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**Infrared Imaging Applied to the Forensic Examination of Automotive Paint  
Honors Thesis**

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# Chapter I

## Introduction

### 1.1 Criminalistics

Forensic science in its broadest definition is the application of science to criminal and civil laws enforced by local, state and federal police agencies in the criminal justice system [1, 2]. Criminalistics is the application of chemistry, physics, microscopy, biochemistry, and other basic sciences to the study of facts and objects relevant to the crime from which a reconstruction and understanding of the crime scene can be developed for the purpose of ascertaining the guilt or innocence of an accused person [3]. Criminalistics, the subject of this honors thesis, should not be confused with criminology, which is a discipline that utilizes the social sciences (e.g., sociology and psychology) to study criminal behavior for the expressed goal of identifying the social forces linked to crime [4].

Criminalistics is about the examination of physical evidence (e.g., fingerprints, glass, paint, and tool marks) to ascertain both the class and individual characteristics of the object or material recovered from the crime scene in order to establish an identity between the evidence (i.e., query sample) and a comparison-test standard (i.e., reference sample). Attributes shared by a group of similar objects can be used to identify the class characteristics of the recovered material, whereas the individual characteristics of the object can be used to discriminate it from objects that share the same class attributes. Physical evidence can provide crucial information about the crime scene and/or the investigation. As physical evidence is factual, it cannot be falsified nor is it wrong. However, it can be misinterpreted, which would devalue its significance. The importance of physical evidence at a crime scene is best understood by considering Locard's exchange principle

[5], which states that an exchange of materials occurs whenever two or more objects come into contact with each other. For a crime scene, objects or materials are added or removed when the perpetrator comes in contact with the crime scene. It is precisely those objects/materials that are removed or added which is the basis for the physical evidence recovered at a crime scene or from the perpetrator of the crime. This is the reason for physical evidence often being referred to as the “silent witness.” Clearly, physical evidence may be crucial in a legal proceeding as it can link the defendant to the crime.

Physical evidence collected at a crime scene can be divided into three broad categories: trace, impression, and pattern evidence. Trace evidence [6] refers to small (often microscopic) amounts of materials that are readily transferred between people and places. Examples of trace evidence include biological fluids (e.g., blood, semen, and saliva), illegal drugs, fibers, hair, glass, paint (architectural and automotive), petroleum products (as accelerants for arson), polymers (e.g., plastics and rubbers), and geological materials. Bodily fluids have been used to link or exclude an individual as a suspect. DNA is extracted from saliva or semen and searched against a database to determine its origin (i.e., the identity of the individual or individuals associated with the bodily fluids). Illegal drugs recovered from a crime scene are analyzed using spectroscopic methods to identify the controlled substance in the seized sample and the manufacturer and/or source (location of sale) using infrared or gas chromatography/mass spectrometry. Hair and fibers, natural or synthetic, usually are matched to comparable substances in a reference collection by common class characteristics to indicate chemical make-up, manufacturer and location of sale. Often, hair and fiber can be individualized to the definitive source from which they originated at the exclusion of all others. By comparing the fibers or hairs found at a crime scene to those recovered from an individual using visible microscopy, a suspect can be linked to the crime scene. Glass shards,

which are often found on the hair, clothing, and shoes of a burglar, can be assigned to specific classes using optical and nonoptical methods of analysis as well as individualized through a fracture match. Paint is also transfer evidence and can provide important clues in investigations involving vehicular crimes. Petroleum products, which are often used as accelerants in arson cases of arson, allow the forensic examiner to reconstruct how the crime was committed and link a suspect to the arson. Geological material, e.g., soil and minerals, found at the crime scene and on the suspect can provide crucial evidence linking the suspect to the crime scene. Because trace evidence is used to associate a suspect with a crime scene, it is often referred to as associative evidence.

Impression evidence [7] often consists of markings generated when one object comes into contact with another, causing an indentation or print to be formed on the second object. Examples of impression evidence include tool marks, tire tracks, shoe prints, and fingerprints. A tool mark occurs as a cut, scratch or abrasion on a softer surface. Even if the suspected tool is not recovered, tool marks left at one crime scene could match those found at other crime scenes suggesting that several crimes were committed by the perpetrator. Tire impressions and footwear are usually found at access or escape routes at crime scenes and can provide a means to identify or exclude a suspect. Impressions made by shoe prints and tire treads often show general features that provide class information, e.g., manufacturer, size and brand. Fingerprints, which are impressions deposited on a surface by the friction ridges of a human finger, is one of the most commonly used forms of forensic evidence. Fingerprints, as in the case of other forms of impression evidence such as tool marks or shoe prints, can directly tie a suspect to the crime scene.

