

FTIR and RAMAN Spectroscopy for Counterfeit Electronics Detection

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Fourier Transformer Infrared (FTIR) and RAMAN spectroscopy are microscopy techniques that utilize the absorption and emission of light to provide qualitative and quantitative information about the chemical composition of materials. Materials are exposed to a light source which, depending upon the relative absorption of each chemical which compromises the material, excites the molecules and produces a spectrum. For FTIR, the relative absorption of material is measured using transmitted or reflected infrared light. In RAMAN spectroscopy, the material excitation from the laser results in scattering of phonons at different wavelengths than the incident laser.

FTIR measurements are typically performed with attenuated total reflectance (ATR) FTIR and require no sample preparation as the sample is placed in direct contact with an ATR crystal. The infrared light source transmits through the ATR crystal to the sample which reflects a portion of the infrared light back through the ATR crystal to a detector. The tradeoff for using ATR FTIR is that its penetration depth is shallow (~ a few micrometers) and only provides data about the surface of the sample. However, the shallow penetration depth of ATR FTIR is sufficient for counterfeit mitigation testing of electronic components. Figure 1 shows an example of the ATR FTIR measurement stage for a Thermo Scientific Nicolet iS50 FTIR.

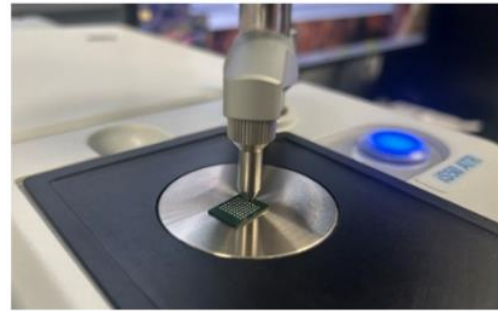


Figure 1. FTIR Measurement Stage

RAMAN spectroscopy also requires no sample preparation. A component is placed onto a microscope stage with the surface brought into focus through the microscope lens. Figure 2 shows the measurement stage of a Thermo Scientific DXR3 RAMAN spectroscope. The area in focus is the area which will be exposed to the RAMAN laser. The spot size of the RAMAN laser is controlled by the objective chosen where higher magnification results in a smaller spot size. For RAMAN, the laser power needs to be carefully chosen as excessive power can burn the surface, but sufficient power is needed to generate a measurable signal.



Figure 2. DXR3 RAMAN Measurement Stage

FTIR and RAMAN microscopes generate spectra with characteristic peaks. Examples of FTIR and RAMAN spectrums for a polystyrene reference material are shown in Figure 3. The polystyrene reference sample has peaks for FTIR and RAMAN which are used for calibration and verification. The location of these peaks for polystyrene is typically within $\pm 1\text{cm}^{-1}$. Typically peaks which are strongly defined in FTIR are weakly defined in RAMAN and vice versa.

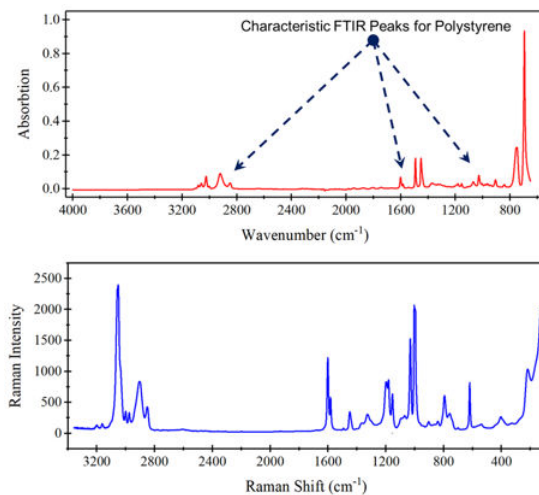


Figure 3. FTIR and RAMAN Spectrums for Polystyrene Material

FTIR and RAMAN Spectroscopy in SAE AS6171:

AS6171 includes /8 and /9 for RAMAN and FTIR, respectively. As FTIR and RAMAN spectra contain information about the component encapsulation and marking material along with any other surface chemistry such as coatings and contaminants, they are suitable measurement techniques for counterfeit detection. Per AS6171, authenticating components using RAMAN or FTIR is done by comparing spectra from devices under test to spectra for known authentic components AS6171 requires that a passing component has a 95% or greater correlation score to the known authentic sample. The criteria per AS6171/8 for authenticating

components using RAMAN spectroscopy is as follows. A similar statement can be found in AS6171/9 for FTIR.

