ATLAS VCSEL Environmental Tests

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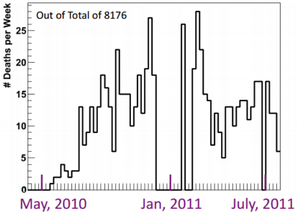
Introduction

- The Pixel and SCT use VCSEL arrays to communicate with the modules. **TrueLight** was the chosen manufacturer.
- **Much earlier** than the expected lifetime, **Pixel and SCT off-detector** started showing a worrying death rate.
- **Pixel on-detector** currently show no deaths to worry about.
- SCT on-detector VCSELs are proton-implant and recorded deaths are mostly attributed to infant mortality, others to random failures.

	On-detector	Off-detector
SCT	Proton implant	Oxide confined
Pixel	Oxide confined	Oxide confined



Introduction

- Main hypothesis for deaths in USA15 after solving ESD issues was **humidity**. Actions taken:
  - SCT crates flushed with **dry air**: humidity down from $40 - 50\%$ to $20 - 30\%$.
  - Qualification of **other manufacturers**: AOC (Finisar) and U-L-M Photonics VCSELs pass 1000 hours in $85^oC/85\%RH$ conditions.
  - SCT off-detector **TrueLight VCSELs replaced by AOC**. Started mid-2011, since Feb. 2012 all plugins are AOC.
- But: **8 channel deaths** have occurred in 7 arrays (SCT+Pixel):

Package	Installation	Dead channel(s), date(s)	Type
T6172	4-7-2011	5, 5-7-2011; 4, 12-7-2011	Infant
T6307	26-8-2011	4, 26-8-2011	Infant
T6208	4-7-2011	6, 5-9-2011	Random
T6633	19-1-2012	2, 28-1-2012	Infant
T6432	29-9-2011	6, 22-4-2012	Random
T6164	4-7-2011	6, 25-5-2012	Random
T6258	4-7-2011	?, 24-5-2012	Random

Introduction

- The Pixel AOC arrays (T6258) has been sent to AOC for failure analysis.
- Two of the AOC VCSEL arrays that failed in the SCT were sent to EAG for failure analysis.
- 4 deaths are considered infant (within days of installation), the other 4 are defined as random (Maverick) failures.
- It is **too soon** to know if the death rate will go up again.
- But we are going to count on it for the sake of **planning**.

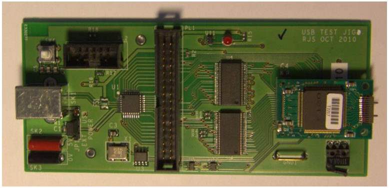
Environmental tests

- Tests performed at U-L-M:
  - High Temperature and Humidity lifetime tests with TrueLight VCSEL arrays, constant driving current $I = 10mA$.
  - $85^o C/85\% RH$ tests on 31 channels.
  - $60^o C/85\% RH$, $85^o C/29\% RH$ each on 31 channels.
  - $85^o C/60\% RH$ on 24 channels.
  - 24 of the 31 (max) channels come from 2 arrays with 12 channels powered and a third array with 7 channels powered.
  - MTTF estimation:

Test	MTTF (h)	Error interval
$85^o C/85\% RH$	658	$(-61, 82)$
$85^o C/60\% RH$	1193	$(-79, 152)$
$60^o C/85\% RH$	1987	$(-57, 55)$
$85^o C/29\% RH$	8109	$(-6459, 2682)$

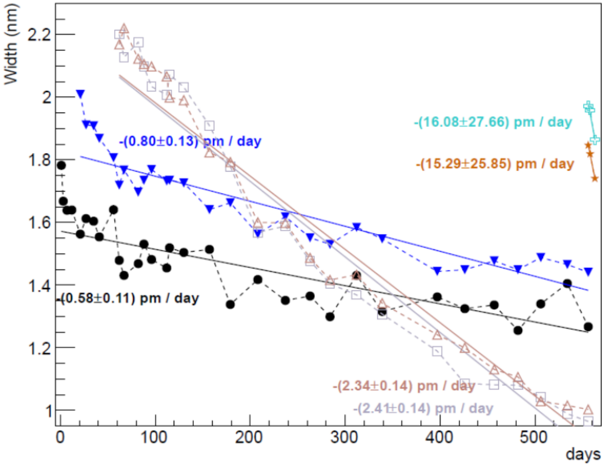
Environmental tests

- Tests in SR1:
  - Running since **November 2010** with TrueLight VCSELs. Test time up to now is close to **600 days** (last update 11/5/2012).
  - Using **USB Jig** to run in same conditions as USA15.
  - 4 arrays at **room temperature and humidity** (around 40 – 50%).
  - 4 arrays in **nitrogen** (dry environment).
  - 2 out of each set of 4 arrays are brand new arrays and 2 are used.
  - So far, **only one channel died** in the set that is running humid, from the used arrays.
  - In May 2012, the test was extended to include **2 AOC arrays** operating in air.



