High Power Laser Diode Array Reliability Analyses

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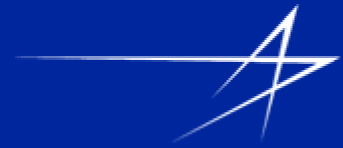
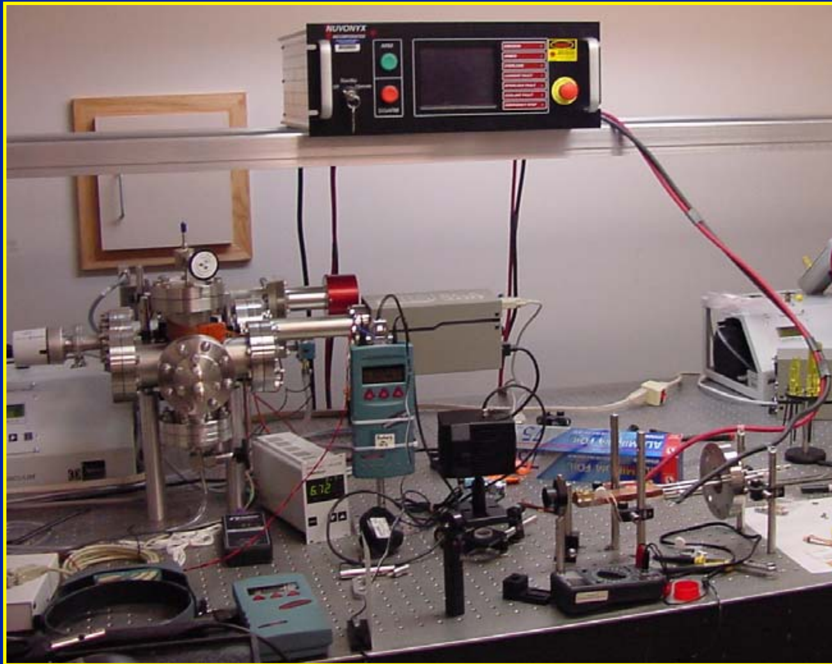


Outline

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

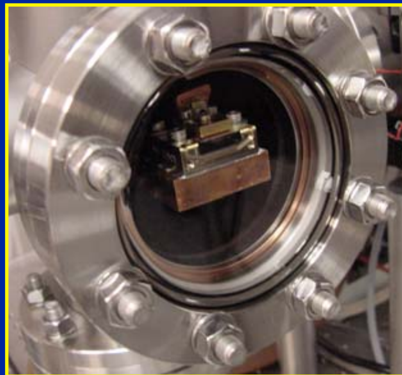
Vacuum Chamber Test Lab

- Six chambers $1x10^{-8}$ torr with turbomolecular pumps, residual gas analyzers, comprehensive E/O diagnostics and computer control



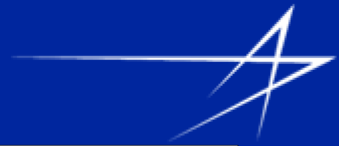
Single Component Vacuum Chamber

Photograph of Portion of Lab



Diode in Vacuum Chamber

Initial Vacuum Testing



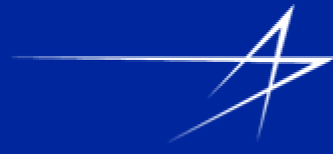
Diode Vacuum Testing - S/N: 28351

Diode Output Power (Watts): 0, 5, 10, 15, 20, 25, 30, 35, 40, 45

Diode Voltage (Volts): -2.00, -1.95, -1.90, -1.85, -1.80, -1.75, -1.70

Elasped Time (Hours): 0, 20, 40, 60, 80, 100

- power
- Diode Voltage
- 10 per. Mov. Avg. (Diode Voltage)
- 10 per. Mov. Avg. (power)



L-I Data Pre/Post-Test

Five one-minute etches O_2 reactive ion plasma 50W drive power had no apparent effect to restore output power lost during vacuum testing

AIR LI Curve, SN 28351

Before Vacuum Test

After vacuum test and O2 etch

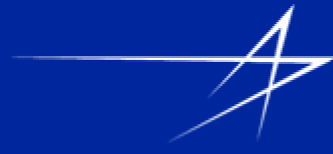
Optical Output Power (Watts)

