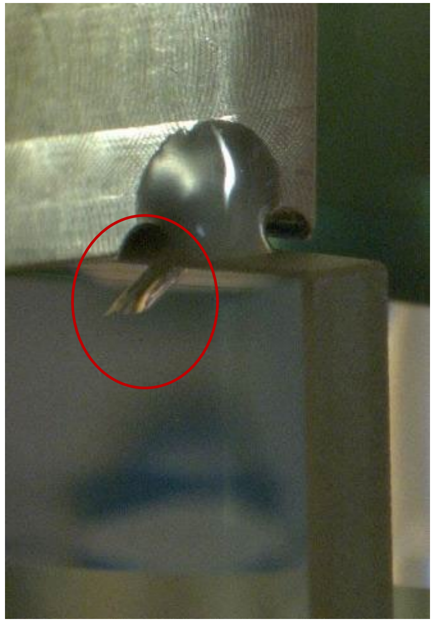


Chips and Cracks are commonly seen within the optical components of laser diodes.

Chips and cracks can lead to a loss of power of the laser. Cracks will propagate in thermal environments which could lead to a latent laser failure.

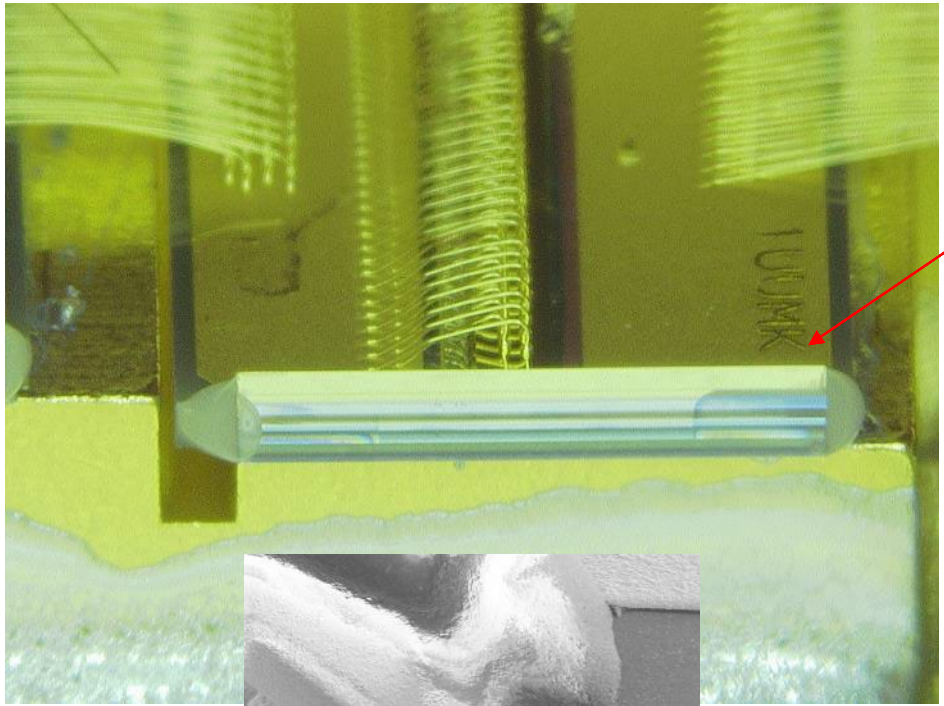


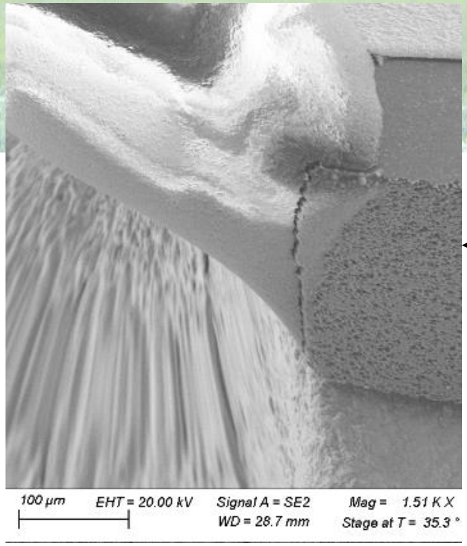




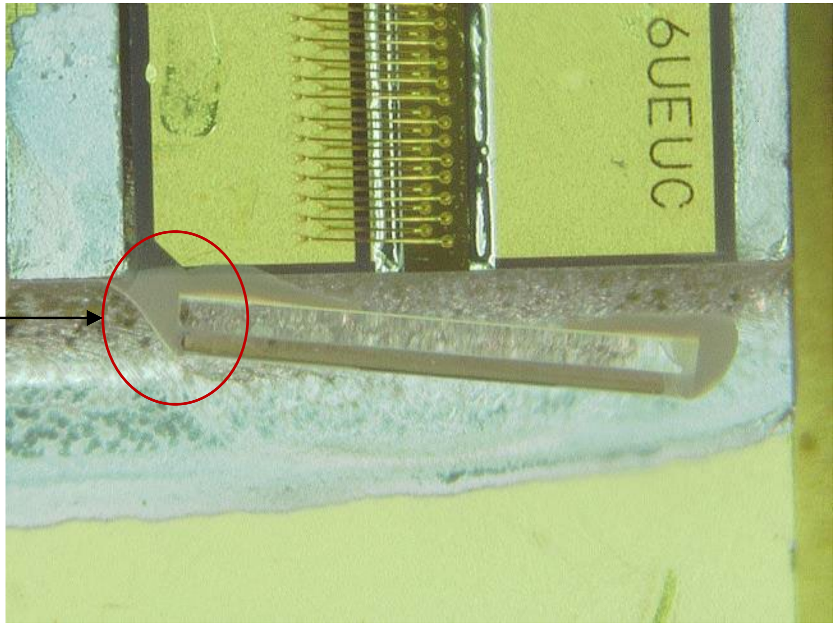
Optical Bond Issues

Images showing the small individual lenses on a 2 pin high power laser diode. The anomaly can be seen through the lens. The surface was not prepped properly which led to the adhesive not sticking to the lens or diode surface. The adhesive line was cracked, leaving the lens barely attached to the diode. The shear strength was in some cases less than 10gf (For reference a correctly attached optic here has a shear force >450gf).