Pattern evidence [8] allows the investigator to reconstruct the actual sequence of events which occurred at the crime scene as well as provide investigative leads. Often, pattern evidence

is referred to as the “mute witness” that can support or contradict statements by witnesses or potential suspects. Examples of pattern evidence include explosion patterns and blood stain patterns. Damage patterns due to explosives can provide investigators with information about how the detonation occurred, specifically the direction of the blast, and the actual site at the crime scene where the detonation occurred. Blood stain patterns, also known as blood spatter, can provide information about the events that occurred during the crime through examination of how the blood is distributed at the crime scene.

## **1.2 Automotive Paint**

Automotive paint is an important category of trace evidence that can provide crucial links in the early phase of an investigation or evidence of association in criminal proceedings. Automotive paint in the form of a chip is often the only physical evidence recovered at the crime-scene of a vehicle related fatality such as a head-on collision or a hit-and-run where injury or death to a pedestrian may occur. An automotive paint chip typically consists of four layers: clear coat, color coat, surfacer-primer and e-coat [9]. All layers contain binder, which serves as the glue that holds the layer together. With the exception of the clear coat layer, each layer may also contain pigments (which are the component responsible for color) and fillers (which are added to a layer to improve its properties). Automotive vehicle manufacturers tend to use a unique combination of pigments and binders in each layer of the paint. It is this unique combination that allows the forensic paint examiner to determine the make, line, and model of a vehicle (within a limited production year range) from which the paint chip originated.

The analytical method used to identify automotive paint relies on the selective absorption of infrared (IR) light by the components in the paint. Each paint layer is physically separated and placed between two diamond anvil cells. Each layer has a unique fingerprint which is reflected in

its IR spectrum. The comparison of the IR spectrum of each paint layer in a manufacturer's paint system (clear coat, color coat, surfacer-primer and e-coat) spectra in an automotive paint database allows the assembly plant at which the paint system was applied to be identified. The database most often used by forensic paint examiners is the paint data query (PDQ) database which was developed by the Royal Canadian Mounted Police.

### **1.3 PDQ Paint Database**

PDQ is a database of the physical attributes, the chemical composition and the IR spectrum of each layer of the original manufacturer's paint system [10-12]. The PDQ concept is to narrow the list of possible vehicles to a reasonable number of potential suspects, not to identify a single vehicle. PDQ contains the complete color, chemical composition, layer sequence and sourcing information on known manufacturer's paint systems as well as the IR spectra of each paint layer, and search and retrieval software to generate a hit list. To use this database, the forensic scientists must first translate the chemical formulation of each paint layer into specific text codes based on the Fourier transform infrared (FTIR) spectrum of the layer. The scientist then enters the color, chemical composition, and layer sequence information derived from the examination and analysis of the paint chip. The software searches the database, comparing all records for make, line, model and years having a paint system similar to the coded information inputted by the user. The final step in this process is to confirm the suitability of each hit as a potential match by manually comparing the IR spectra of each unknown paint layer against the spectra identified in the database and associated with the hit list. PDQ can also serve as a source of information to assist the user in assessing the significance of a correspondence between a questioned sample and known original paint system.

PDQ is a source based, not a population based database. Hence, information culled from querying the database will not result in the frequency of occurrence population statistics for the number of vehicles on the road having a particular paint system. However, it will provide an indication of which vehicles manufactured over the past forty years have similar paint systems. This is valuable information in the quest for quantitative assessment of evidence significance. PDQ is the largest international automotive paint database in existence.

