# Using STEM EELS to Probe Local Bonding Environment in VCSEL Oxide Apertures

**STEM EELS provides a method to locate secondary phases that could possibly correlate to degraded performance.**

## Introduction

Vertical cavity surface emitting laser (VCSELs) have become an integral technology in optoelectronics ranging from consumer electronics to medical applications. Achieving high reliability and performance requires fine control over growth and device fabrication. One important aspect is precise oxidation of the aperture layer, responsible for current confinement. Improper aperture oxidation can lead to high stress or introduce unintended defects ultimately resulting in failure. Here, we present a study using STEM EELS to provide a method for measuring differences in oxygen bonding.

## Discussion

In this study, three different VCSELs were analyzed – two failures and one control. Figure 1 shows STEM analysis on a failed VCSEL device. Initially, a plan-view sample, Figure 1 (a), was prepared to observe defect behavior across the entire structure. From the plan-view sample, a cross section was extracted from the region displayed in the yellow box using focused ion beam (FIB). Figure 1 (b) shows a STEM bright-field image of the extracted cross-section with dislocations propagating from the oxide tips into the MQWs. The green box in Figure 1 (c) shows the EELS mapping location and extracted EELS spectrum. Figure 1 (d) corresponds to the red box from the spectrum image. The EELS spectrum is centered at the O-K edge. There are two sharp peaks near the onset of the O-K edge. For typical $Al_2O_3$, we only observe the higher energy peak centered at 542 eV.

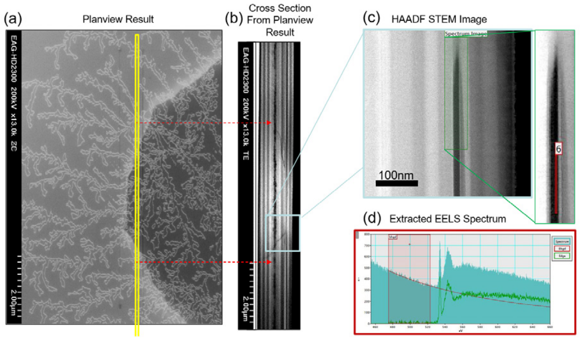

*Figure 1: STEM imaging and EELS from a failed VCSEL.*
*(a) shows an image of the sample in plan-view orientation with a yellow overlaid box corresponding to the position of the extracted cross-section shown in (b).*
*(c) shows an HAADF STEM image of the cross-section with the corresponding EELS spectrum image performed at the green boxed region with an extracted spectrum shown in Figure 1 (d).*

Figure 2 shows the resulting cross sections from the three samples in this study. Although the imaging itself shows little difference, STEM EELS reveals very different behavior in the O-K edge, corresponding to changes in bonding. Relative to the control sample, we observe that the two degraded devices exhibit a more intense peak

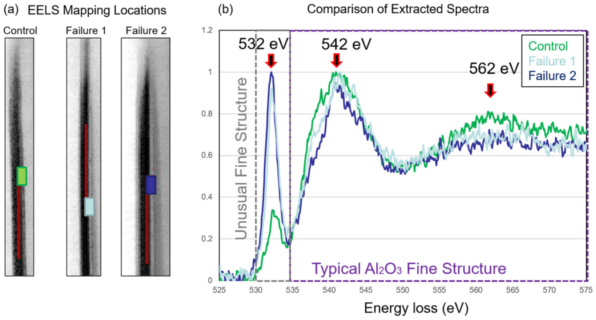

*Figure 2: EELS analysis of the O-K signal for the three VCSELs.*
*(a) shows the spectrum images for each device with red boxes corresponding to extracted spectra shown in (b).*

present at 532 eV. In typical $Al_2O_3$, there is octahedral coordination which is responsible for the peak centered at 542 eV. The 532 eV peak is shown to correspond to $\pi^*$ bonding or tetragonal coordination and is found in a wide variety of materials.

## Conclusion

Although we observe a clear change in the oxygen-K fine edge structure, there was no clear change in the fine edge structure for Al. Further, we did not observe significant amounts of Ga or As. There are several possibilities on the origin of the 532 eV peak in this layer from trapped water molecules to a different aluminum oxide stoichiometry. However, this experiment provides a new pathway to diagnose changes in thin oxide aperture layers that may correlate to changes in device performance. Contact us today to learn more about this new application.