0 5 10 15 20 25 30 35 40 45 50

0 10 20 30 40 50 60

Diode Current (Amps)

Test Article #28351, junction image 7, “clean facet area” after 100 hour test



Mag = 2.00 K X
Detector = SE2
EHT = 1.50 kV
10µm

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

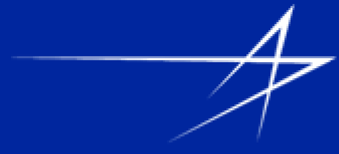
360µm wide at emitters and 90µm spacers between emitters.

1cm long array & 450µm per emitter -> 22 emitters

Test Article #28351, junction image 8, “clean area” after

Mag = 5.72 K X
Detector = SE2
EHT = 1.00 kV
2µm

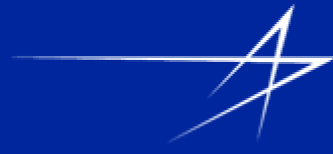
Locating the junction/emitters is as shown. In a clean area of the diode facet, the thin bar, with edges marked by the arrows, represents the laser diode waveguide.



Test Article #28351, junction image 9, "clean area" after

Mag = 12.08 K X
Detector = SE2
EHT = 1.00 kV
1µm

Another view, showing a few of the epitaxial layers

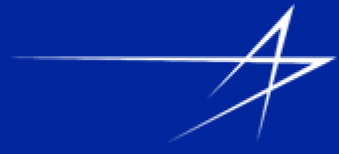


Test Article #28351, junction image 10, “clean area” after

Mag = 2.88 K X
Detector = SE2
EHT = 1.00 kV
10µm

Distinct “Alligator” – shaped landmark.

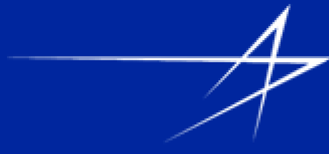
Note the thin dark line on the facet near this feature – origin is uncertain, possible delamination of epitaxial layers



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

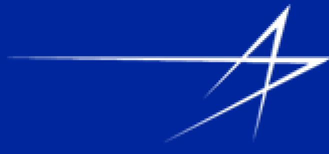
Mag = 2.57 K X
Detector = SE2
EHT = 1.00 kV
10µm

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

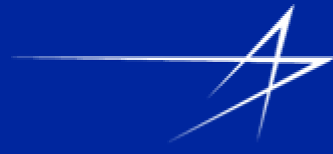
Cursor measurement between markers reveals the narrow spacing is 87 microns.



Test Article #28351, junction image 13, “clean area” after

Pa 1 = 88.23 µm
Pb 1 = 358.9 °
Pa 1
Pa R1
Mag = 2.08 K X
Detector = SE2
EHT = 1.00 kV
10µm

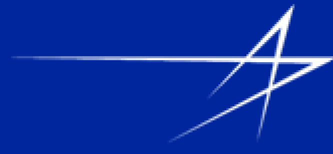
Cursor measurement between markers shows the wide spacing (between which lies the emitters) of 88micron.



Test Article #28351, junction image 15, “clean area” after

Pa 1 = 313.4 µm
Pb 1 = 358.5 °
Pa 1
Pa R1
Mag = 507 X
Detector = SE2
EHT = 1.00 kV
20µm

Another lower magnification view of the emitters, spacers and isolation trenches



Test Article #28351, junction image 18, "eruption area" after

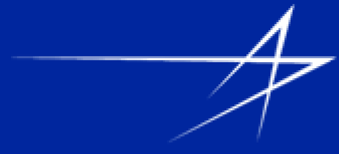
Mag=113x
Detector = SE2

EHT = 1.00 kV

100µm

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.



