Whiskers of Tin-Lead (Sn-Pb) on REFLOWED Die Attach Solder Used in the Manufacture of a Laser Diode Array

20 microns

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Images/Failure Analysis Provided by
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Compiled by
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Intent

- Intent of this presentation is to depict a mechanism for creating damaging electrical shunts on laser diodes:

Failure Mechanism =

Metal Whisker Formation from Die Attach Solder

- Key Observations:
  - Metal Whisker Formation from **Sn-Pb Eutectic Solder** (Sn63Pb37)
  - Whiskers Formed on Die Attach Solder that had been **Reflowed**
  - Whisker **LENGTHS as Small as 5 microns** sufficient to create shunt

Background

In 2003 an evaluation of GaAs Laser Diode Arrays at NASA Goddard Space Flight Center revealed "Metal Whisker Formation"emanating from the Reflowed Eutectic Tin-Lead Solder die attach material (Sn63Pb37).

Evidence of electrical shunts created by these whiskers is documented herein.

Salient Factors

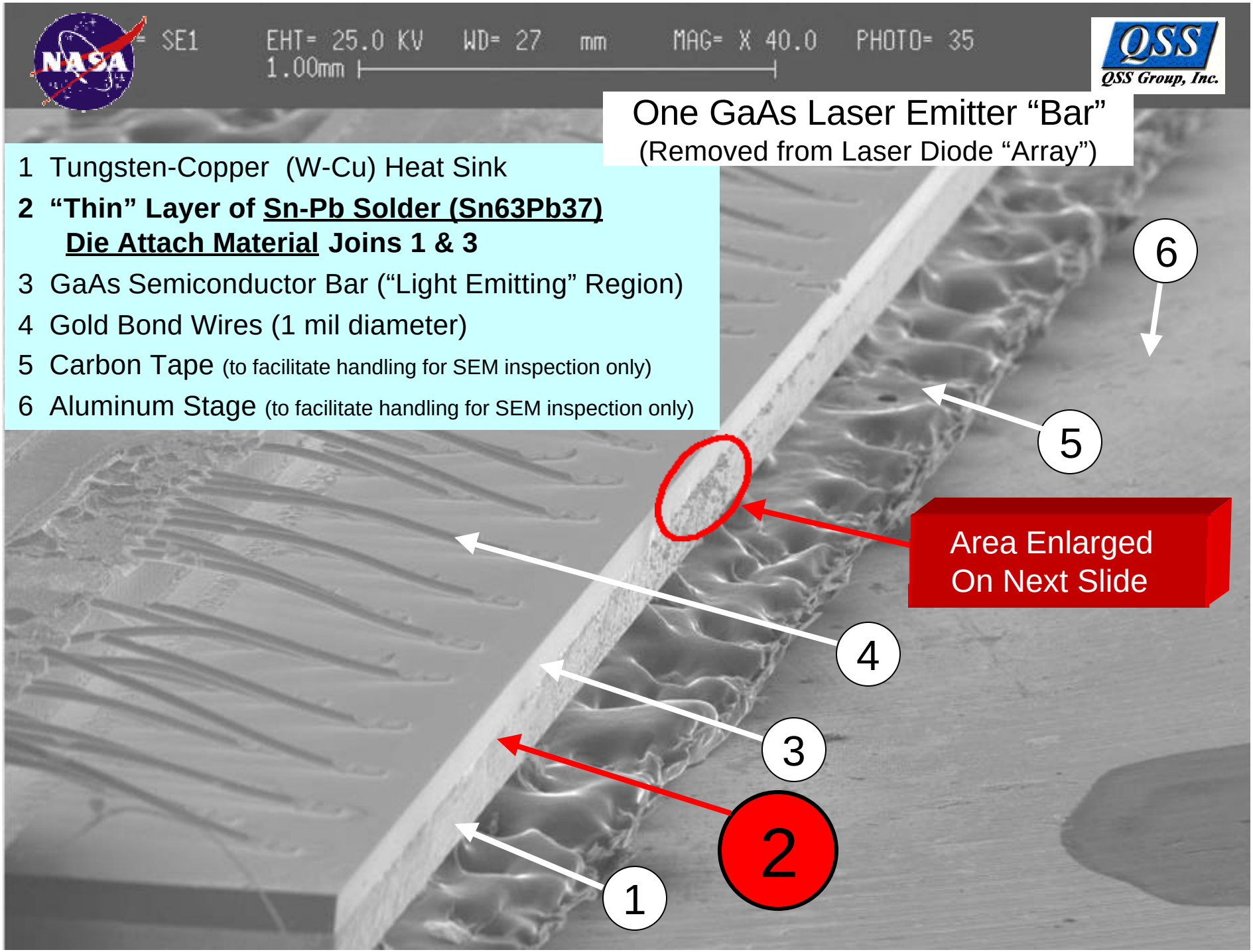
Die Attach Material:	**Eutectic Tin-Lead (Sn63Pb37) Solder**
Whisker Lengths Observed:	**25-30 microns max.**
Shunting Distance:	**2.5 - 3.0 microns (Heat Sink to Laser Diode)**

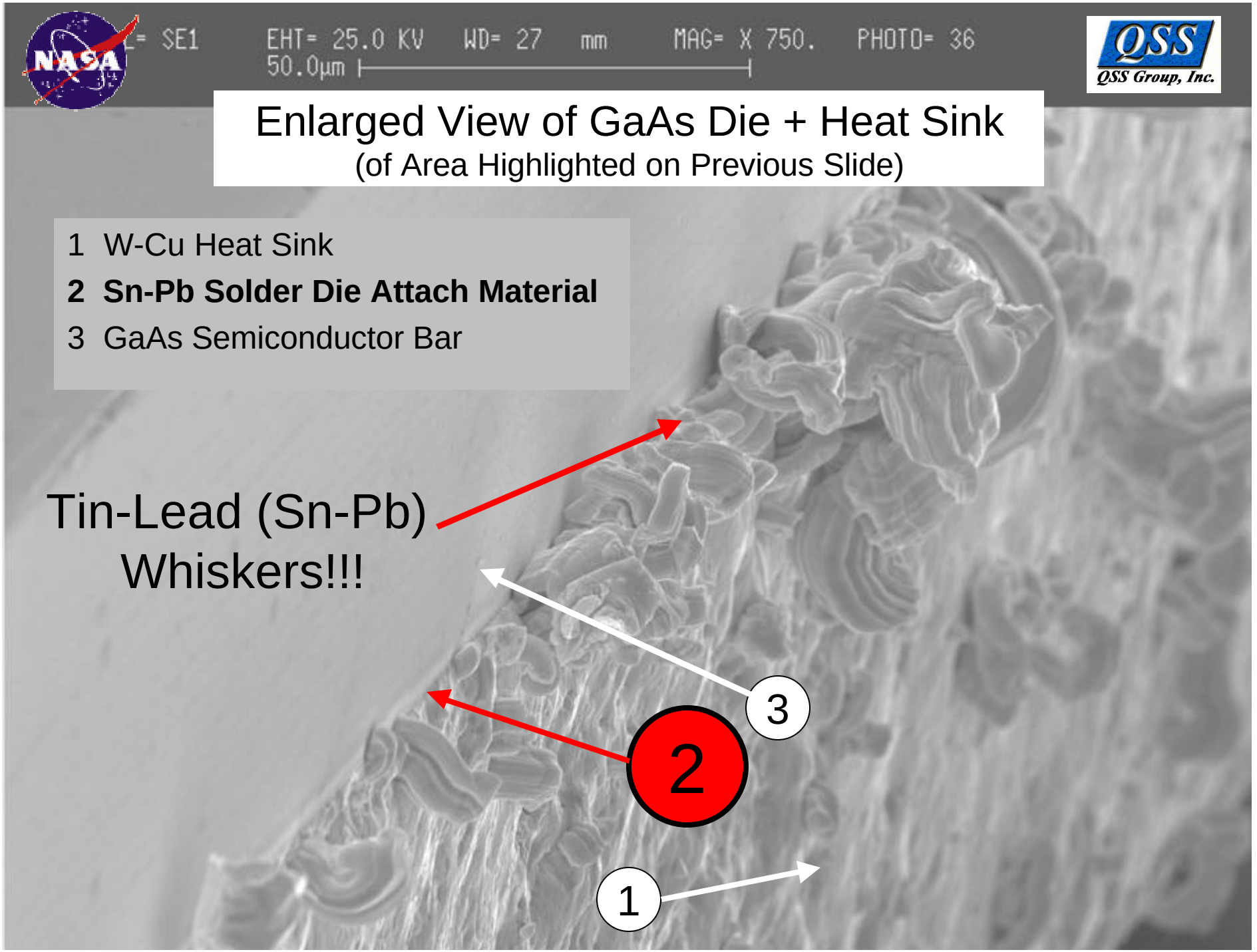
Operational Factors:

Normal frequency of pulsing:	**10-40 Hz (up to 500 Hz during accelerated test)**
Diode Junction Temp Rise:	**up to 40°C during a single pulse (normal ops.)**
Solder Temp Rise:	**less than junction temp rise (not calculated)**

**General Construction of Laser Diode Array (Mostly Disassembled)

**Shown is a Mostly Disassembled “G9” Unit with 3 Laser Emitter Bars Still Intact (6 Removed)
Similarly Constructed Devices Have Been Made with 2, 7, 11 or 16 Bars


SE1
EHT= 25.0 KV
WD= 27 mm
MAG= X 40.0
PHOTO= 35
1.00mm
QSS Group, Inc.
One GaAs Laser Emitter "Bar"
(Removed from Laser Diode "Array")
1 Tungsten-Copper (W-Cu) Heat Sink
2 "Thin" Layer of Sn-Pb Solder (Sn63Pb37) Die Attach Material Joins 1 & 3
3 GaAs Semiconductor Bar ("Light Emitting" Region)
4 Gold Bond Wires (1 mil diameter)
5 Carbon Tape (to facilitate handling for SEM inspection only)
6 Aluminum Stage (to facilitate handling for SEM inspection only)
6
5
Area Enlarged On Next Slide
4
3
2
1



Enlarged View of GaAs Die + Heat Sink

(of Area Highlighted on Previous Slide)

1 W-Cu Heat Sink

2 Sn-Pb Solder Die Attach Material

3 GaAs Semiconductor Bar

Tin-Lead (Sn-Pb) Whiskers!!!