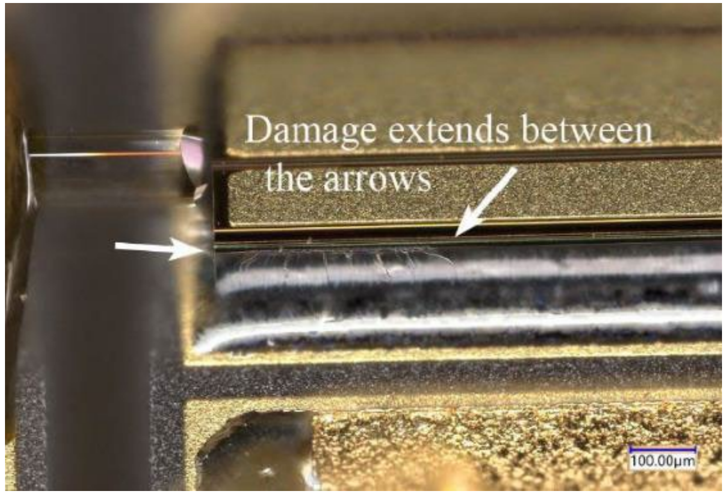


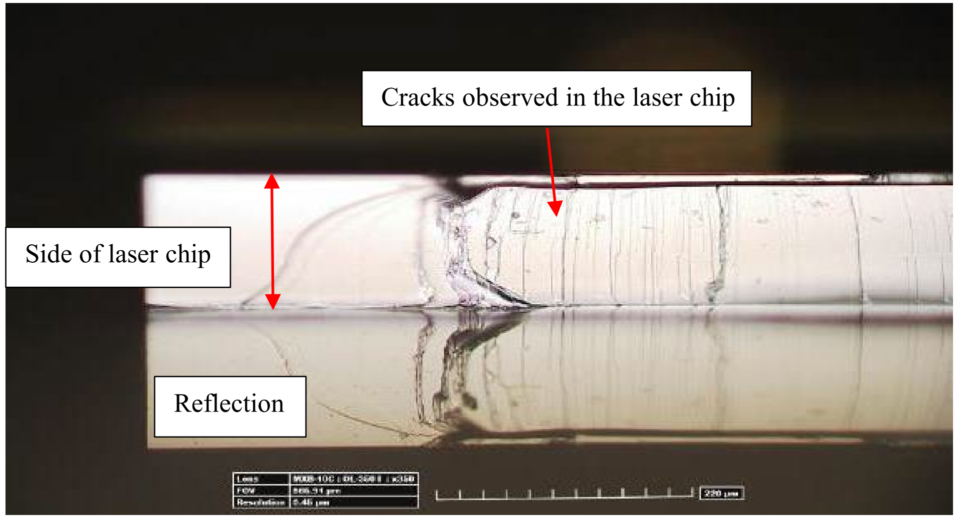


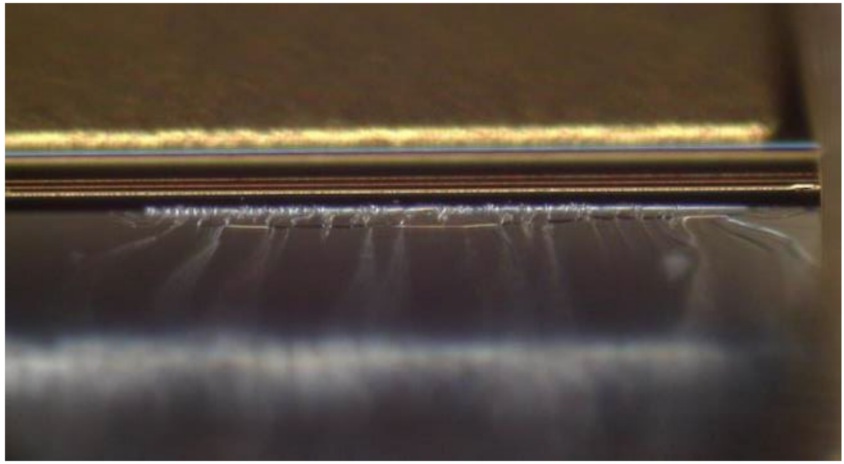
Chiplet lens epoxy failure



Laser Bar Damage



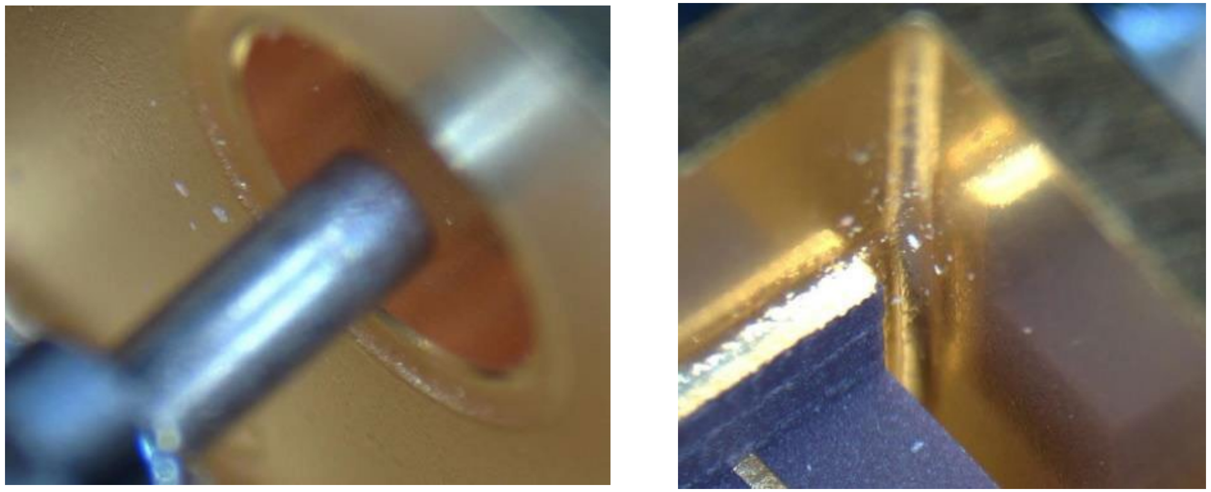




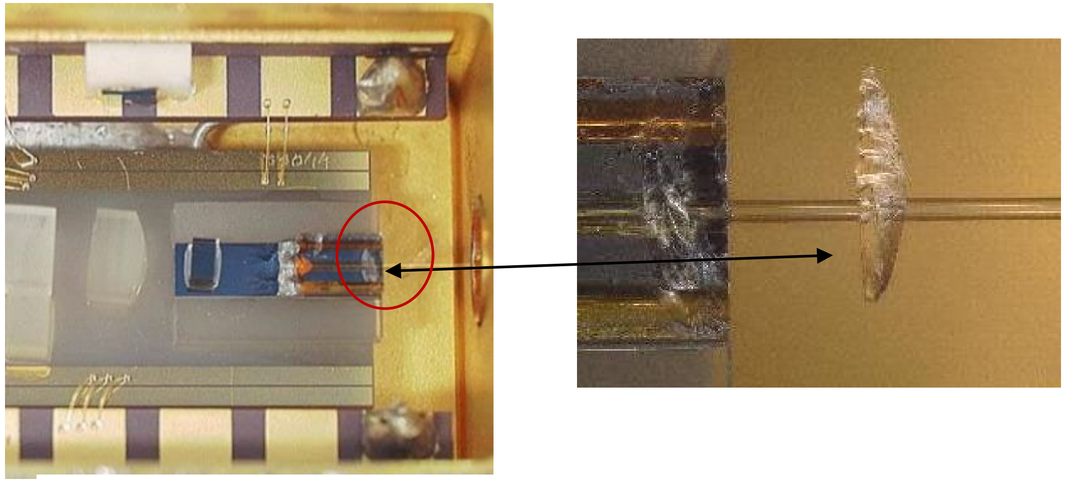
