Raman Spectroscopy to Monitor UV Curing in Semiconductor Production

Application Note

KEYWORDS

- UV-cured epoxies
- Die-attach processing
- Semiconductor production

TECHNIQUES

- Raman

APPLICATIONS

- Reaction monitoring
- Process control

Isn't it nice to find a tool that helps you in multiple ways? Tools are usually tailored for a specific task, but in complex industries such as semiconductor production there is often a need to make the most out of the available resources. And since time is money, time-consuming steps in these production processes end up costing users more, especially when multiplied across many thousands of units.

For example, anyone that has ever repaired something with glue knows that it can be frustrating to wait until the adhesive is cured, and one rarely knows if it is fully secure; this same problem occurs during the die-attach step in semiconductor assembly.

The die-attach process most often uses some type of 1- or 2-part epoxy to bond components and is typically heat-cured (1). However, extended curing times and the potential for temperature stress on the components can make these common epoxies less than ideal. By using UV-cured epoxy, which also can

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be heat-cured, components can be rapidly set in place by curing the exposed perimeter and locking in the position and alignment **(Figure 1)**. From there, the usual heat treatment can be done to cure any masked areas.

So, in the short term, how do we know that the UV cure is complete? And thinking long-term, how can we test and determine rate constants for potential die-attach process improvements?

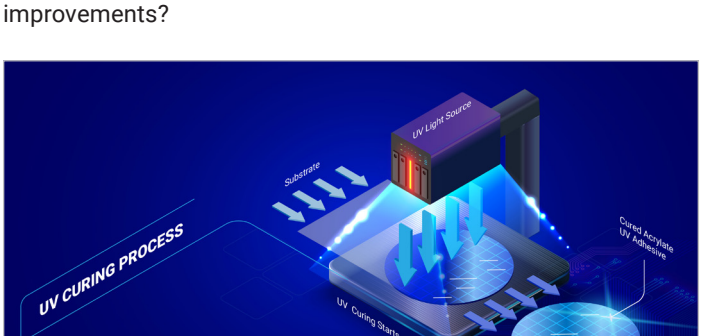

Figure 1. The use of UV curing technology is among several die-attach options commonly used in semiconductor production.

Raman Spectroscopy for Process Control

Raman spectroscopy is a powerful technique that has been around for decades but only recently has been adopted into mainstream production flows. This laser-based technique allows for rapid detection and tracking of sample parameters that are hidden or especially challenging for standard broadband spectroscopy approaches to measure.

Raman emission peaks often correspond to some chemical compound. In the case of UV-cured adhesives we can track the reduction of an epoxy peak over time to ensure the component is fully cured.

The study presented here evaluated a common semiconductor UV-epoxy using a QE *Pro* 785 nm Raman spectrometer bundled with a 785 nm excitation Raman laser module and 785 nm-compatible Raman probe **(Figure 2)**. We investigated signal quality as a function of integration time and spectral averaging, since the total scan time is the integration time multiplied by the number of averages. For example, a 200 ms integration time at 3 scans-to-average will yield 600 ms total scan time.

Figure 2. A high-sensitivity spectrometer like the QE *Pro*-Raman+ can be combined with the appropriate laser and probe for convenient Raman analysis of a wide range of samples.

Optimizing Measurement Parameters

What is the best combination of integration time and averaging when tracking a fast-cure adhesive? Should you give more weight to integration time for larger (more) signal, or to averaging for more stability? In the following plots we look at three different total scan times – 3 seconds, 1 second and 0.25-second (4 Hz) -- as we track the drop in intensity in the 1630 cm^{-1} peak during the curing process.

In **Figure 3**, Plot A shows the response giving weight to the integration time and using no averaging, but this yields somewhat distorted peaks and no discernible change for the fastest scan rate. Alternatively, when giving priority to averaging in Plot B by using 3-scans-to-average for each, we see better peak behavior and some detectable changes even at the fastest 4 Hz speed. In Plot C, by giving additional wavenumber smoothing with a boxcar setting of 3, we see even more coherent peaks and extractable numbers. The lesson here is that averaging will often give you clearer Raman results than merely increasing integration time to amplify signal.