Tin - Lead (Sn/Pb) Whisker

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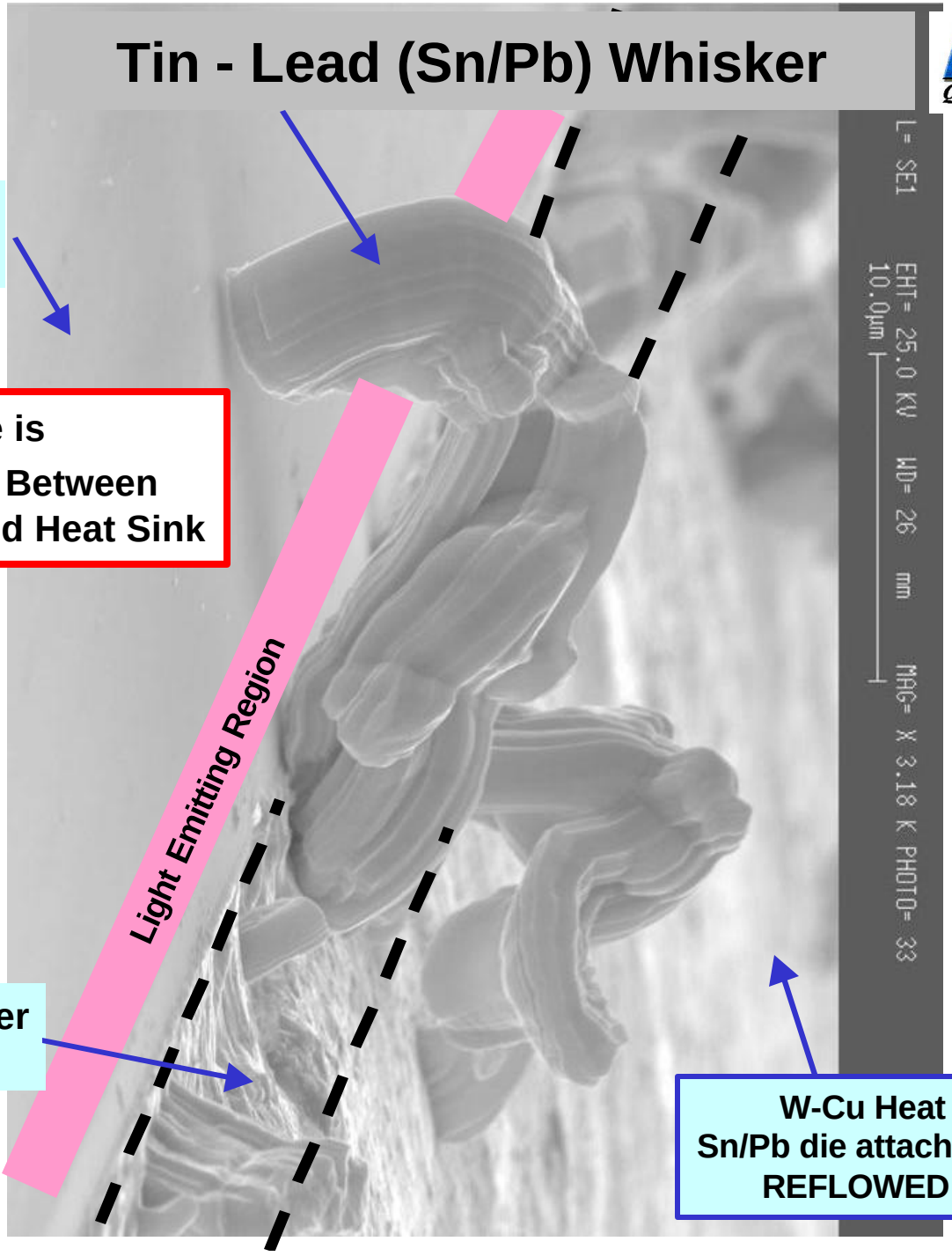


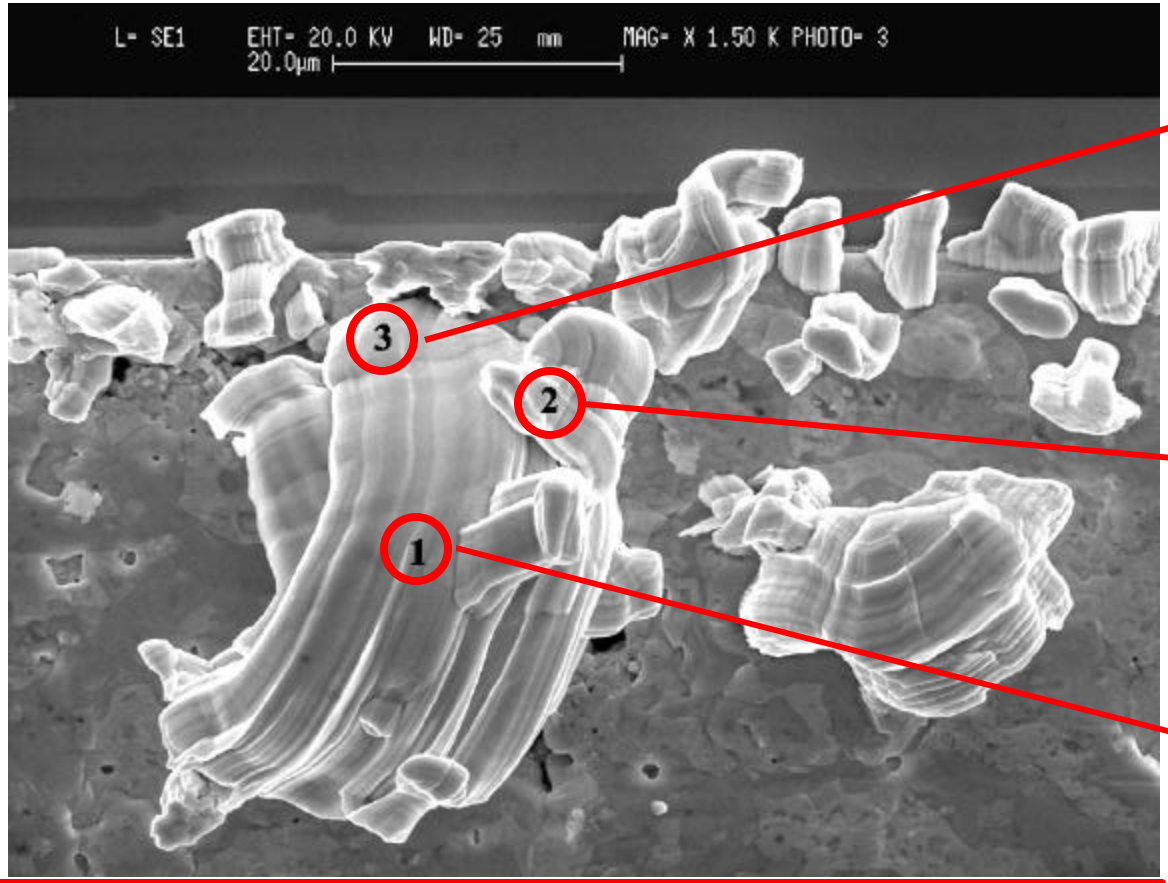
Gallium Arsenide Substrate

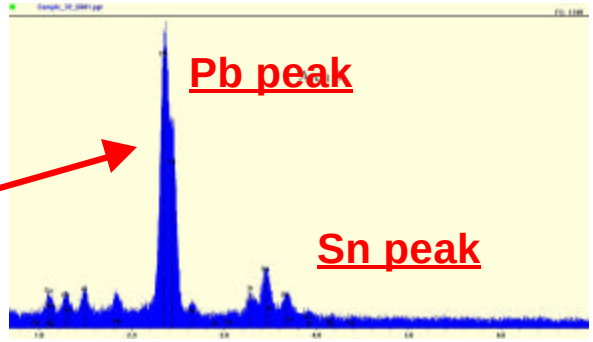
Note: Shunting Distance is <u>only 2.5 - 3 microns</u> Between Light Emitting Region and Heat Sink