Damage to the laser bar is not acceptable in any high reliability laser diode application.

If found during pre-cap inspection, the part is immediately removed from the lot and high reliability use.
Most examples of laser bar damage shown were after laser failure.

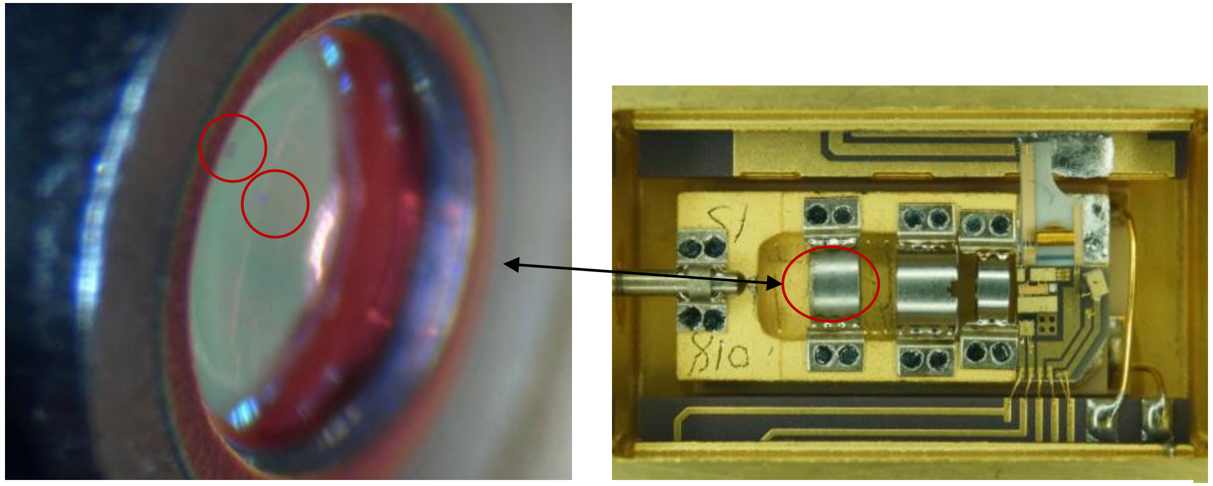
Non- Conductive Debris: Optical Concern



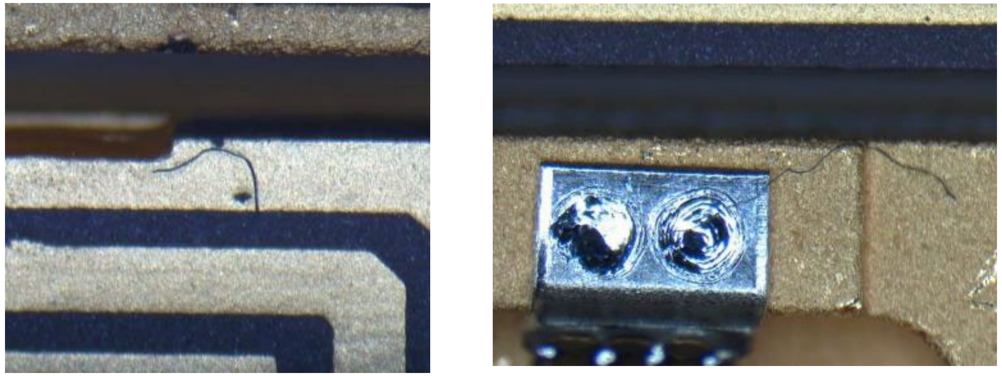
While other parts exhibited some of this white debris, this particular part had significantly larger amounts in various locations.