Also, we can calculate the anticipated curing resolution using the time-resolved data in the following equation, where $I_{low\%}$ and $I_{high\%}$ are the observed intensities at the two known cure conditions:

$$Cure\ Resolution = \frac{\left(2 * StDev(I_{low\%})\right) * \Delta Cure\%}{Abs\left(Ave(I_{high\%}) - Ave(I_{low\%})\right)}$$

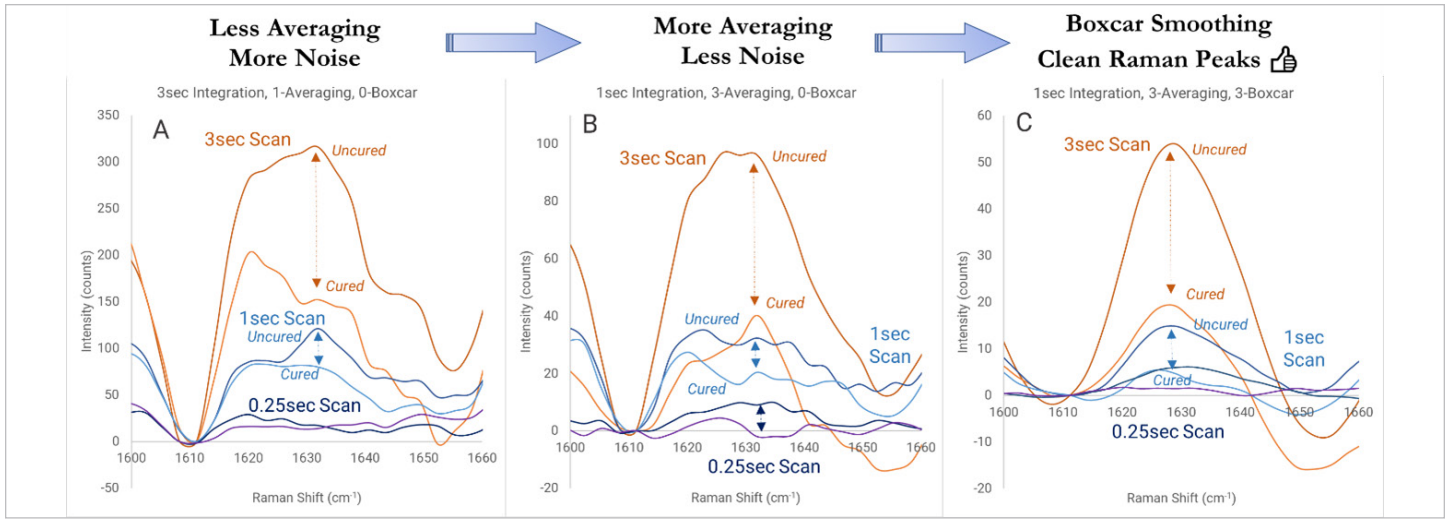

Figure 3. Plot A shows higher integration time and less averaging, Plot B shows lower integration time and more averaging, and Plot C shows the Plot B trends with 3-boxcar smoothing applied.