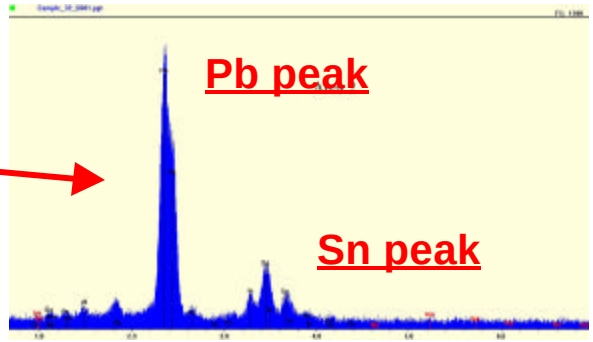
Eutectic Sn-Pb Solder Die Attach Region

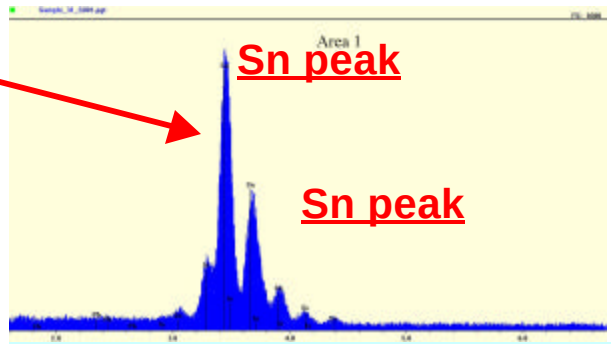
W-Cu Heat Sink. Sn/Pb die attach solder has REFLOWED on top

Analysis Confirms These ARE ***Sn-Pb Whiskers***









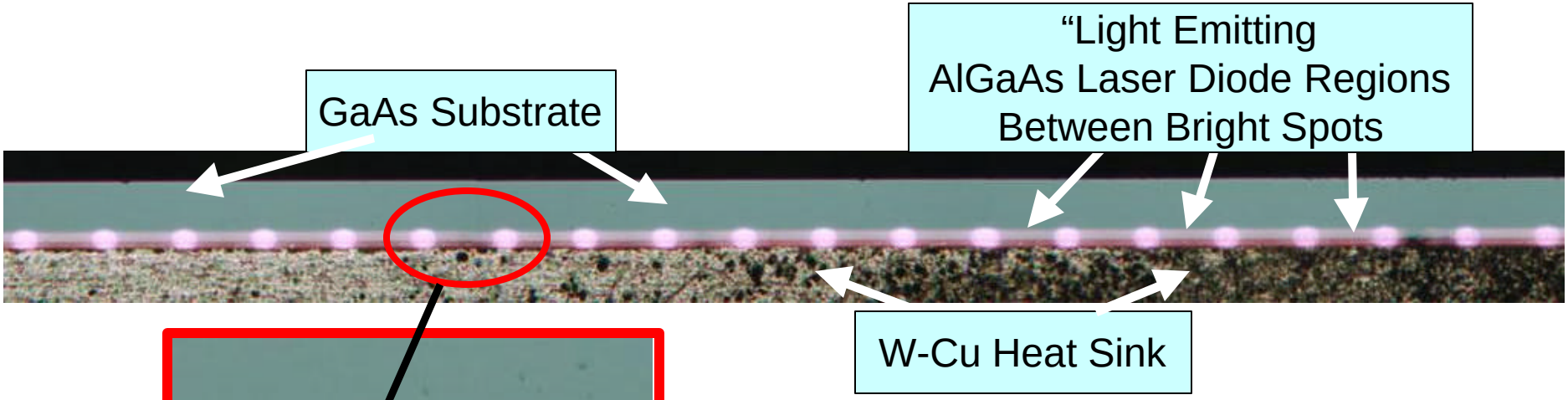
SEM/EDS Analysis Results

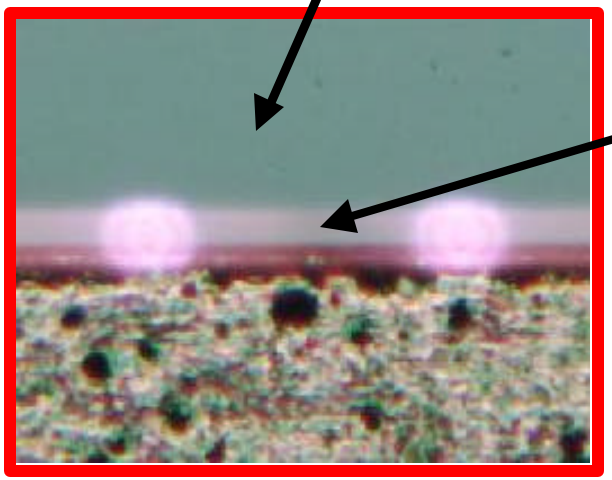
Reflowed Eutectic Sn-Pb Solder Die Attach Material is ONLY Possible Source of Sn and Pb Here

One GaAs Laser Bar "Operating" at Low Current Levels

~ 1 Amp is Being Passed Through Laser Bar to Locate the Position of the Recombination Regions Around the Semiconductor Junctions.