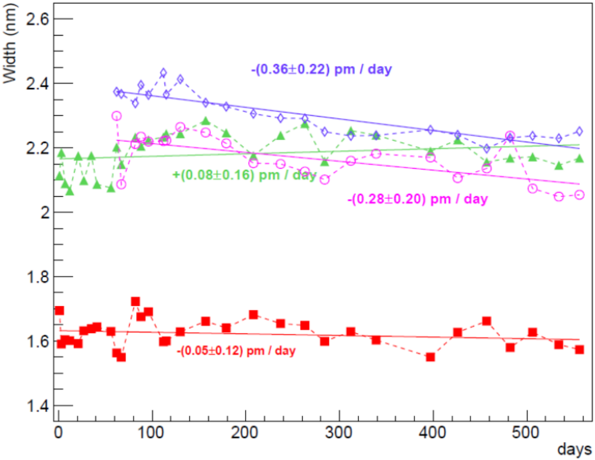
Environmental tests

- Tests in SR1: spectral width evolution, VCSELs in air.
  - Older VCSELs show less narrowing.



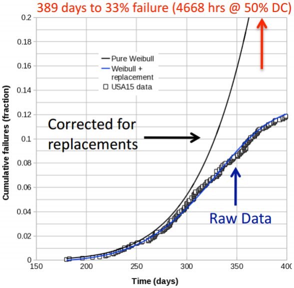
Environmental tests

- Tests in SR1: spectral width evolution, VCSELs in Nitrogen.
  - Negligible narrowing for both VCSELs ages.



USA15 deaths

- Fit has been done only with TrueLight VCSEL deaths.
- Two crates groups running at slightly different temperature and humidity: 0-3 are $T = 26.1^o C, RH = 42.2\%$ and 4-7 are $T = 23.7^o C, RH = 51.3\%$.
- Mean Times to Failure calculated by Alexandru Dafinca are $MTTF_{0-3} = 20340 \pm 862\ h$, $MTTF_{4-7} = 18350 \pm 842\ h$.



389 days to 33% failure (4668 hrs @ 50% DC)

Corrected for replacements

Raw Data

Consistency of the results

- Relationship among USA15, SR1 and ULM data
- **Arrhenius equation** applicable to temperature differences:

$$AF_T = \exp\left(\frac{E_a}{k_B}\left(\frac{1}{T_{stress}} - \frac{1}{T_{ref}}\right)\right)$$

  - First problem is: what is the **actual temperature** of the junction? Depends on thermal resistance . . .
  - . . . as well as the **input electrical power** . . .
  - . . . but it also depends on the **number of channels** that are turned on.
- Model for **relative humidity acceleration**:

$$AF_H = \exp\left(a_H\left(RH_{stress} - RH_{ref}\right)\right)$$

  - Yes, there's a problem with that, too. . .
  - . . . **device surface** has a slightly higher temperature than the ambient. . .
  - . . . and that **lowers the relative humidity** around the device.

Consistency of the results

- But since we can account for those differences, it's possible to try to fit the USA15 data with U-L-M tests.
- USA15 runs at AC current between $I_{off} = 1mA$ and $I_{on} = 10mA$ with 50% duty cycle, while U-L-M drives the VCSELs at $I = 10mA$ DC.
- Correct USA15 MTTF values to account for this difference: $MTTF_{0-3} = 10.2k\ h$, $MTTF_{4-7} = 9.2k\ h$.
- Two (main) sources of errors:
  - The fact that U-L-M tests use only 3 devices with a total number of 31 channels. Very **low statistics**.
  - The **exponential nature of acceleration factors**.

Consistency of the results

U-L-M and SR1 vs USA15

- First, let's compare U-L-M data with USA15:
  - Factoring the differences and assuming there are errors in the fit:

$$E_a = 0.498 \pm 0.042 eV \qquad a_H = -0.024 \pm 0.004/\%$$

$$MTTF^{est}_{0-3} = 51k\ h \pm 18.1k \qquad MTTF^{est}_{4-7} = 49.8k\ h \pm 16.9k$$

  - Not only the errors are huge, but the estimated values are far away from the ones that apply to USA15.
  - The environmental tests **expect USA15 VCSELs to live 5 times longer**.
- But what happens with SR1?
  - If no acceleration factor is considered between SR1 and USA15, the probability of finding only one death or no deaths at all in SR1 is $p \approx 0.0003$.
  - If we assume an acceleration factor in USA15 wrt SR1 of 1.3, that probability is $p' < 0.05$.