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

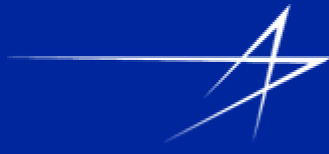
Mag=113x
Detector = SE2

EHT = 1.00 kV

100µm

Low-magnification view of central portion of diode facet

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



Test Article #28351, junction image 1, eruption area after

solder

Junction/emitter near this interface

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

facet

Material deposited from “event” resulting from heating and/or vacuum operation
Not expected

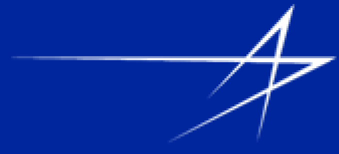
Mag = 2.55 K X
Detector = SE2
EHT = 2.00 kV
10µm

Test Article #28351, junction image 2, eruption area after

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.

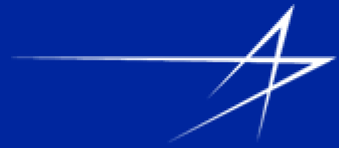
Test Article #28351, junction image 3, eruption area after



Mag = 8.83 K X
Detector = SE2
EHT = 1.50 kV
1µm

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.



Test Article #28351, junction image 4, eruption area after

Mag = 4.73 K X
Detector = SE2
EHT = 1.50 kV
2µm

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.

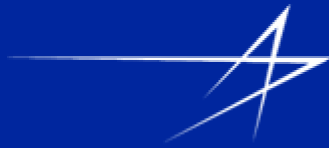
Source of carbon is unclear, despite bake-out and cleaning prior to test

Test Article #28351, junction image 5, eruption area after

Mag = 643 X
Detector = SE2
EHT = 1.50 kV
20µm

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 O_2 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).

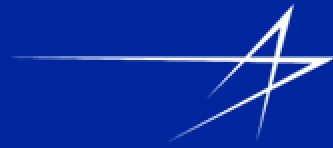
Lighter shade = higher concentration

ct.109.map: 28351 center swipe, "crater" area
2006 May 18 5.0 keV 0 FRR
Al2
Lockheed Martin
32.77 min

SEM 111.0 14.0 2 µm 2 µm
O1 52.4 0.0 2 µm 2 µm
C1 124.8 10.9 2 µm 2 µm
Cl1 21.1 0.0 2 µm 2 µm
In1 29.9 0.0 2 µm 2 µm
Al2 36.3 0.0 2 µm 2 µm

Test Article #28351, Auger analysis

after vacuum test, before O_2 plasma etch



ct.101.spe: 28351 facet(1); junction(2) Lockheed Martin
2006 May 18 5.0 keV 0 FRR 1.1165e+004 max 12.01 min
Sur1/Area1/1 (S9D5)

ct.101.spe

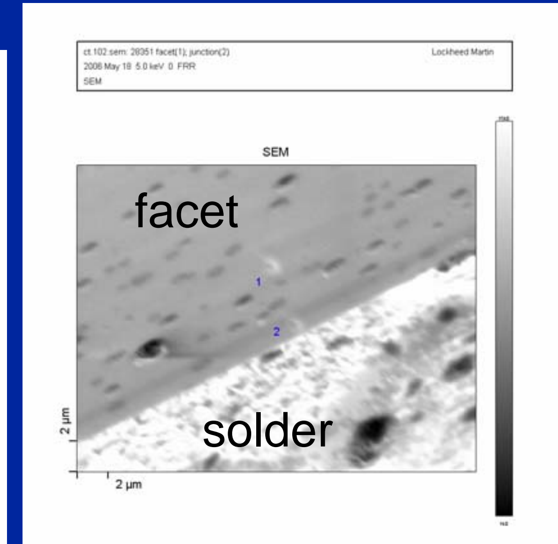
x 10^4

c/s: 3.5, 3, 2.5, 2, 1.5, 1, 0.5, 0, -0.5, -1

Area 1: C, In, O, Al

Area 2: S Cl, C, In, O, Al

Kinetic Energy (eV): 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000

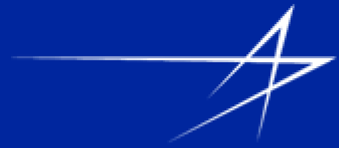


Analysis of two areas (area 2: near junction and area 1: away from junction) indicate similar chemical signatures.

Area 2 has notably larger peaks for S, Cl, and In.