NOTE: the Proximity of the Active Region to the Heat Sink



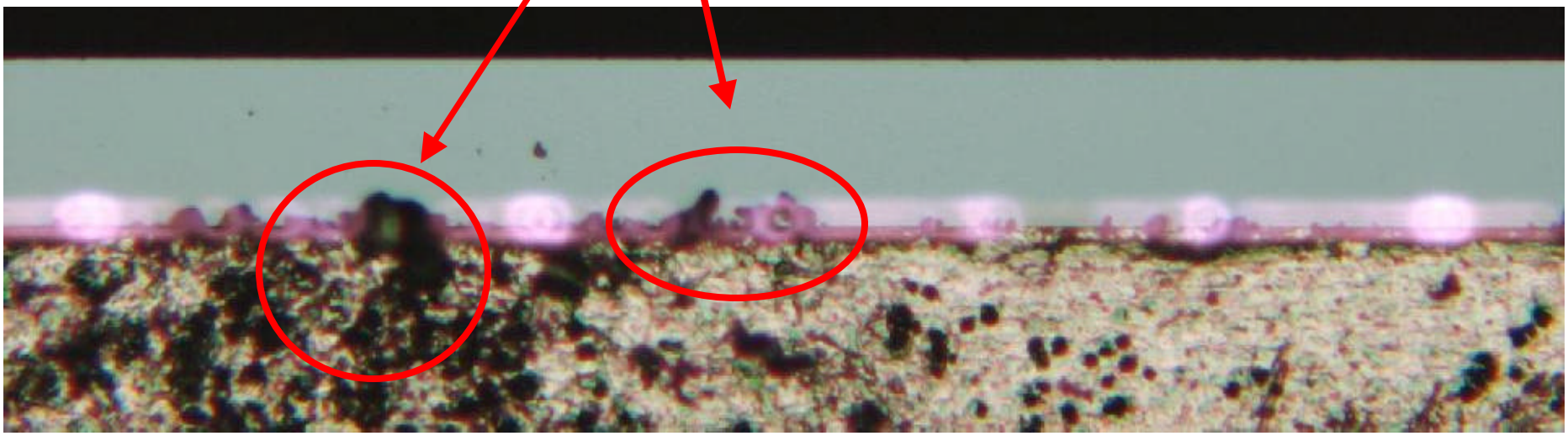


Each GaAs Laser Bar has up to 79 Laser Diodes

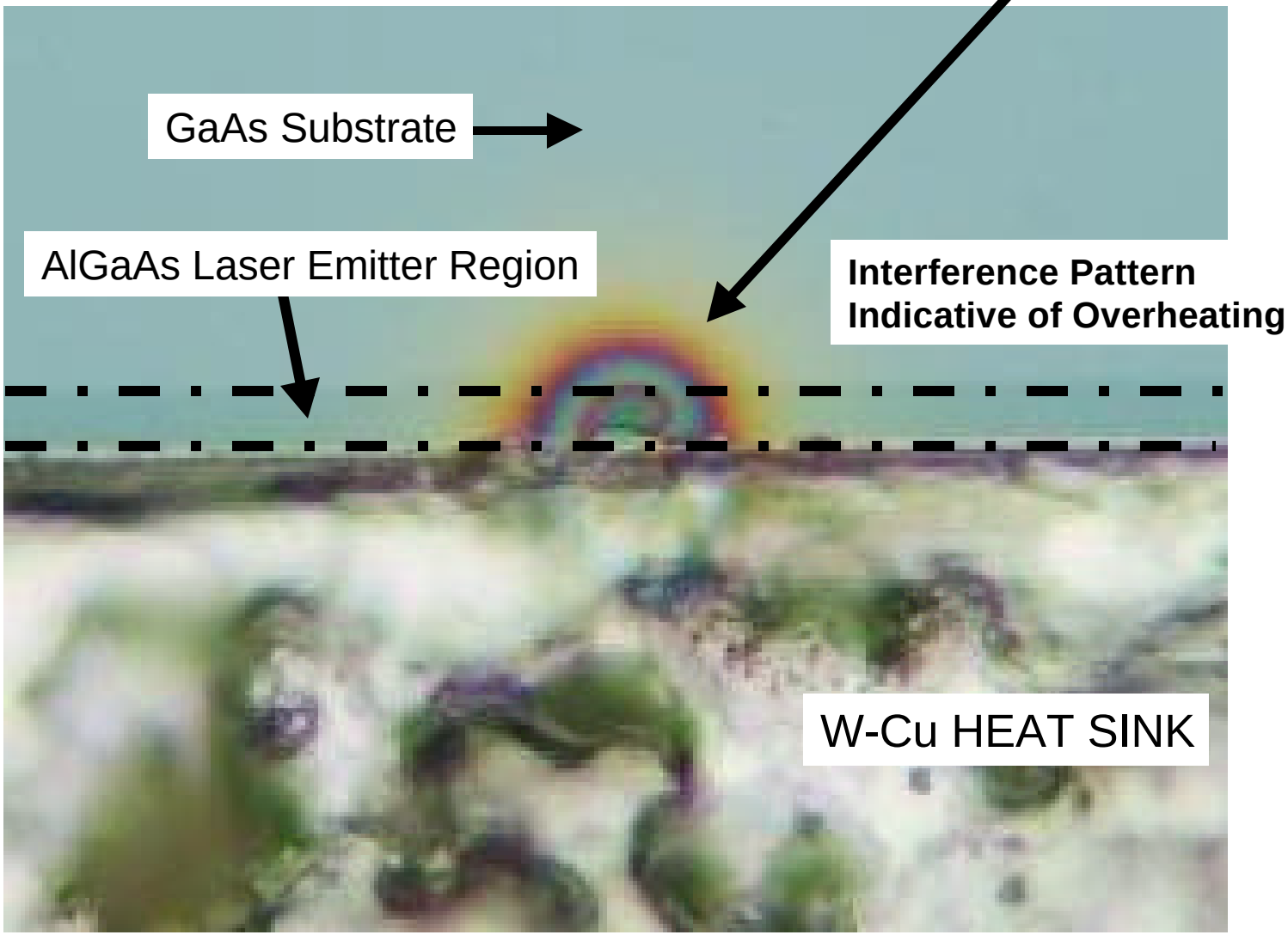
FYI: When Operated at Higher Current Levels above the Lasing Threshold, the Region BETWEEN the bright spots will Lase perpendicular to the die while the bright spots shown here (under low current operation) will become darker.

What Harm Could the Sn-Pb Whiskers Do?

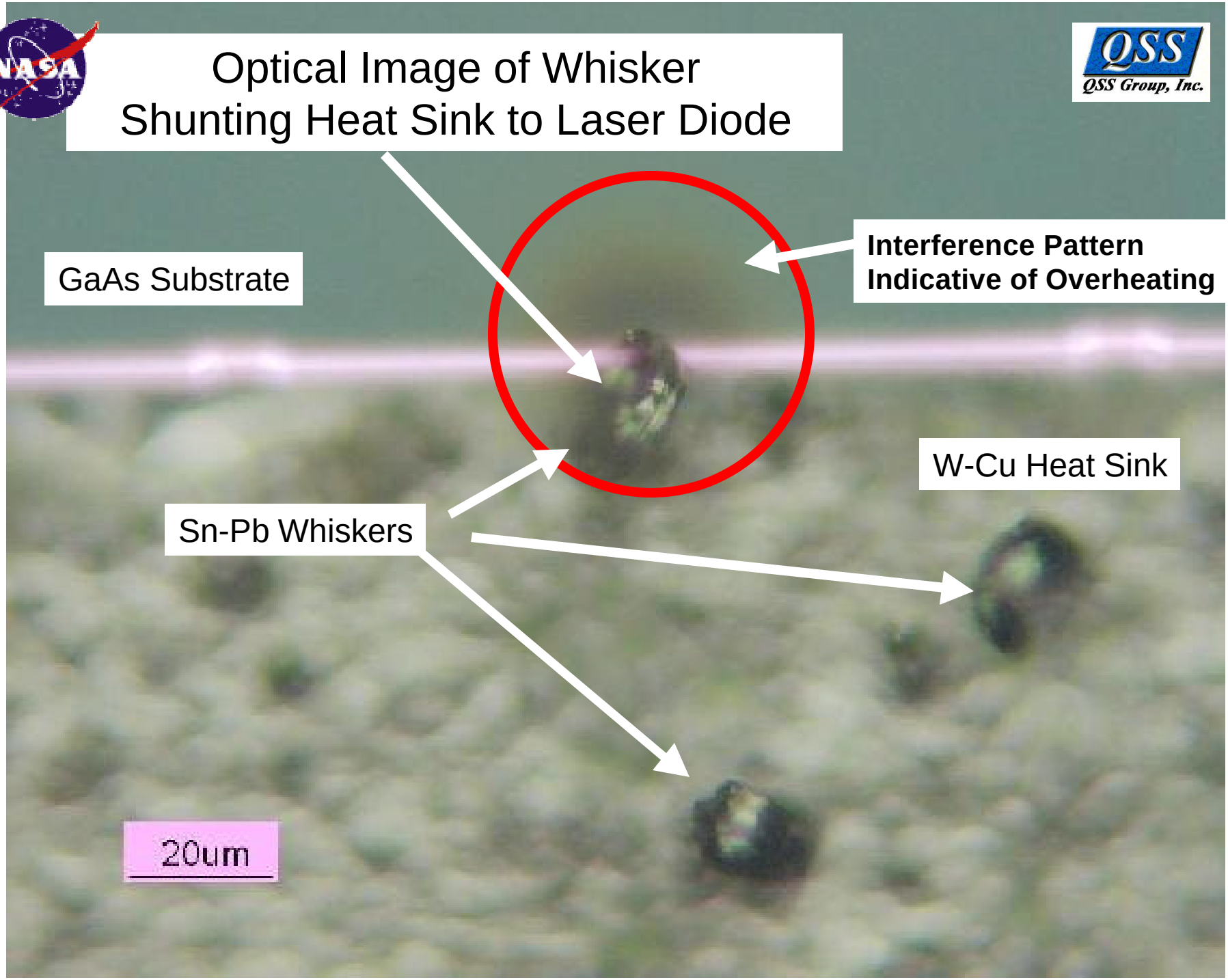
Are those Dark Spots Sn-Pb Whiskers Blocking the Emission of Light or Possibly Shunting the Heat Sink to the Laser Diodes?

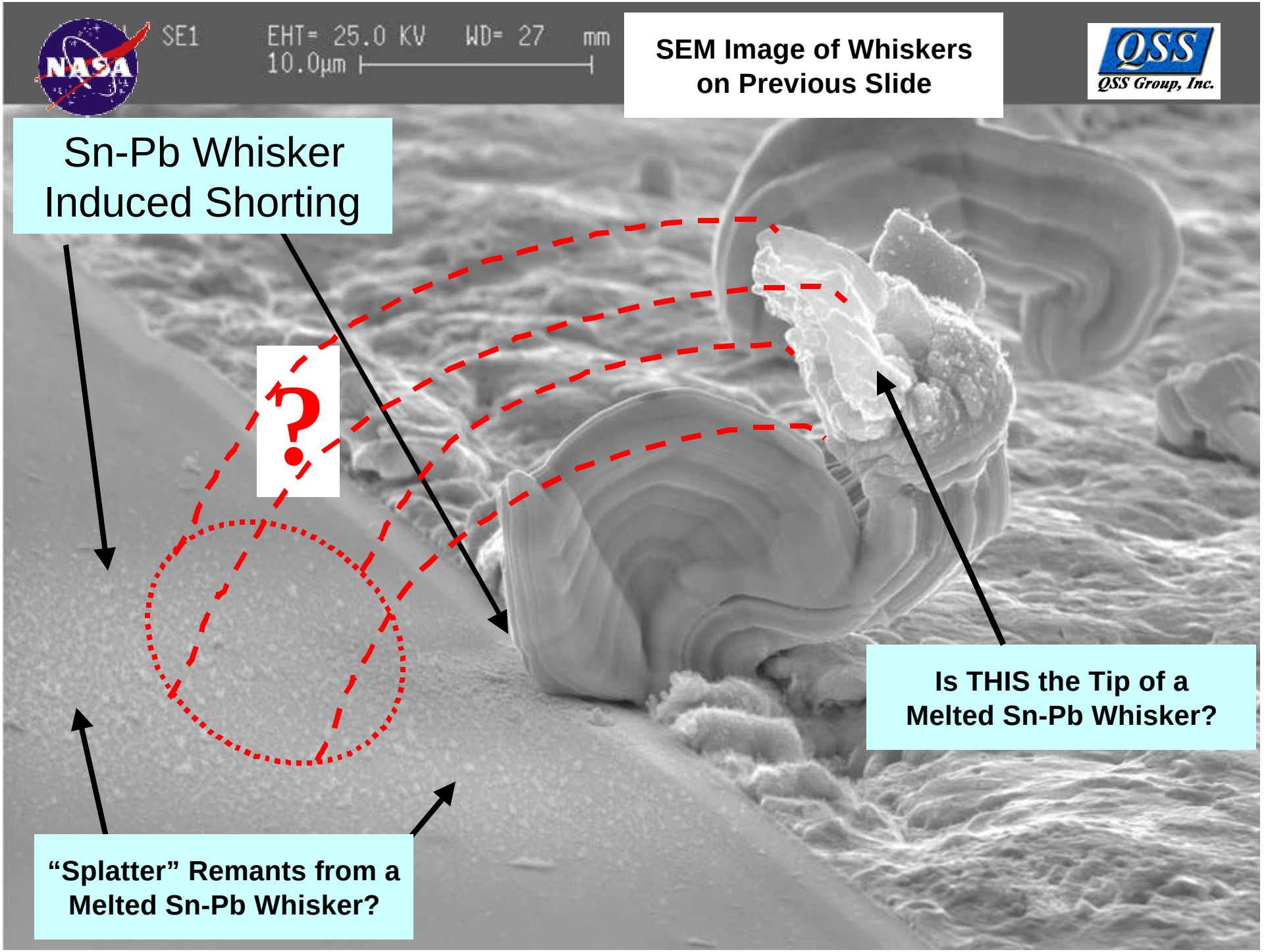


Did a Sn-Pb Whisker Cause ***This***?