8.1 Material Analysis - Comparison of DUT Spectra to Known Authentic Parts. *When a known authentic part is available, one or more spectra shall be obtained from the known authentic part. The spectra obtained from the known authentic part shall serve as the "reference spectra" for comparison with those obtained from the DUT. These spectra shall include the range of wavenumbers from 650 to 4000 cm^{-1} at a minimum, and matching shall be conducted over the whole spectrum. The reference spectra (from the known authentic part) shall be added to a user created database and the DUT spectra compared using an applicable search routine. The lab shall establish matching criteria of at least **95% out of a possible 100% correlation** which shall occur for a material of the DUT to be tentatively judged the same as the material of the known authentic part. Some software packages may display a 0.95 out of a possible 1.00 correlation, which shall be equivalent to a 95% match.*

Another method that can be used to authenticate components is to compare spectra against the material safety datasheet (MSDS) published by the manufacturer. FTIR and RAMAN systems can break down the individual materials that make up the various peaks in a complex spectrum and identify the chemical compounds for each material.

Figure 4 is an example of a plastic encapsulation mold compound from a Texas Instruments MSDS. 80-90% of the molding compound is composed of fused silica (amorphous SiO_2), 10-20% being epoxy/resin and carbon black as the coloring agent. What differentiates the molding compounds of each manufacturer is the various other additives which are often at very low percentages. The spectrum from a sample can be analyzed for its constituent components and compared to the MSDS to determine if the sample contains any substances that are not in

the MSDS or lacks a specific substance found in the MSDS. Typically, this analysis is best done with both FTIR and RAMAN as some materials only have strong peaks in FTIR or RAMAN but not both.

Category	Material	CAS No.	Weight (g/mol)	% by Weight	Mass (mg)
Other Inorganic Materials	Fused Silica	60676-86-0	397.33	88.00%	880.000
Other Organic Materials	Carbon Black	1333-86-4	1.35	0.30%	3.000
Other Organic Materials	Organic Phosphorus	1330-78-5	2.48	0.55%	5.500
Thermoplastics	Epoxy	85954-11-6	50.34	11.15%	111.500
Sub-Total	—	—	451.51	100%	1,000.000

Figure 4. Plastic Encapsulation Mold Compound

The last method for counterfeit mitigation is to do a comparison of FTIR or RAMAN scans of the top and bottom surfaces of the component. Assuming that both top and bottom surfaces are made of the same materials, the top and bottom surfaces should have the same surface chemistry. Components which are not remarked or resurfaced counterfeits should have a correlation score of > 95% when comparing top and bottom surfaces. This method is only applicable to determine if a component top surface has been modified (remarked/resurfaced) and will not be useful for detecting clone counterfeits which have homogenous top and bottom molding compound.

Establishing a robust and extensive library of RAMAN and FTIR spectra for known authentic and counterfeit components is the best strategy for developing RAMAN and FTIR for counterfeit mitigation. Scanning components in various package types from different assembly locations across all date codes for each manufacturer provides the best coverage for all the variables that could influence correlation scores.

Benefits of FTIR and RAMAN Spectroscopy for Counterfeit Mitigation:

FTIR and RAMAN spectroscopy can efficiently and accurately identify resurfaced or remarked counterfeits. With an established library of authentic spectra, resurfaced or remarked counterfeits can be identified in less than 10 minutes. The advantage, specifically for FTIR, can be seen in a case study using FTIR to analyze samples of Xilinx XC3000 FPGAs. Figure 5 shows photos of samples from two different lots of Xilinx XC3030A-7PC84C FPGA.

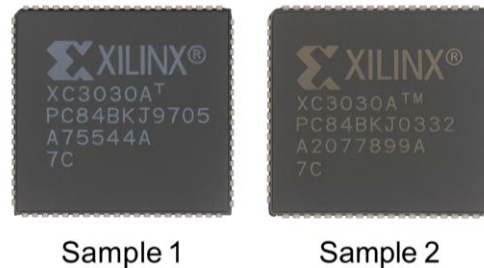


Figure 5. Xilinx XC3030A-7PC84C FPGA Samples

SMT has an established FTIR spectra model for Xilinx plastic encapsulation molding compound (Figure 6) in the PLCC84 package (Xilinx package code PC84).