Piece of epoxy had chipped away and stuck to fiber.

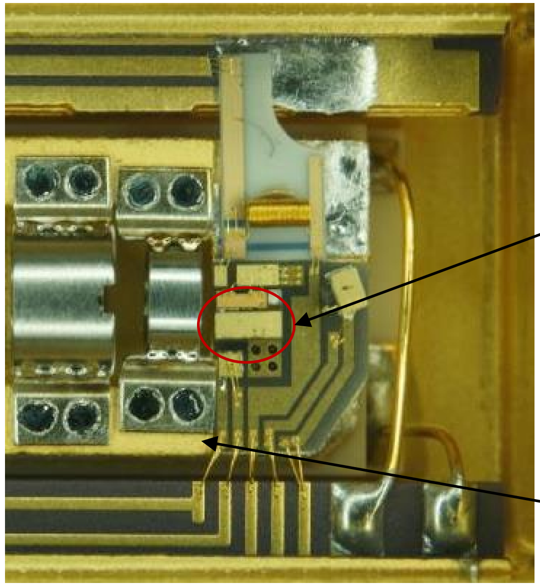


The fiber side of the focusing lens was found to have 2 small pieces of debris.

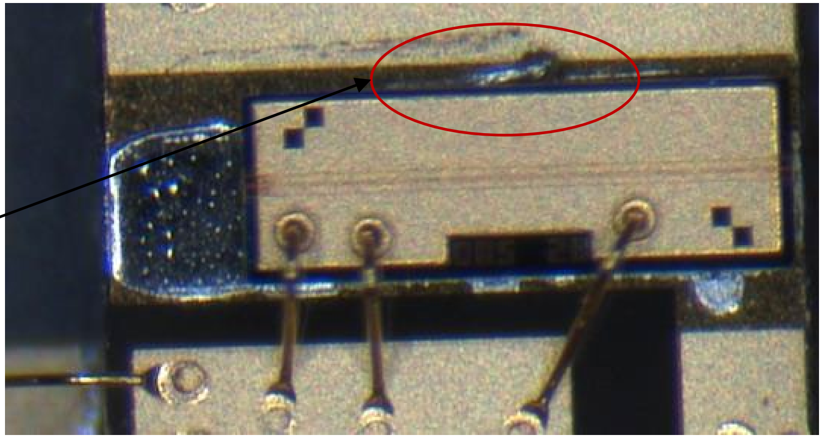


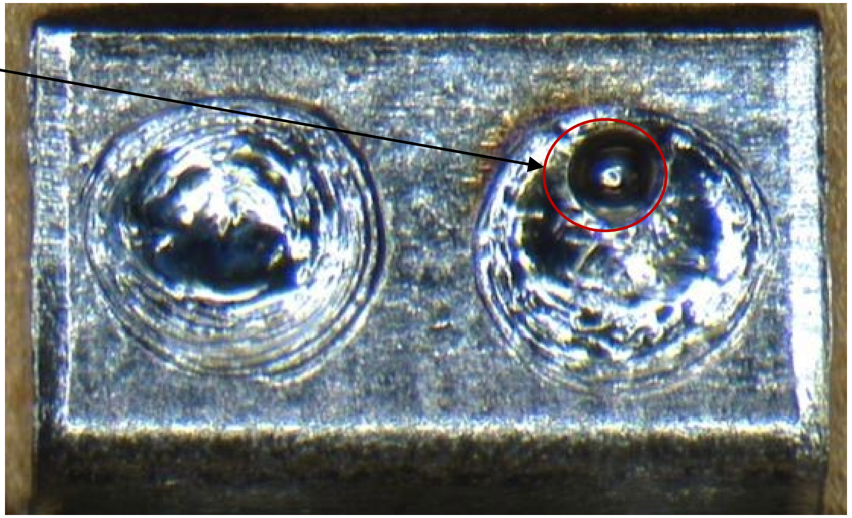
Some other examples of larger debris was observed in a handful of parts.