#### **1.4 Forensic Automotive Paint Analysis**

In the forensic examination of automotive paint, each layer of paint is visually and chemically analyzed. The paint sample examined often consists of multiple and unique layers of paint. The more unique the paint layers are in the sample, the more information is contained in the sample and the stronger are the forensic conclusions that can be drawn. However, for each additional layer of paint in a sample, more time must be spent analyzing the sample because, currently, each layer must be analyzed individually. For architectural paint, forensic science is normally interested in comparing each layer from a crime scene, such as a door frame, to a suspect, such as a pry bar found in the suspect's possession. Likewise, for automotive paint, paint found on the clothing of a victim of a hit-and-run incident may be forensically compared to the paint from a suspect's vehicle. However, often, there are no witnesses to a hit-and-run and police are unable to develop a suspect. In these situations the chemistry of the automotive paint layers recovered from the victim's clothing may be analyzed and, with the aid of an automotive paint database, the data can be correlated with a particular model from an automobile manufacturer. This information can then be used to assist the police to find the vehicle involved.

The chemical analysis of paint samples in forensic laboratories is typically done using FTIR [13]. Some laboratories, particularly in Europe, will embed the entire paint fragment, cross-



section it, and then analyze each layer using an IR microscope fitted with an ATR accessory. Other forensic laboratories, particularly in North America, are more likely to hand-section each layer and present each separated layer to either an IR microscope fitted with an ATR accessory, or will collect transmittance spectra directly by placing the layer between diamond anvils. With either technique, sampling too close to the boundary between adjacent layers may produce an IR spectrum that is a mixture of the two layers. Not having a “pure” spectrum of each layer will prevent a meaningful comparison between each paint layer or, in the situation of searching an automotive paint database, will prevent the scientist from developing an accurate hit list.

One way to minimize the time necessary for data collection would be to collect concatenated IR data from all of the paint layers in a single analysis. This would be achieved by scanning across the cross-sectioned layers of a paint sample using an IR microscope. Once the data has been collected, it could then undergo deconcatenation using chemometrics (e.g., multivariate curve resolution techniques) to obtain a “pure” IR spectrum of each paint layer. This approach, not only eliminates the need to analyze each layer separately, but would also ensure that the final spectrum for each layer is “pure” and not a mixture from the interface between layers. Minimizing the probability of collecting a mixed spectrum would result in a time savings as well as objectively ensuring that only “pure” spectra from each layer have been collected and are used in subsequent comparisons or database searches. IR spectral data of automotive paint is particularly well-suited to the exploration and application of concatenation-deconcatenation methods because a large database of pure IR spectra from automotive paint systems already exists in the form of the Royal Canadian Mounted Police’s PDQ database.

The research described in this honors thesis is directed towards three specific goals: (1) development of a methodology to prepare thin sections of an automotive paint chip (which

involves exposing the edge of the sample using a microtome) for IR image analysis, (2) application of multivariate curve resolution techniques to deconvolute the IR spectral image into the layers of the paint comprising the paint chip from which the image is generated, and (3) determining the investigative lead information present in a paint smear using attenuated total reflection IR imaging microscopy. For this study, a procedure to simulate the type of paint smear generated in vehicle-vehicle or vehicle-pedestrian hit-and-run collisions and recently developed in the lab of Professors Barry K. Lavine (Department of Chemistry) and Professor Kaan Kalkan (Department of Mechanical and Aerospace Engineering) at Oklahoma State University (OSU) was utilized. Currently, paint smears encountered in a vehicle collision cannot be created in a laboratory. The technique developed by these two OSU faculty members can simulate an automobile collision with controllable collision speed and direction as well as momentum/energy transfer. A long term goal of the proposed paint transfer system is the development of forensic standards for automotive paint transfer and paint smear analysis.

## Chapter II

### Background and Methodology

#### 2.1 Introduction

An automotive paint chip recovered from a vehicle or the clothing of a pedestrian involved in a hit-and-run is often the only form of trace evidence recovered from the crime scene of a vehicle related fatality. As there are often no witnesses to these crimes, the paint chip cannot be compared to the vehicle of a potential suspect. However, each layer of the paint chip can be examined and compared to a forensic automotive paint database to identify the manufacturer, make, line and model of the vehicle within a limited production year range from which the paint chip originated. The Royal Canadian Mounted Police (RCMP) have reported in several studies [14, 15] that automotive vehicles can be differentiated by make and model by comparing their color, layer sequence and the chemical composition of each layer of the manufacturer's original paint system. A forensic paint database known as the paint data query (PDQ) database was developed by the RCMP to make these forensic comparisons possible [16, 17]. PDQ contains over 21,000 samples with 84,000 individual automotive paint layers, with information about the chemical composition of each layer determined from its IR spectrum collected using a high pressure diamond anvil cell [18].