Test Article #28351, Auger analysis

after vacuum test, before O_2 plasma etch



ct.106.spe: 28351 center swipe, smooth area
2006 May 18 5.0 keV 0 FRR
Sur1/Area1/1 (S9D5)

7.5960e+003 max

Lockheed Martin
15.34 min

ct.106.spe

Atomic %	
C1	43.0
Al2	28.1
O1	26.0
In1	2.7
Cl1	0.2

Al
Cl
C
In
O
Al

c/s: 8000, 6000, 4000, 2000, 0, -2000, -4000, -6000, -8000, -10000

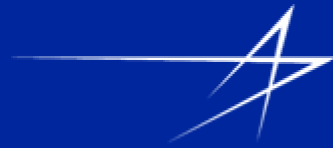
Kinetic Energy (eV): 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000

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



ct.107.spe: 28351 center swipe, "crater" area
2006 May 18 5.0 keV 0 FRR
Sur1/Area1/1 (S9D5)
4.5259e+003 max
Lockheed Martin
12.67 min

ct.107.spe

Atomic %	
C1	75.5
O1	21.4
Si2	1.9
In1	1.2

c/s: 5000, 0, -5000, -10000
Si, In, O, C
Kinetic Energy (eV): 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000

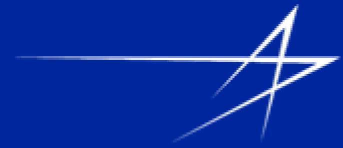
Analysis of "dirty" area:

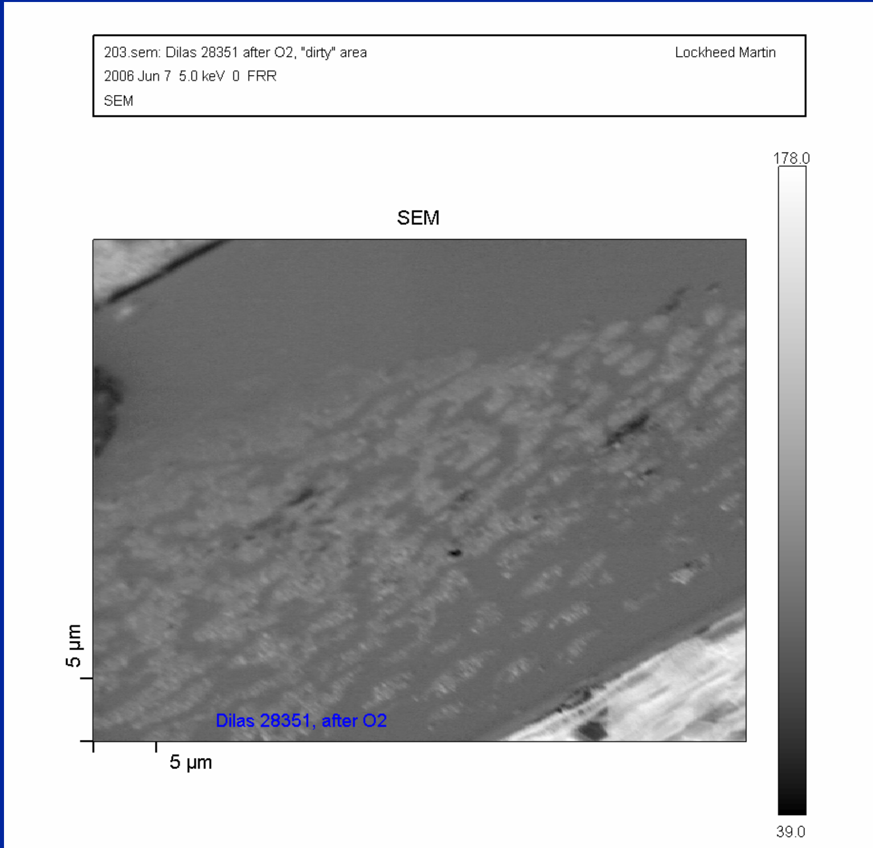
Carbon: 75.5%
Oxygen: 21.4%
Silicon: 1.9%
Indium: 1.2%

