High Power Laser Diode Array Reliability Analyses

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Duane Smith, Andrew Schober, John Hobbs, Dale Bruns, Bruce Tiemann, Nathan Woody, Orion Esch, Mike McFarland, Wayne Garrett, Brian Corcoran, John Wenzel, Glenn Bennett

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work performed at

Lockheed Martin Coherent Technologies
135 South Taylor Avenue
Louisville, CO 80027-3025

duane.d.smith@lmco.com +1 (303)379-3137 (telephone), +1 (303) 604-2500 (fax)
Outline

- Test Facility
- Preliminary performance & reliability data
- Electron microscope surface images
- Auger microprobe analyses
- Observations / Conclusions
Vacuum Chamber Test Lab

- Six chambers $1 \times 10^{-8}$ torr with turbomolecular pumps, residual gas analyzers, comprehensive E/O diagnostics and computer control

Single Component Vacuum Chamber

Diode in Vacuum Chamber

Photograph of Portion of Lab
Initial Vacuum Testing

Diode Vacuum Testing - S/N: 28351

- Elapsed Time (Hours)
- Diode Output Power (Watts)
- Diode Voltage (Volts)

- Power
- Diode Voltage
- 10 per. Mov. Avg. (Diode Voltage)
- 10 per. Mov. Avg. (Power)
L-I Data Pre/Post-Test

Five one-minute etches O₂ reactive ion plasma 50W drive power had no apparent effect to restore output power lost during vacuum testing.

![Graph showing L-I curve with data points for Before Vacuum Test and After vacuum test and O2 etch.](image)
Test Article #28351, junction image 7, “clean facet area” after 100 hour test

Current and optical isolation trenches are periodically etched into the diode surface (here, the facet view).

360μm wide at emitters and 90μm spacers between emitters.

1cm long array & 450μm per emitter -> 22 emitters
Test Article #28351, junction image 8, “clean area” after

Locating the junction/emitters is as shown. In a clean area of the diode facet, the thin bar, with edges marked by the arrows, represents the laser diode waveguide.
Test Article #28351, junction image 9, “clean area” after another view, showing a few of the epitaxial layers.
Test Article #28351, junction image 10, “clean area” after

Distinct “Alligator” – shaped landmark.

Note the thin dark line on the facet near this feature – origin is uncertain, possible delamination of epitaxial layers.

Mag = 2.88 K X
Detector = SE2
EHT = 1.00 kV

10μm
Test Article #28351, junction image 11, “clean area” after

Note pits in the surface of the solder – potentially bubbles of gas/flux that had burst.
Test Article #28351, junction image 12, “clean area” after

Cursor measurement between markers reveals the narrow spacing is 87 microns.
Test Article #28351, junction image 13, “clean area” after.

Cursor measurement between markers shows the wide spacing (between which lies the emitters) of 88micron.
Test Article #28351, junction image 15, “clean area” after another lower magnification view of the emitters, spacers and isolation trenches.
Test Article #28351, junction image 18, “eruption area” after

Low magnification view of the left edge of diode bar (looking head-on) where “debris” was ejected and deposited.

Can see where the diode light “blasted” its way through deposits.

Mag=113x
Detector = SE2

EHT = 1.00 kV

100µm
Test Article #28351, junction image 19, “eruption area” after

Low-magnification view of central portion of diode facet

Similar to optical photos, patchy facet coating near the swipe on the right.

Mag=113x
Detector = SE2

EHT = 1.00 kV
Test Article #28351, junction image 1, eruption area after

- **solder**
- **facet**
- **Junction/emitter near this interface**

Note residue of melted (or partially melted) material near emitter, and associated “pile” that accumulates near the solder interface.

Material deposited from “event” resulting from heating and/or vacuum operation. **Not expected**
This area is heavily coated with “debris” – “debris” appears to be dominated by Carbon in the first 25 Angstroms. (see Auger results for detailed composition).

Note laser light (or local heating) appears to have burned out a half-moon shape in the deposited layer on the facet surface. Power was not affected by this facet contamination.
In some places, build-up appears near the facet-solder interface. Sometimes, a thin line (possibly along the emitter) appears as well. Chemical composition of this line is being investigated.
In many places, the deposits are beaded. Again, a thin dark line near the interface appears – possibly indicating a residue at the junction/emitter.

Auger analysis reveals that the beaded deposits are largely carbon, at least on the top 25 angstroms.

Source of carbon is unclear, despite bake-out and cleaning prior to test.
Near the center of the facet, a large swipe that is coincident with the ejection of “debris” on the die block – is visible to the unaided eye.

Note the facet, appears wet and mopped – origin uncertain.
Test Article #28351, Auger analysis
after vacuum test, before O₂ plasma etch

Map of surface spanning “clean” and “dirty” sections of the sample indicate “dirt” contains increased amounts of carbon and oxygen, and decreased amounts of indium and aluminum (as compared to “clean” area).

Lighter shade = higher concentration
Test Article #28351, Auger analysis
after vacuum test, before O$_2$ plasma etch

Analysis of two areas (area 2: near junction and area 1: away from junction) indicate similar chemical signatures.

Area 2 has notably larger peaks for S, Cl, and In.
Test Article #28351, Auger analysis after vacuum test, before $O_2$ plasma etch

Analysis of “clean” area:

Carbon: 43%
Aluminum: 28.1%
Oxygen: 26%
Indium: 2.7%
Chlorine: 0.2%
Test Article #28351, Auger analysis
after vacuum test, before O$_2$ plasma etch

Analysis of “dirty” area:
Carbon: 75.5%
Oxygen: 21.4%
Silicon: 1.9%
Indium: 1.2%

Note absence of Al compared to “clean area”
residue is not gone after 50W RF/5 minute O$_2$ etch that nominally removes 1$\mu$m of non-refractory deposits, but appearance has changed and is cleaner
Test Article #28351, Auger analysis after $O_2$ plasma etch

Analysis of “dirty” area:

- Oxygen: 34.8%
- Aluminum: 24.9%
- Potassium: 14.1%
- Sodium: 12.8%
- Calcium: 6.4%
- Carbon: 3.5%
- Indium: 3.4%

Carbon content went from 75% to 3.5% after $O_2$ plasma etch
Test Article #28351, Auger analysis after O$_2$ plasma etch

Analysis of “clean” area:
- Oxygen: 36.8%
- Aluminum: 36.4%
- Carbon: 14.7%
- Calcium: 10.7%
- Indium: 1.3%

Carbon content went from 45% to 14.7% after O$_2$ plasma etch
Summary – Preliminary Results

- Carbon everywhere after vacuum test
  - 75 atomic% on “eruption” areas with obvious visible contamination
  - 45 atomic% on “clean” areas with no obvious visible contamination
  - Aluminum, oxygen, and indium are also present on output facet
- Carbon content can be reduced with O\textsubscript{2} etch (50 W RF power, 1 min x 5 cycles)
  - 3.5 at. % on “dirty” areas
  - 14.7 at. % on “clean” areas
  - Potassium, sodium, calcium also appear after O\textsubscript{2} etch; especially in “dirty” areas – source uncertain
  - Laser diode power was not recovered
- Carbon source(s) are being identified and characterized with further tests
- Caveat - this sample has been subject to invasive SEM inspection on multiple occasions; with observed ejection of material – results may not be typical, more work required to reproduce observed data and trends