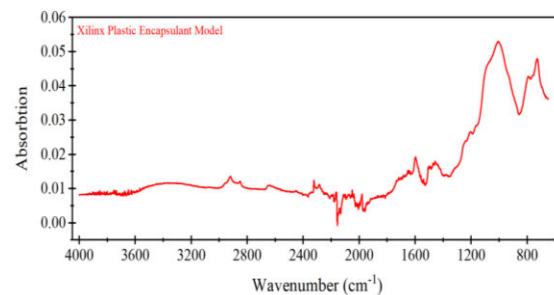


Figure 6. FTIR Spectra Model for Xilinx Plastic Encapsulation Molding Compound

FTIR measurements were performed on the two samples shown and the spectra were overlaid on the Xilinx plastic encapsulant FTIR spectra model. Figure 7 shows the spectra from Sample 1 (blue) and Sample 2 (green) along with the model (red).

Sample 1 has identical spectra to the model and Sample 2 is a remarked counterfeit. Correlation scores of 97.68% for Sample 1 and 6.98% for Sample 2 quantitatively verify what was qualitatively observed.

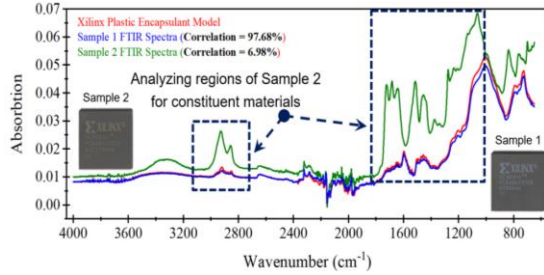


Figure 7. Comparison of Xilinx Samples

The FTIR software can analyze various areas in a spectrum and provide a breakdown of the individual materials with correlation scores to specific materials. Analyzing the two highlighted regions from the Sample 2 FTIR spectra (Figure 8), the software reports that the regions to be resurfacing material which is most likely made of varnish or paint.

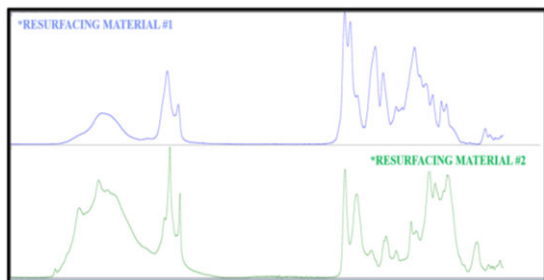


Figure 8. Analysis of Sample 2 Deviations

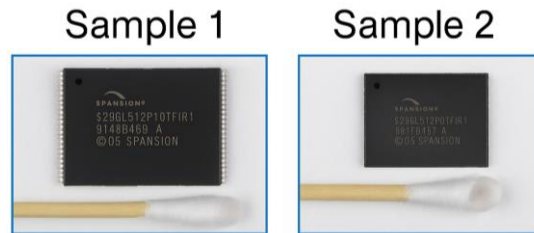
Another advantage of FTIR and RAMAN is the ability to verify remarking and resurfacing evidence that is too subtle to conclusively determine from counterfeit mitigation test methods. SMT recently performed counterfeit mitigation testing on lots of Spansion S29GL512P10TFIR1 flash memories (Figure 9).



Sample 1 Sample 2

Figure 9. Sample 1 and 2 of Spansion S29GL512P10TFIR1 Flash Memories

As part of the AS6171 counterfeit mitigation testing, solvent testing for resurfacing was performed. Sample 1 showed no evidence of material transfer to the cotton swab, however Sample 2 showed a small amount of material transfer to the cotton swab (Figure 10).



No indication of resurfacing material.

Slight indication of resurfacing material.

Figure 10. Solvent Test Results

Material transfer during heated solvents testing is associated with liftoff of resurfacing material but can also occur for authentic components when the plastic encapsulation softens during exposure and partially transfers to the cotton swab. As there was only a subtle degree of transfer to the cotton swab for Sample 2, additional testing was required to verify the results. FTIR was used to analyze the surface of the components to determine if the material transferred was from resurfacing or was accidental transfer of plastic.

At the time of this paper, SMT did not have any reference spectra for authentic Spansion flash memory. With the primary concern being

resurfacing, the top and bottom FTIR comparison method was utilized to check for differences in surface chemistry to verify the results from solvent testing. The results (Figure 11) for Sample 1 show a 98.9% correlation from top to bottom surfaces which corroborate the lack of material transfer observed in solvent testing. The FTIR results for Sample 2 show a correlation of 85.2% between the top and bottom surfaces.