Automotive paint is a complex multicomponent system applied to the frame of a vehicle to protect it from corrosion, photochemical degradation while providing the vehicle with the desired color and finish [19]. Automotive paint contains binders, pigments and additives. Binder is the polymer matrix that maintains the physical integrity of the paint and serves as the medium for the pigments and additives suspended in it. Acrylic melamine enamel is the most common

binder used in finish coats of North American vehicles [19]. The pigment, which is a powdered compound insoluble in the paint's solvent, imparts color, luster, and opacity to the paint. Titanium dioxide (in the form of rutile) is the most common pigment used in automotive paint coatings. Other compounds such as kaolin, calcite (calcium carbonate), quartz (silicon dioxide) and barites (barium sulfate) known as additives or extender pigments [20], have a refractive index similar to the binder, do not affect its optical properties but increase the bulk matter in the paint. Automotive assembly plants use a unique combination of binders and pigments for each layer of automotive paint. It is this unique combination that allows forensic scientists to determine the manufacturer, make, line, model, and year of the vehicle from a paint chip recovered from a crime scene.

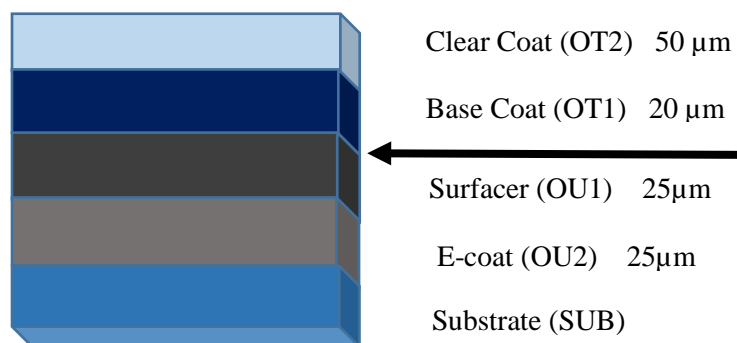


Figure 2.1 Modern automotive paint system

Modern automotive paint systems consist of four distinct layers: e-coat, primer surfacer, color coat and clear coat respectively from the substrate (see Figure 2.1). All four layers contain binder and the color coat, surfacer-prime and e-coat layers contain both pigments and fillers [21]. The metal substrate to which the manufacturer's paint system is applied is pretreated with phosphate to protect it from corrosion and to enhance adhesion of the e-coat layer which is applied to the substrate by electrodeposition. The e-coat layer promotes corrosion resistance for the substrate and provides elasticity and resistance against stone chipping as well as forming a bond with the surfacer primer layer. The function of the surfacer-primer layer is to provide support for

the color coat layer, which imparts a specific color to the vehicle. The attributes of the surfacer-primer layer are defined by the choice of binders and resins used. The top most layer, the clear coat layer, is colorless, glossy and protects the color coat layer from UV radiation. The clear coat layer is the thickest layer (approximately 50 $\mu$ m in thickness compared to 25  $\mu$ m or 20  $\mu$ m for the other layers). Modern automotive clear coats are either acrylic melamine styrene polyurethane or acrylic melamine styrene [22]. Clear coats form a glossy and transparent coating which is in direct contact with the environment. For this reason, the clear coat layer must be resistant to abrasion, stone chipping, and ultraviolet light.

For the forensic analysis of automotive paints, many techniques have been developed to characterize automotive paint samples. Pyrolysis-gas chromatography-mass spectrometry [23-25] is the technique used to characterize the monomers comprising the binders in each layer after hand sectioning the paint chip. The binder decomposes into volatile fragments after applying thermal energy, and these fragments are separated by gas chromatography and characterized by mass spectrometry. The drawbacks of this technique is the lengthy time for analysis and the destruction of the sample. Furthermore, the mass of the sample must be at least 10 micrograms. Many paint chips recovered from the crime scene are often less than 10 micrograms. Other techniques for automotive paint analysis such as scanning electron microscopy coupled with energy dispersive spectrometry and micro-x-ray fluorescence are limited to elemental analysis and are complementary [26].