Optical Image of Whisker Shunting Heat Sink to Laser Diode




SE1
EHT= 25.0 KV
WD= 27 mm
10.0µm
SEM Image of Whiskers on Previous Slide
QSS Group, Inc.
Sn-Pb Whisker Induced Shorting
?
Is THIS the Tip of a Melted Sn-Pb Whisker?
“Splatter” Remants from a Melted Sn-Pb Whisker?

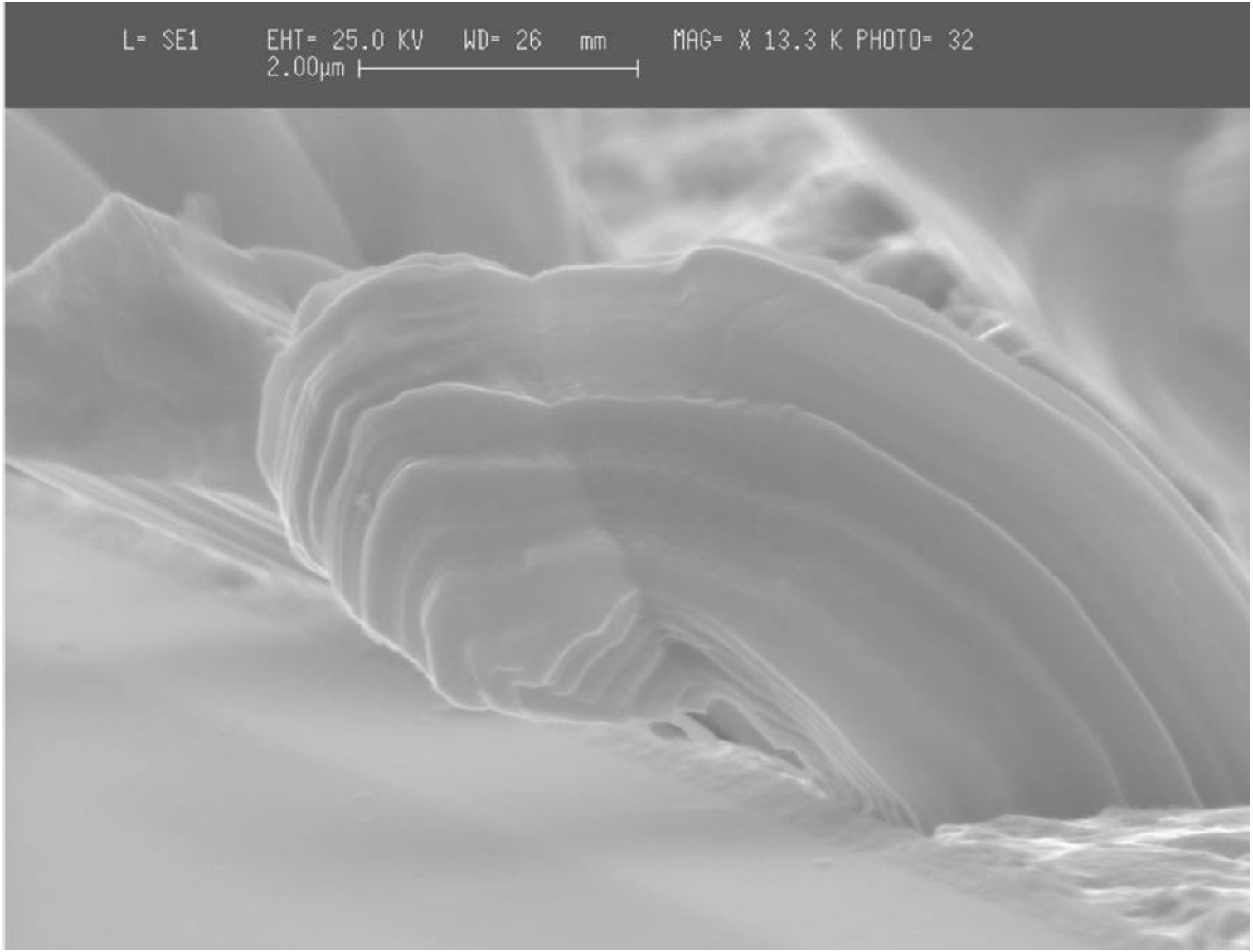
Discussion

- Q: What Problems Could These Types of Whiskers Create?
- A: 1) Direct Shunt Between Heat Sink to Laser Diodes
  (Shorting distance is ONLY ~ 2.5 to 3.0 microns)
  2) "Block" Light Emission if in Direct Path of Light Source
    - Secondary Effect of Blocking may be light reflected from whiskers may generate some additional local heating of Laser Diode

- Q: What Made These Whiskers Grow?
- A: **UNKNOWN.**

- Speculation!!! -
  - *** Theory #1:** Metal from solder die attach migrates via ELECTROMIGRATION under high current densities used in this device application
    - Similar whisker growths reported with other die attach materials including pure Tin, Tin/Lead, Indium and Tin/Gold (90/10).
      (*Mitsuo Fukuda, "Reliability and Degradation of Semiconductor Lasers and LEDs", 1991, Artech House Inc.)
  - **Theory #2**: CTE mismatch of materials (solder, heat sink, die) coupled with thermal cycling from "pulsing operation" of laser diode induces observed whisker growth
    - During manufacturing some of the Sn/Pb die attach solder extends to the edge of the GaAs die (not on it). Also some Sn/Pb solder wets the edge of the W-Cu heat sink.
    - Thermal cycling caused by normal "pulsing" operation (10 - 40 Hz) of this device creates, a ΔT up to 40°C at the semiconductor junction (somewhat "less" at the solder).

More Sn-Pb Whisker Images



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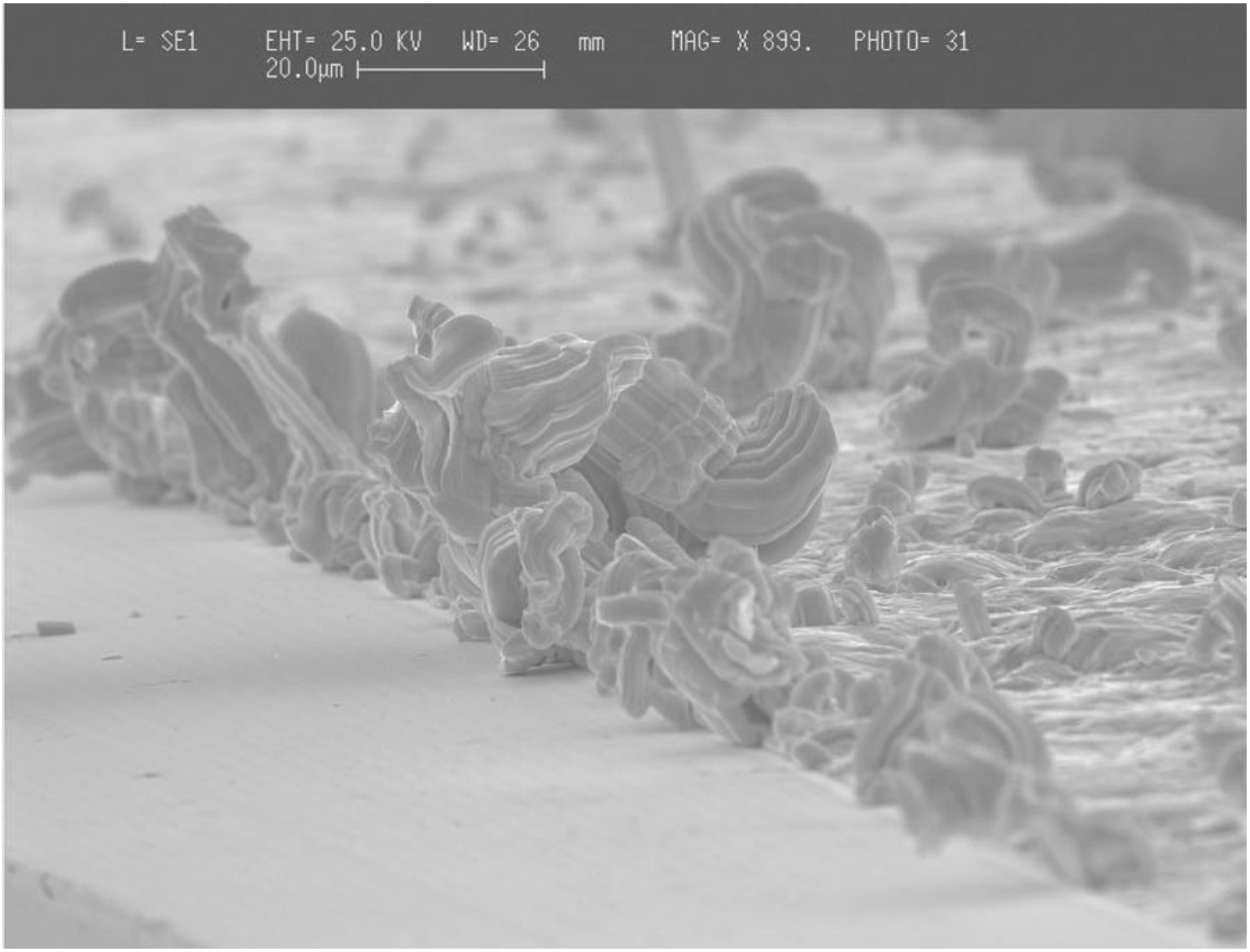