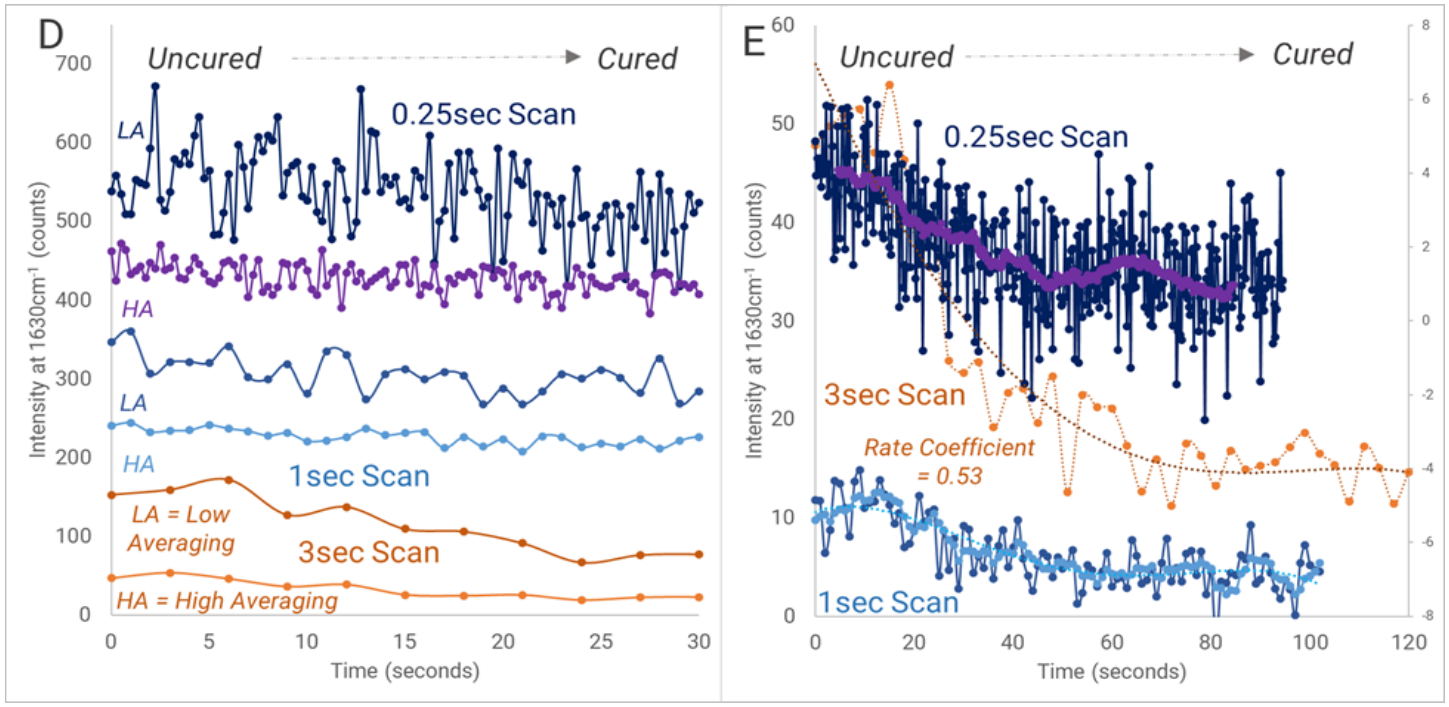

Figure 4. Plot D shows raw, time-resolved data at different integration times and averaging; Plot E shows decay curves with 5-second running-average applied for rate coefficient determination.

In the case of Plot B in **Figure 3**, which uses 1-second integration and 3-scans-to-average, this ultimately works out to be slightly better than 20%, meaning we can be confident that the epoxy has chemically reacted to beyond 80% completion.

This information is immediately useful to the assembly team working with products going out the door, but earlier we talked about tools having multiple uses. Indeed, there is a longer-term value for this measurement related to the process engineers tasked with optimizing overall production. These time-resolved trends can be used to determine rate constants of the curing process, which ensure current epoxies are performing to specification, and to evaluate future epoxies for faster cure times.

In **Figure 4**, Plot D shows some time-resolved comparisons of

Raman peak trends at different integration times and averaging. Note how much smoother the higher-averaging trends turn out. Plot E shows the raw decay data but also with a 5-second running average to further smooth the response. This allows tight curve fitting to extract the rate coefficient

Summary

What is shown here is meant to be valuable for monitoring adhesive curing in a production setting, but these are concepts that hold value across general Raman use cases.

Boxcar smoothing is a powerful tool that does not affect the total scan time the way standard spectral averaging does, but rather smooths the signal across its neighboring pixels. However, this can be tricky with Raman spectroscopy since sharp peaks are often monitored and can be quickly muted by boxcar smoothing. But in cases where we know our peak location and are dealing with low-intensity acquisitions, it can be helpful to use some minor boxcar smoothing to add coherence to the signal.

The third type of averaging used during post-processing is the running-averages shown in light blue and purple in Plot E in Figure 4. While the core scans-to-average feature is merely accumulating scans and dumping them all at once, a running average is looking back continuously at the most recent scans to provide a time-smoothed curve without adding to the total scan time.

UV curing is a crucial process step and experimentation is required to achieve the best performance for a particular component and process (2). By using the right combination of integration time, scan averaging, boxcar smoothing, and running averaging, you can extract surprisingly useful Raman data from seemingly chaotic or miniscule emission peaks. With this data we can extract immediate information about process conditions as well as broader behavior parameters that allow long-term process improvements.

While we didn't have time to touch on how similar spectral devices can also monitor the UV intensity being delivered, there is certainly no shortage of applications that can take advantage of broadband spectroscopy in semiconductor assemblies.

References

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