Raman Spectroscopy [27, 28] is another technique which has been used to characterize an automotive paint sample as it provides information about organic binders, inorganic pigments, and extenders present in the each layer of the paint sample. However, fluorescence is often a problem, and there are no Raman automotive paint libraries for vehicle identification. Infrared (IR)

spectroscopy [29 - 31] is at present the established method for the forensic analysis of automotive paints in North America. IR spectroscopy can characterize binders, extenders, organic and inorganic pigments. However, sample preparation can be lengthy as each layer must be hand sectioned using a sharp scalpel. Furthermore, sampling each layer with a sharp knife or scalpel too close to the boundary between layers can result in an IR spectrum that is a mixture of two paint layers. As a result, the accuracy of an infrared library search can be affected. Not having a “pure” IR spectrum of each layer prevents the forensic paint examiner from developing an accurate hit-list of potential vehicles after performing a search of the unknown paint sample against IR spectra in the PDQ database.

This chapter describes the methodology used to remedy the problems described in the previous paragraph for analysis of automotive paint chips and paint smears. Specifically, the application of transmission and attenuated total reflection infrared spectroscopy can facilitate both the speed and accuracy of forensic automotive paint analysis. In the remaining two sections of this chapter, transmission and attenuated total reflection infrared spectroscopy are described. The discussion on these two techniques is brief and attempts to strike a careful balance between theory and application.

## **2.2 Transmission Infrared Imaging Microscope**

A transmission infrared imaging microscope consists of a FTIR spectrometer coupled to an optical microscope (see Figure 2.2). The entire beam from the interferometer is focused by the condenser onto the sample using Cassegrain optics. The radiation transmitted by the sample is collected by the objective of the microscope and passed to the interferometer and MCT detector

of the FTIR spectrometer. The application of IR microscopy coupled to cross sectioning (which will be described in the next chapter) facilitates both speed and accuracy of the analysis.

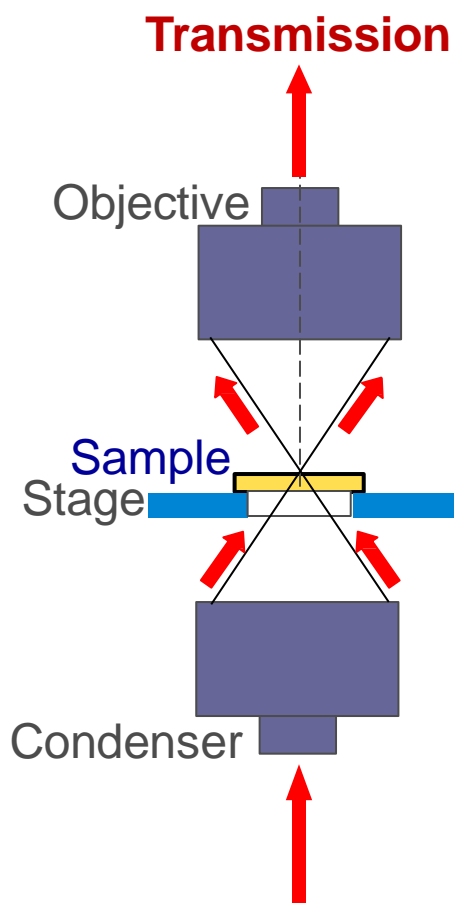


Figure 2.2 Transmission infrared microscope

### 2.3. Attenuated Total Reflection (ATR) Infrared Imaging Microscope

An attenuated total reflection FTIR imaging microscope is shown in Figure 2.3.