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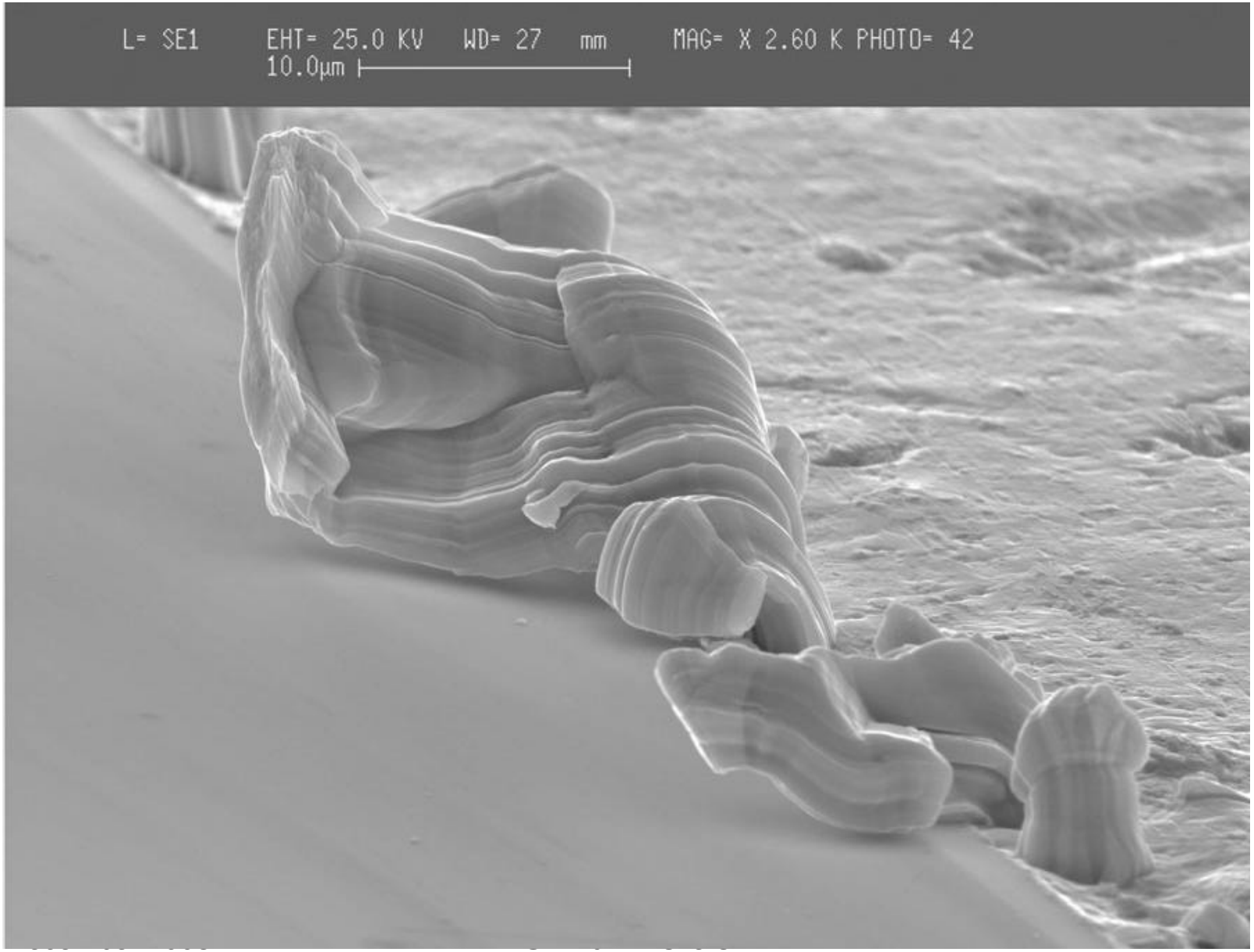

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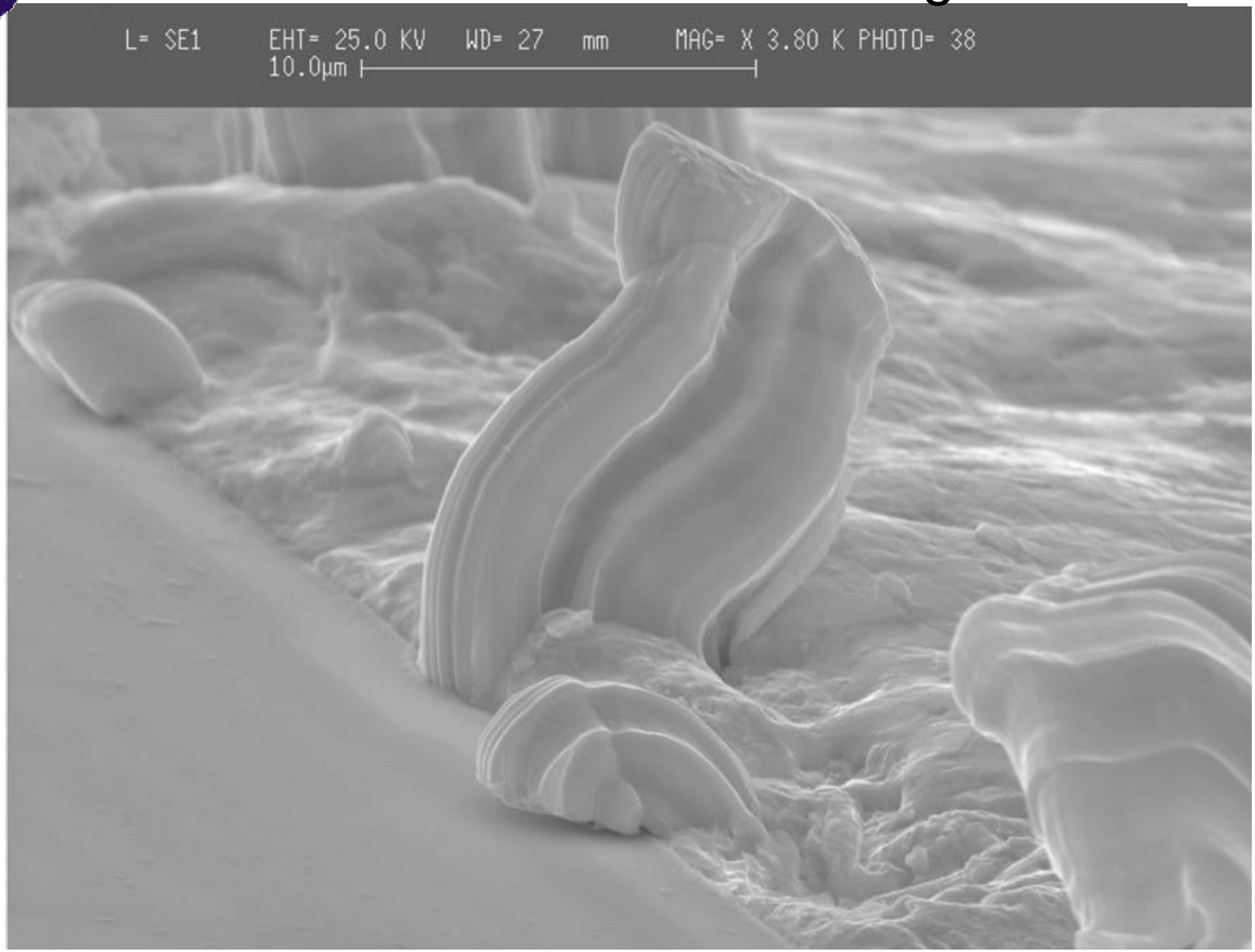