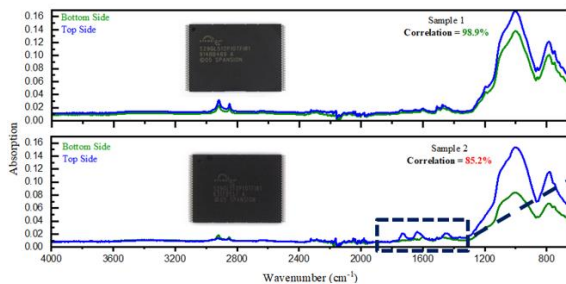


Figure 11. FTIR Comparison of Top and Bottom for Spansion Sample

While the overlaid scans visually appear to be similar there is a small region centered around 1600cm⁻¹ where there are several unique peaks in the top surface that are not found on the bottom surface. Zooming in on this region shows the subtle and thin resurfacing that was applied to the surface of sample 2 resulting in a correlation score less than 95% validating that the material transfer in solvent testing is in fact resurfacing material.

FTIR and RAMAN spectroscopy also have the advantage of accurately identifying the individual components from the various peaks in the spectra. This accuracy is of most importance for detecting clone components. Unlike remarked or resurfaced counterfeits, clone counterfeits do not have evidence of any modifications to the surface where the plastic encapsulation is homogeneous from top to bottom. An example of using RAMAN microscopy to differentiate between authentic and clone components can be

seen in a case study for Texas Instruments OP07CP Op Amps (Figure 12).

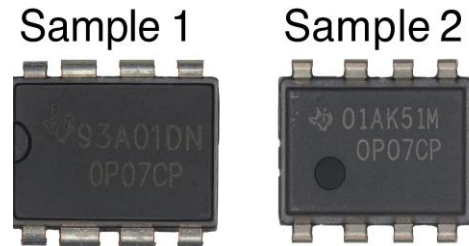


Figure 12. Samples 1 and 2 for Texas Instruments OP07CP Op Amps

In this case study, SMT has a sample of a clone version along with samples of the authentic component. For reference, when both samples are subjected to scanning electron microscopy testing there is no evidence of surface texture differences across the edge of the components (Figure 13) which is expected for both authentic components as well as clone counterfeits. Evidence of surface texture is commonly associated with resurfacing or surface modifications that occur for traditional counterfeits.

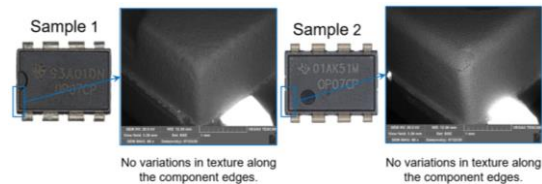


Figure 13. SEM Results for OP07CP Op Amp Samples

To determine what differences can be observed between authentic and clone components, RAMAN microscopy was used to scan the surface of each sample. Figure 14 shows the RAMAN spectra for Sample 1 (blue) and Sample 2 (red). The highlighted region is the dotted rectangle that shows two peaks which are correlated to carbon black. Carbon black is known to have strong RAMAN peaks and is expected to be a component in the plastic encapsulation for a Texas Instruments OP07CP op amp.

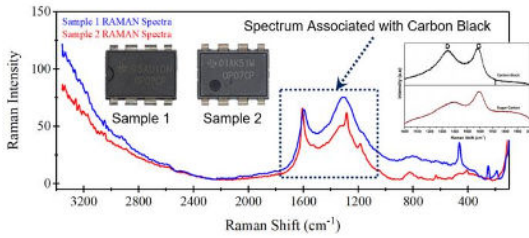


Figure 14. RAMAN Spectra Comparison of OP07CP Op Amp Samples

This is known from the published MSDS from Texas Instruments for a OP07CP. An important fact to note is that the percent composition of a material per the MSDS is not directly correlated to the strength of the RAMAN or FTIR response. Although carbon black is less than 1% of the plastic encapsulation, it has a very strong peak in RAMAN due to its absorption of the incident laser. Another peak of interest is observed in sample 1 in a region between 300 and 600 cm^{-1} . Figure 15 shows the same RAMAN results but with a zoomed in inset graph of the region with a peak in sample 1 at 460cm^{-1} .