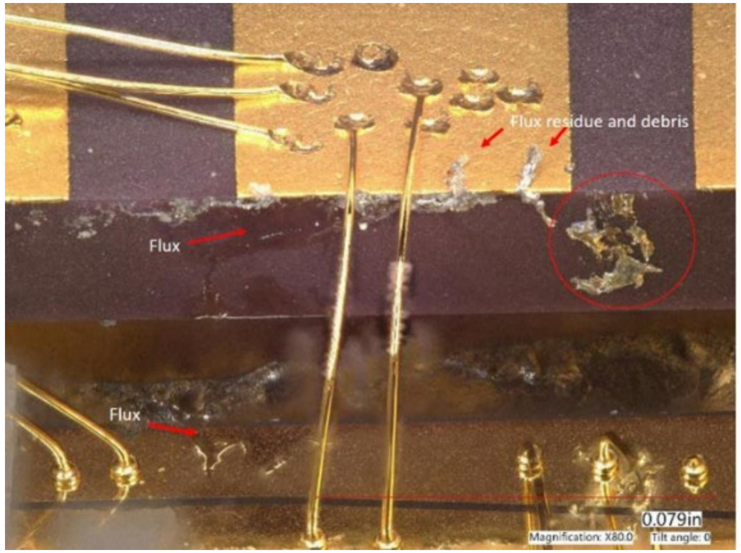
Conductive Debris: Electrical and Optical Concern

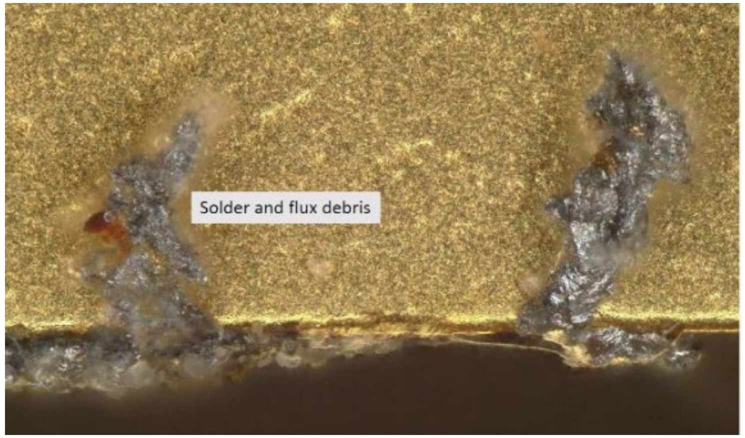


Solder balls found during precap inspection near the laser diode chip.