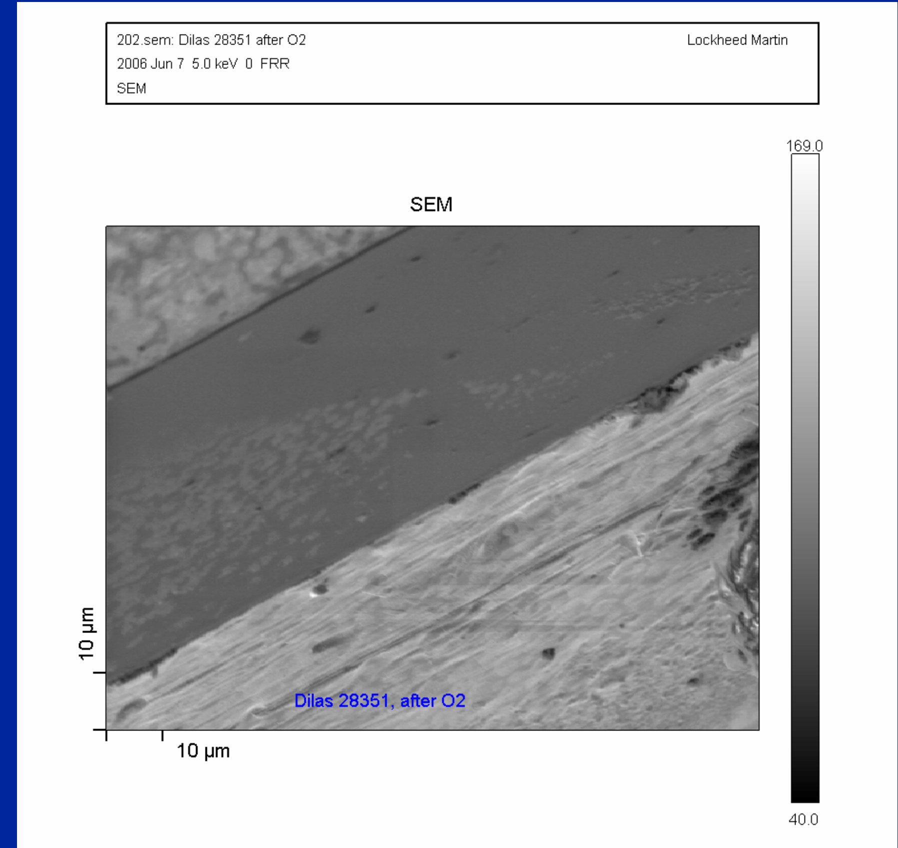
Note absence of Al compared to "clean area"

Test Article #28351, SEM

after O_2 plasma etch



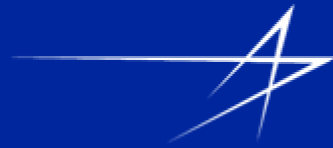




residue is not gone after 50W RF/5 minute O_2 etch that nominally removes 1μm of non-refractory deposits, but appearance has changed and is cleaner

Test Article #28351, Auger analysis

after O_2 plasma etch



204.spe: Dilas 28351 after O2, "dirty" area
2006 Jun 7 5.0 keV 0 FRR
Sur1/Area1/1 (S9D5)
1.0975e+004 max
Lockheed Martin
28.01 min

204.spe

x 10^4

c/s

Kinetic Energy (eV)

Al, K, C, Ca, In, O, F, Na, Al

Atomic %	
O1	34.8
Al2	24.9
K1	14.1
Na1	12.8
Ca1	6.4
C1	3.5
In1	3.4

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

205.spe: Dilas 28351 after O2, "clean" area
2006 Jun 7 5.0 keV 0 FRR
Sur1/Area1/1 (S9D5)
1.5484e+004 max
Lockheed Martin
18.67 min

205.spe

Atomic %	
O1	36.8
Al2	36.4
C1	14.7
Ca1	10.7
In1	1.3

c/s (x 10^4): 2, 1.5, 1, 0.5, 0, -0.5, -1, -1.5, -2

Kinetic Energy (eV): 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000

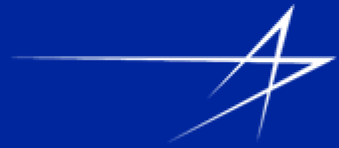
Peaks: Al, C, Ca, In, O, Al

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_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_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