Conclusions

- **VCSEL deaths** in the SCT and Pixel off-detector are still **happening** . . .
- . . . even after changing to humidity resistant devices.
- For the SCT off-detector, we have 3 sets of data:
    - USA15 deaths history. A large amount of devices, very good statistics.
    - SR1 tests. A very long test with few devices that we would have expected to die earlier.
    - U-L-M tests. Several environmental tests that we have tried to use to understand the effect of humidity in the VCSELs.
- And what we learn from them is:
    - U-L-M tests and SR1 tests are consistent. SR1 behaves like U-L-M central values would like it to behave.
    - USA15 deaths are still unclear, as they do not show consistency with neither U-L-M environmental tests nor SR1 tests.
    - **We would expect USA15 VCSELs to live longer.**
- That makes us think that **humidity is not the end of the story**.
    - Are we back to ESD or EOS?
    - Are there any **unfactored effects** that accelerate deaths?

Conclusions

- What are the **differences** among setups?
  - U-L-M tests are performed on bare VCSELs.
  - Both USA15 and SR1 use packaged VCSELs with the BPM12 chip.
  - SR1 uses an USB Jig.
  - USA15 has the optopackage in a board together with other circuitry.
- Other possible failure causes:
  - **Pin holes in the epoxy layer** that is meant to keep moisture from entering the device.
  - **Mechanical damage** during wirebonding.
  - Stress during **temperature cycling** with the epoxy on top of the VCSEL.

Outlook

- It is **too soon** to know AOC VCSELs are going to fail as TrueLight did in the past.
- But for the sake of **planning**, it might be wise to assume that they will.
- So we need a contingency plan until the end of 2012:
  - We have 25% **spares** at CERN.
  - The backup option is another vendor solution: U-L-M arrays in **Xloom-iFlame Tx** (after a long delay).
  - **Stock** of old TrueLight TXs.
  - New limited production run.
- And of course, we are still investigating on the causes of failure.
- Now **discussing with a VCSEL expert**, Bob Herrick. We hope to do better tests to really understand the cause of failures for TrueLight VCSELs in damp heat tests.

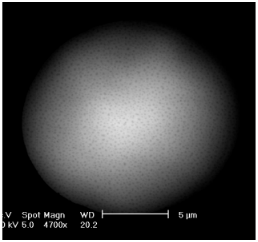
Backup slides

Backup slides

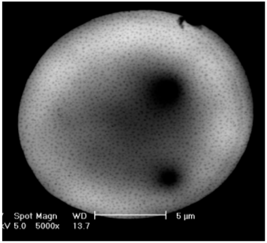
Failure analysis

- Failure analysis: Electron Beam Induced Current (EBIC). Done at EAG.
- Scanning electron microscope beam to reveal defects in a biased device.
- The picture shows two channels on a used Pixel TX. Left image is a healthy channel, right is a dead channel.
- The dead channel shows dark points, indicating significant effects.

Ch A: WORKING

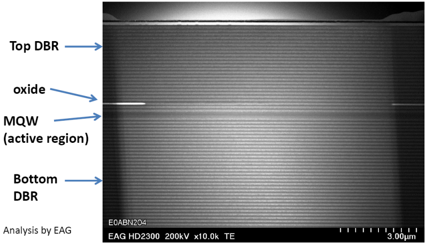


Ch B: DEAD

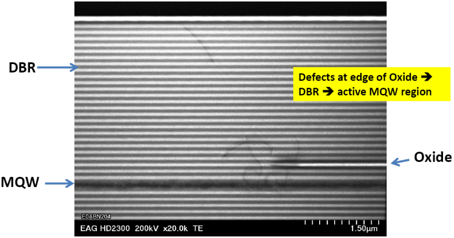


Failure analysis

- Scanning Tranmission Electron Microscopy (STEM): planar slice of the device showing Quantum Wells and Oxide layers. Also done at EAG.
- Left image is a healthy unused channel. Right image is of a failed channel, showing defects in the Oxide and the QW.



Analysis by EAG



Defects at edge of Oxide ➔ DBR ➔ active MQW region