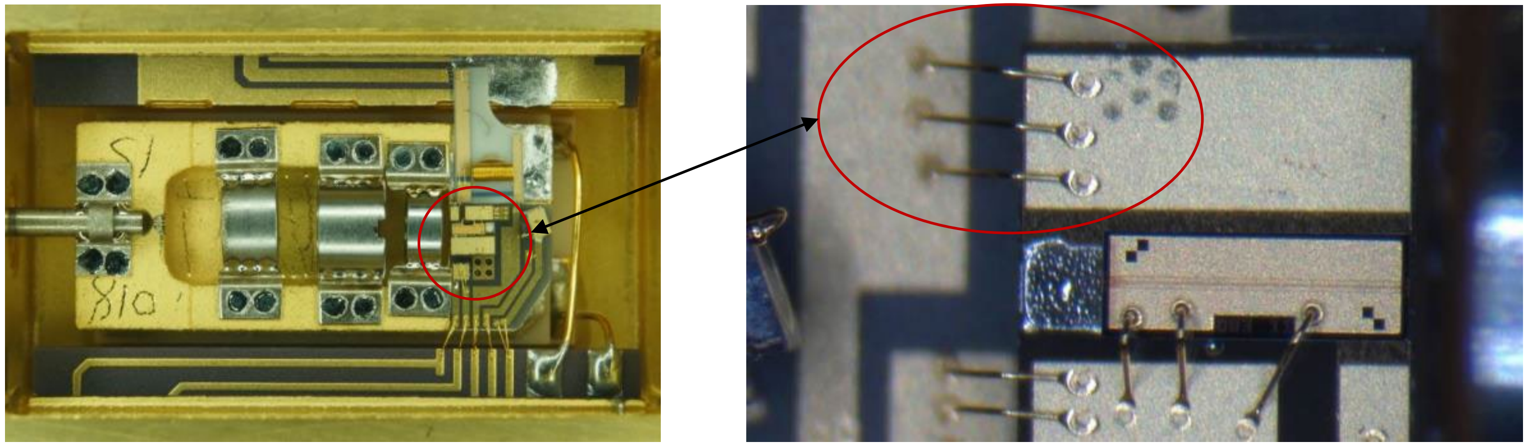




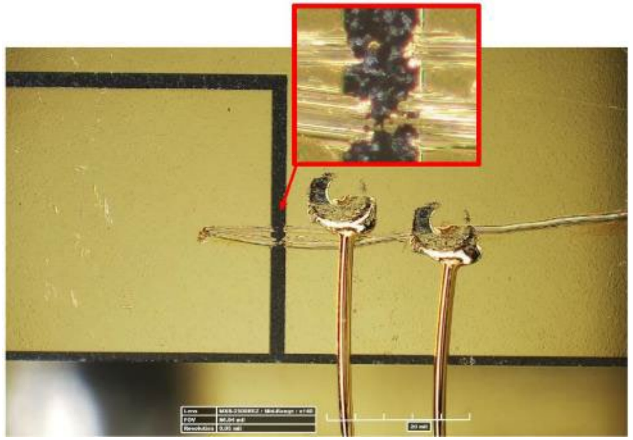


Solder and Flux Debris inside of laser diode package

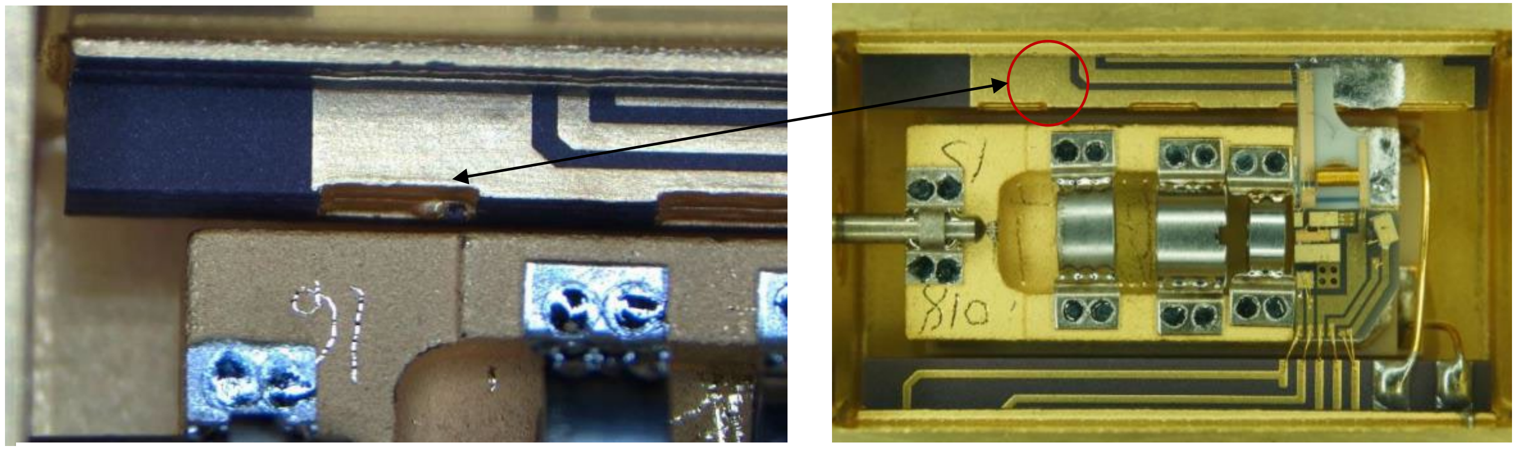
Keep Your Eyes Open during Precap Inspection: One-off Issues