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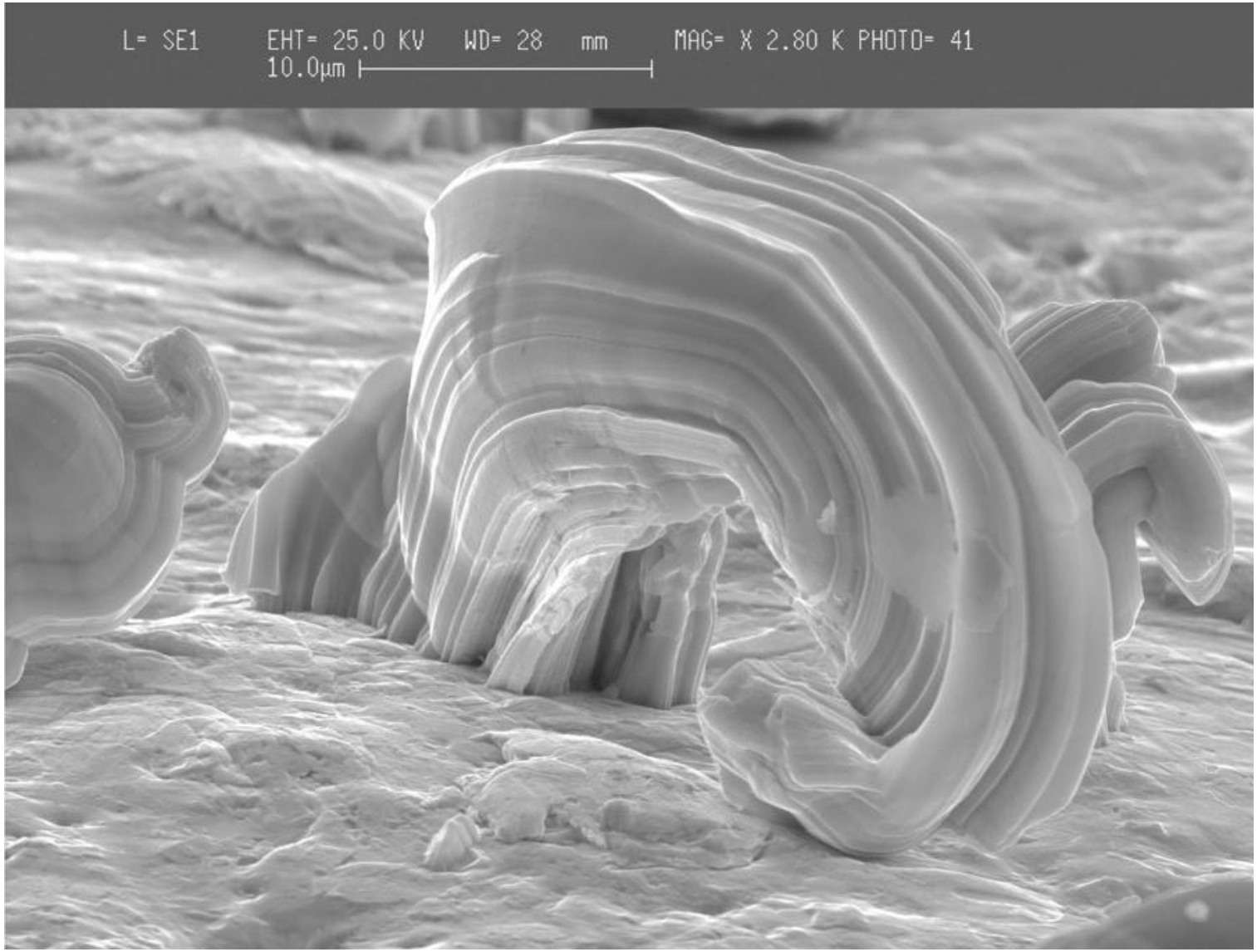

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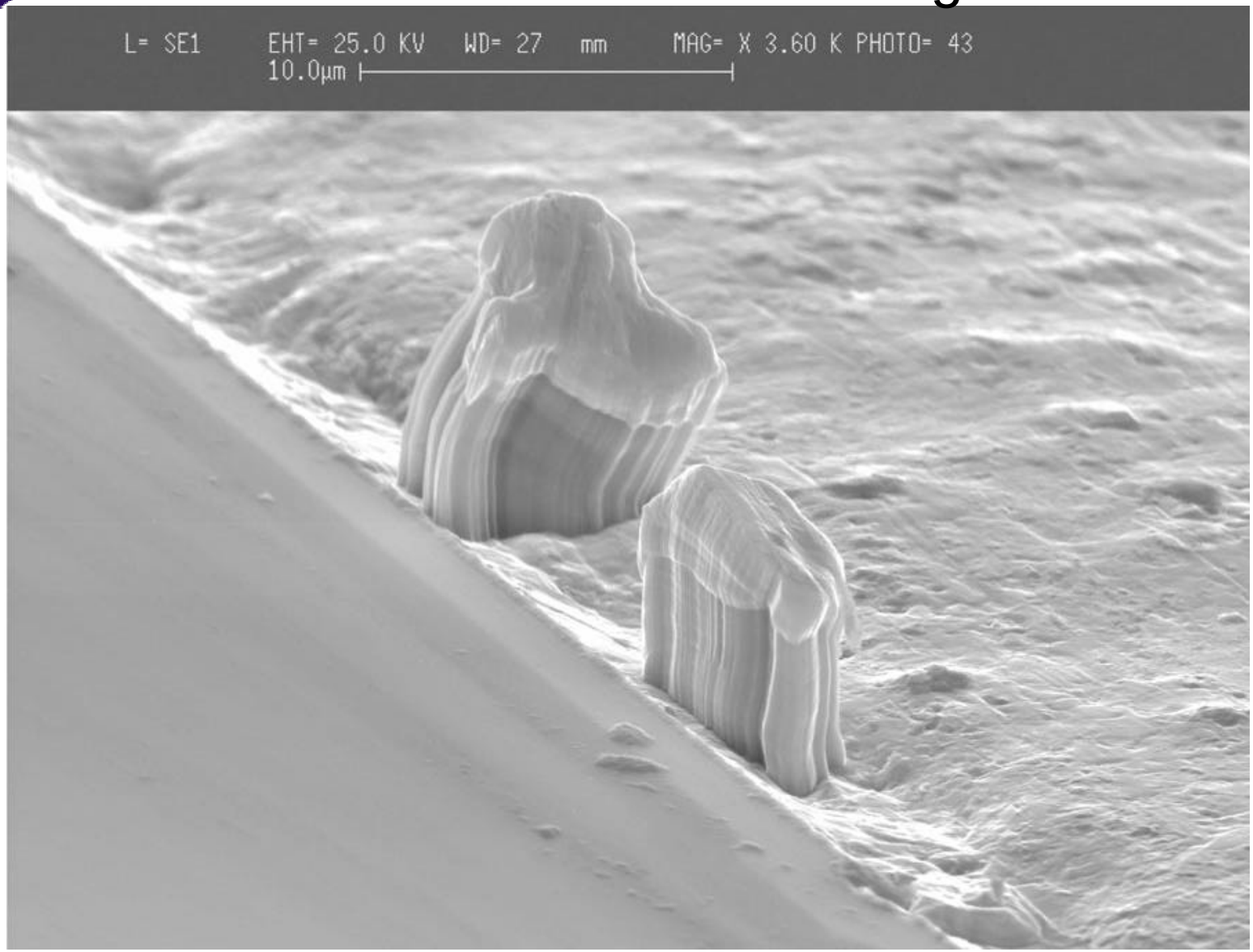

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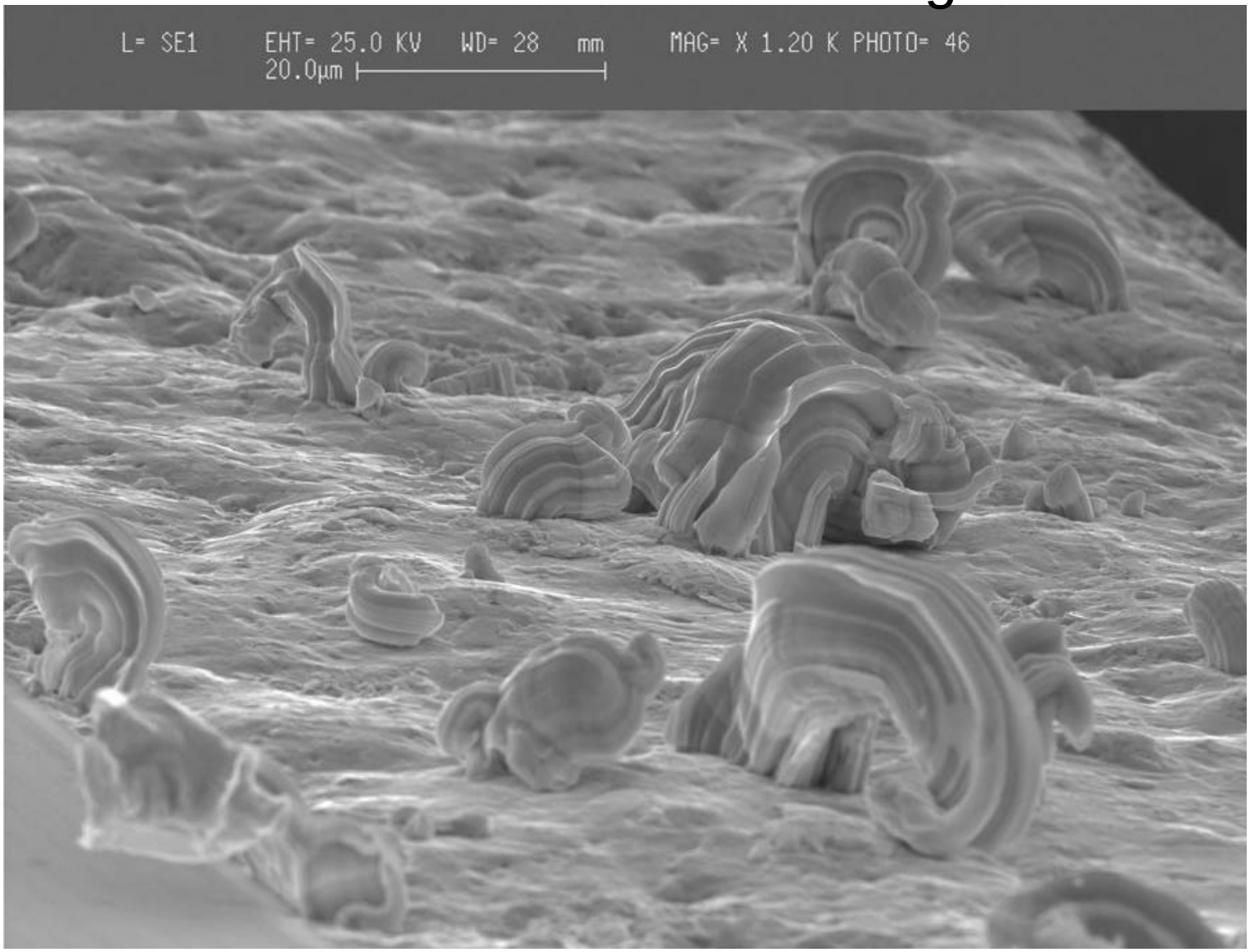