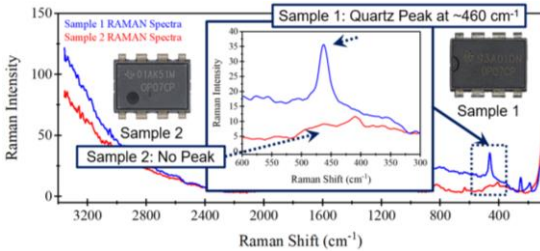


Figure 15. RAMAN Spectra comparison for OP07CP op amp samples

The software reports this peak is correlated with quartz (crystalline SiO_2). This peak is not observed in sample 2. Per the MSDS, the plastic encapsulation is primarily composed of fused silica. Both sample 1 and sample 2 contain SiO_2 in the plastic encapsulation but the RAMAN spectroscopy system can differentiate between the structure of the material. Crystalline solids are highly ordered structures with repetitive atomic structure whereas amorphous solids have

no ordered structure with disordered atomic arrangement. The response to the RAMAN laser is different for the different structures of SiO_2 .

Based on the results, it was determined that sample 1 is a clone component due to the presence of quartz in the RAMAN spectra which is not found in the manufacturer’s MSDS.

Based on the observation of quartz in this clone example, SMT examined a variety of clone samples to see if quartz is a “fingerprint” that would observe in any clone counterfeit. SMT analyzed 20 different clone part numbers using RAMAN spectroscopy. A sample of 3 sets of clones and authentic parts is shown in Figure 16 for three different part types.

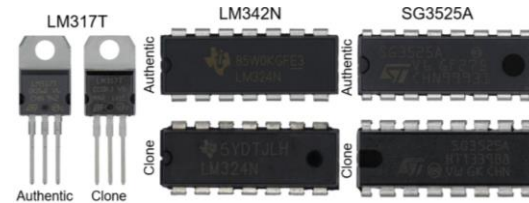


Figure 16. Quartz Study Samples

The RAMAN results for these 3 sets of part numbers (Figure 17) show that all 3 of the clone versions include quartz peaks at 460cm^{-1} . Out of the 20 different clone part numbers analyzed, 14 parts were observed to have quartz in the RAMAN spectra. While not all clone parts included quartz, the presence of quartz should be considered a red flag that warrants further investigation and SMT considers quartz in the RAMAN spectra as a “fingerprint” for clones.

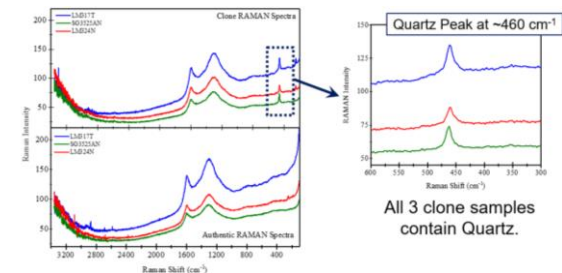


Figure 17. Results of Quartz Study on 3 Samples

Considerations for FTIR and RAMAN Spectroscopy for Counterfeit Mitigation

The primary challenge for FTIR and RAMAN spectroscopy for counterfeit mitigation is the requirement of a robust and extensive library of RAMAN and FTIR spectra for authentic and counterfeit components (including clones). Any single RAMAN or FTIR result in isolation is not sufficient evidence for an unknown device without comparison against a set of reference data or models. None of the FTIR or RAMAN manufacturers sell material database libraries that can be used to perform this comparative analysis, so the database needs to be created using samples of authenticated and counterfeit components. Access to a wide range of devices from different manufacturers, date codes, assembly locations, package types is needed to establish a comprehensive library. Without the library both false positive and false negative results could occur for RAMAN and FTIR.

In early 2025, SMT began the process of creating a large electronic component library to be used in our RAMAN and FTIR analysis. The process involves scanning three samples per part in both RAMAN and FTIR regardless of customer requirements so that all in-process work builds the library database. As all the parts will undergo AS6171 authentication testing, the FTIR and RAMAN results will be corroborated through the other counterfeit mitigation tests normally performed. In addition to scanning parts that are active orders by our customers, SMT has access to 150,000 unique electronic component part numbers through Excesser, Inc., which has a large inventory of electronic components that can be used to build the library and for real-time comparisons to active SMT orders if the need arises.