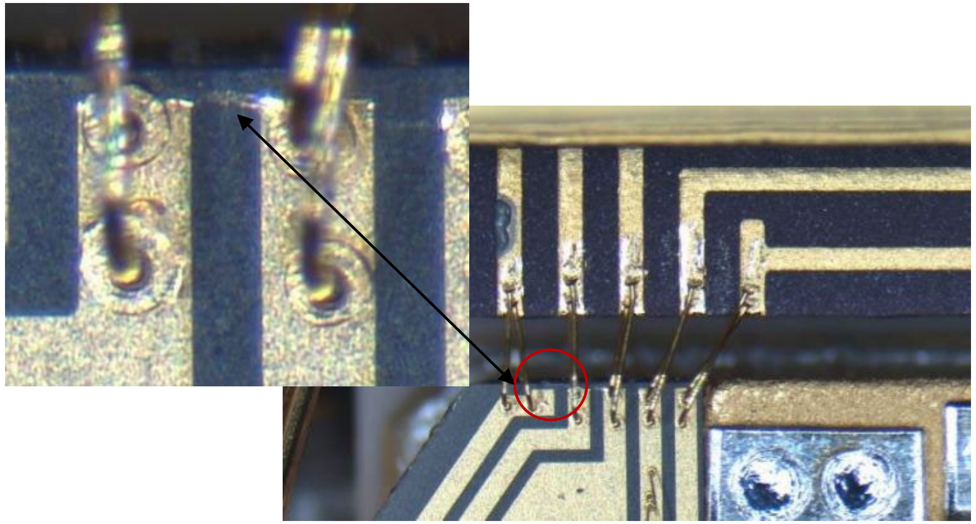
Three extra wire bonds were found on this device, which created a path to bypass the inductor.



A short almost caused by a scratch



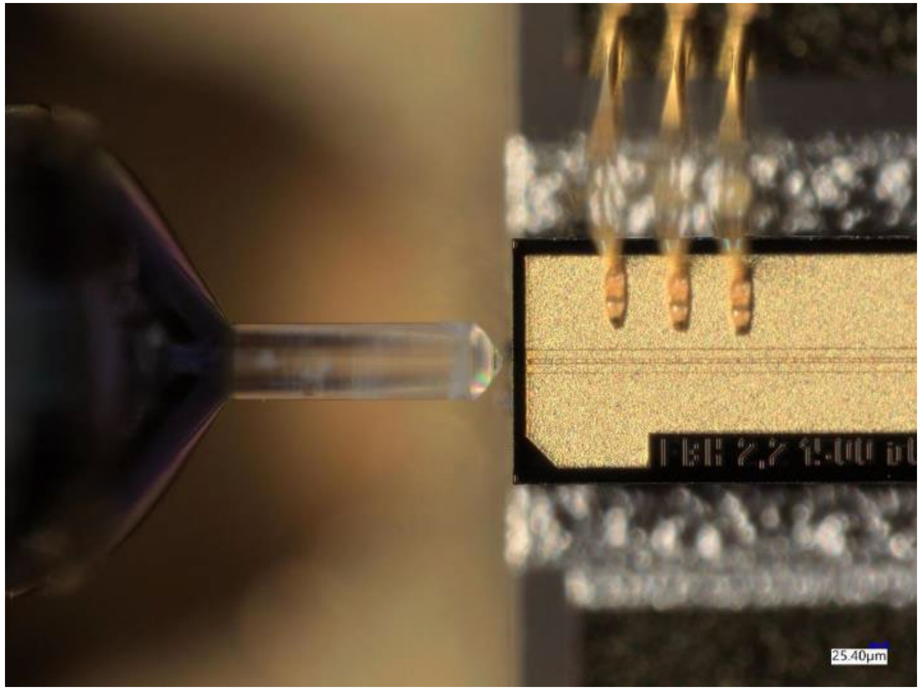
Images show a defect in the ceramic lead frame feed-through. This is a package level defect and not an assembly/workmanship defect.



Mechanical smearing of material almost forming a short between non-common circuit elements.

Acknowledgements

- We would like to acknowledge the NASA GSFC Code 562 Part Analysis Lab for their support with performing construction analysis and their expertise when diagnosing and solving many of these problems.
  - Specific recognition to Chris Greenwell and Ron Weachock who performed much of the work presented here.
- We would also like to recognize the remainder of the NASA GSFC Code 562 Photonics Group who perform screening and qualification testing on optoelectronics components on a daily basis for the past 20+ years



THANK YOU FOR YOUR TIME!

Acronyms

- COTS = Commercial Off the Shelf
- DFB = Distributed Feedback
- EEE = Electrical, Electronic, and Electromechanical
- FBG = Fiber Bragg Grating
- GaAs = Gallium Arsenide
- GSFC = Goddard Space Flight Center
- LED = Light Emitting Diode
- LIDAR = Light Detection and Ranging
- SEM = Scanning Electron Microscope
- SRS = Stimulated Ramen Scattering
- SBS = Stimulated Brillouin Scattering
- TEC = Thermoelectric Cooler