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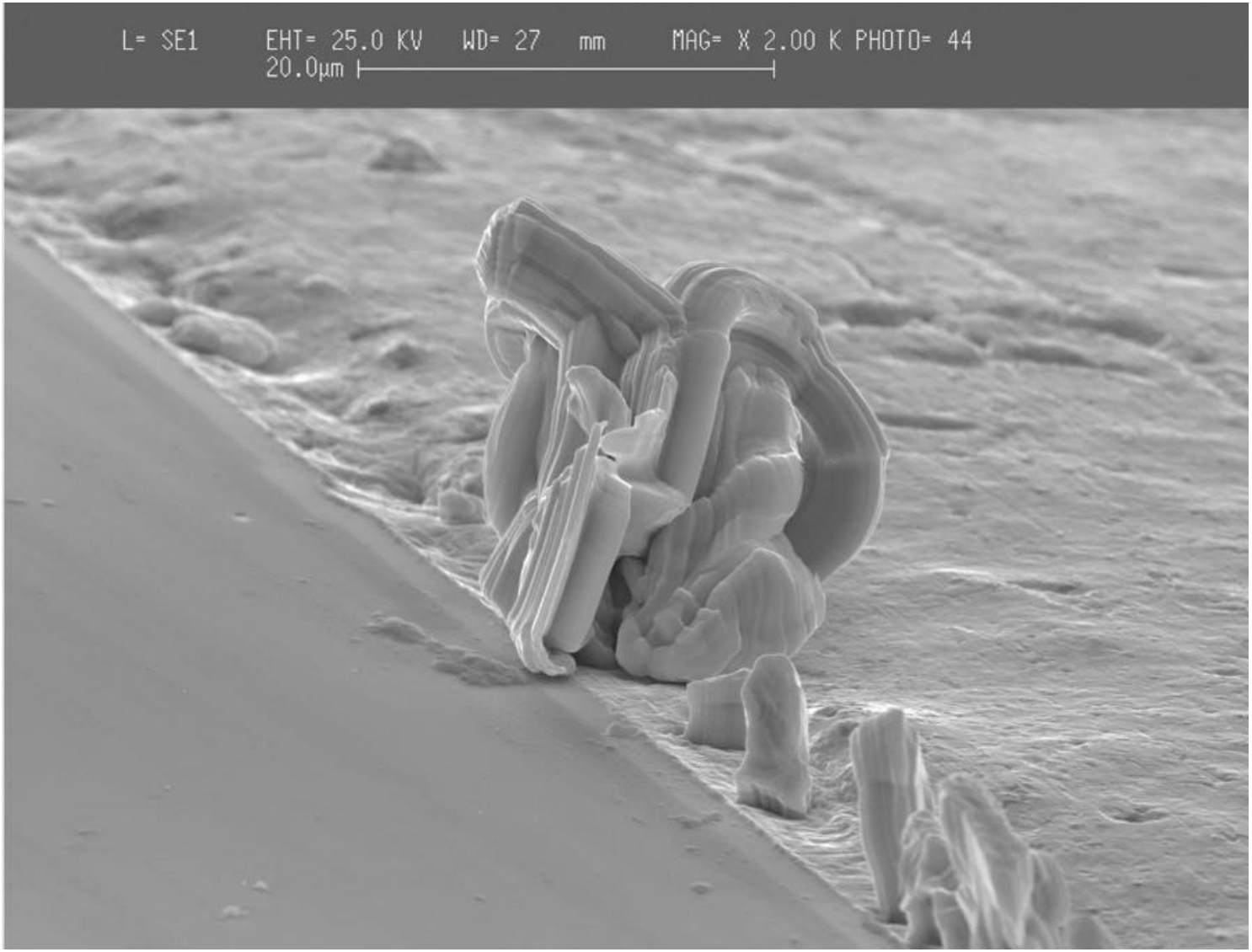

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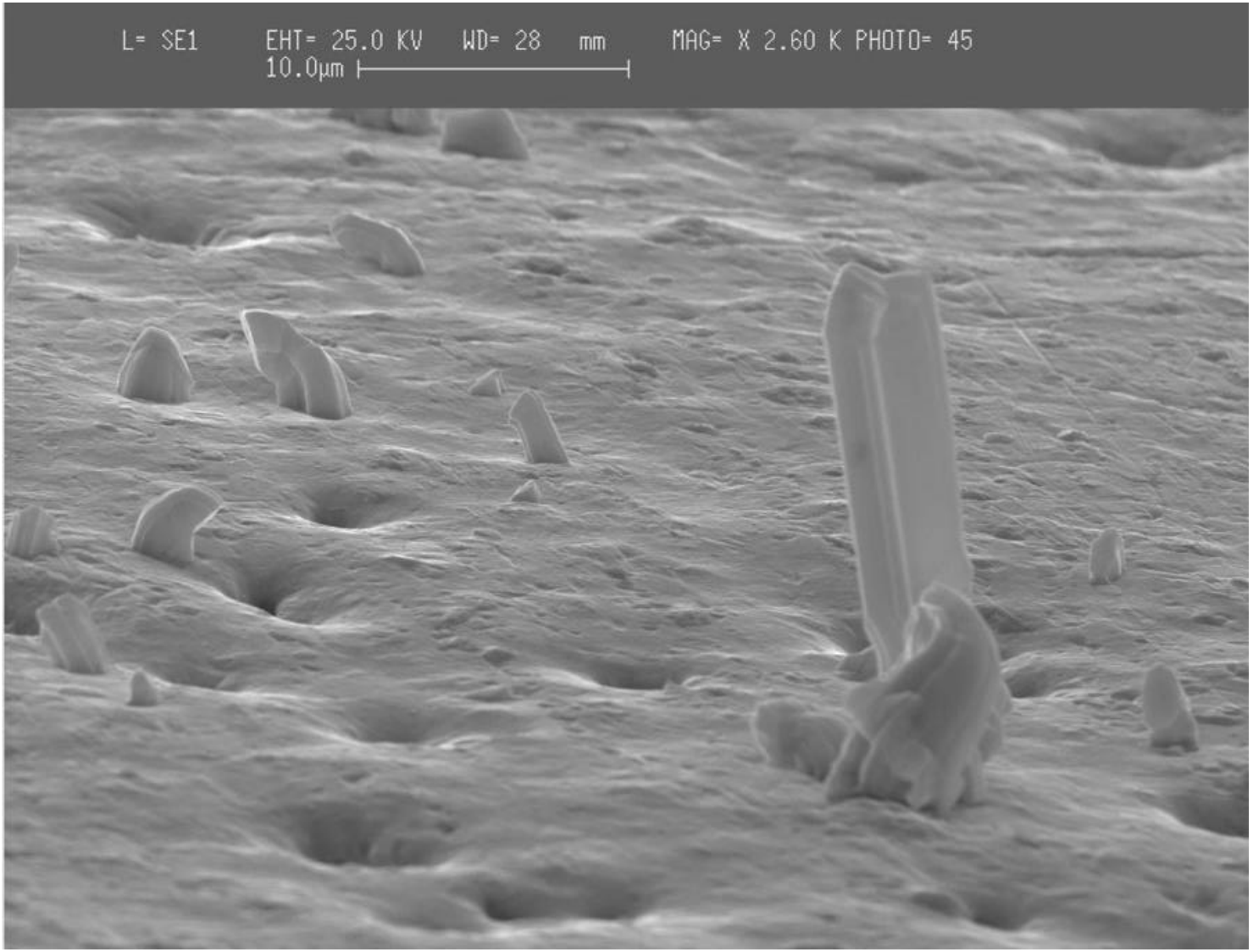

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NASA Goddard Tin (and Other Metal) Whisker WWW Site

http://nepp.nasa.gov/whisker