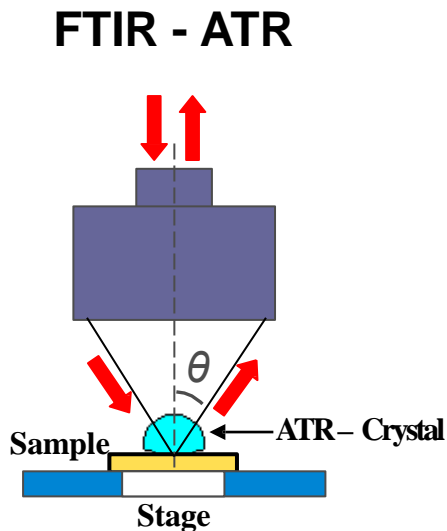


Figure 2.3 Attenuated total reflection infrared microscope

The microscope utilizes reflecting optics and spherical surfaces adapted to infrared radiation in order to minimize optical aberrations [32]. The spatial resolution that can be achieved by an ATR imaging microscope is given by Equation 2.1 where  $d$  is the spatial resolution,  $\lambda$  is the wavelength, and  $NA$  is the numerical aperture of the microscope objective, which is defined in Equation 2.2, where  $\theta$  is the half-angle of the inverted cone of illumination entering the objective, and  $n$  is the refractive index of the imaging medium. (The half-angle of the cone is used in this equation since only half of the inverted cone of illumination is passed to the sample.) In a transmission microscope, the numerical aperture is equal to 0.6 (as  $n = 1$  and the half-angle of the cone is  $36.87^\circ$ ) and the spatial resolution can be approximated by the wavelength of the radiation. For an ATR imaging microscope using a germanium crystal, ( $n = 4$  and the numerical aperture equals 2.4), the spatial resolution is one-fourth of the wavelength of the incident radiation.



$$d = \frac{1.22\lambda}{2(NA)} \quad (2.1)$$

$$NA = n_1 \sin \theta \quad (2.2)$$

Due to the magnification provided by the Germanium ATR crystal, the size of the sample image interrogated by the IR microscope is only one-fourth the size of the corresponding sample image for the transmission microscope. For example, a 25 $\mu\text{m}$  x 25  $\mu\text{m}$  map image which is typically used in transmission infrared microscopy as it is the minimum size needed to obtain enough infrared energy corresponds to 6.25  $\mu\text{m}$  x 6.25  $\mu\text{m}$  field of view in ATR infrared microscopy. This is a significant advantage over transmission when analyzing a laminated structure such as an automotive paint chip whose layer thicknesses are typically 20  $\mu\text{m}$ .

## Chapter III

### Results and Discussion

#### 3.1 Analysis of Automotive Paint Chips

In a vehicle related fatality such as a “hit-and-run” where injury or death to a pedestrian has occurred, paint fragments containing all four layers are often transferred from the vehicle to the victim's clothing or to an object such as a post. To analyze these paint fragments, a new approach to automotive paint analysis has been developed which is highlighted in this thesis. The new approach to forensic automotive paint analysis involves cross sectioning the paint fragment with a microtome and then collecting infrared spectra from the entire paint chip in a single analysis by scanning across each layer using a transmission or ATR infrared microscope. After the spectral data from the microscope has been collected, the data is subject to deconvolution using alternating least squares to extract the “pure” IR spectrum of each layer from the image. Cross-sectioning eliminates the need to analyze each paint layer separately and is faster than the current method which involve hand sectioning each layer. The use of an imaging method can ensure that an IR spectrum of each paint layer is “pure” and is not a blend of multiple layers. The benefit of not collecting a mixed IR spectrum is higher quality matches when performing searches against PDQ or other forensic automotive paint databases.

For vehicle related fatalities involving pedestrians, the size of the paint fragment transferred from the vehicle to the clothing of the pedestrian is often less than one mm in length. These chips are too small to hand section or to cross section for infrared image analysis using a conventional microtome. For these paint fragments, the use of a Leica EMUC<sub>6</sub> ultra-microtome for cross sectioning the paint chip in order to obtain a representative sampling of all four layers

has been investigated as part of this thesis research. The Leica EMUC<sub>6</sub> equipped with both glass and diamond knives has been used by other workers to section very small tissue samples for microscopic analysis. The sample holder of the Leica EMUC<sub>6</sub> (which is designed to accommodate samples of one mm or less in size) and a controller that can be used to adjust the cutting window to a specified sample thickness (as small as 700nm to 900nm) is ideally suited for these small paint fragments (i.e., paint slithers).

Figure 3.1 depicts the cross sectioning of a one millimeter paint chip using the Leica EMUC<sub>6</sub> ultra-microtome. The paint chip is separated from the metal substrate containing the paint sample by first bending the substrate using pliers and then cutting off a one millimeter fragment to mimic an automotive paint sample that is recovered from a crime scene. The one millimeter paint fragment is firmly placed in the sample holder of the ultra-microtome. A glass knife is then inserted into the knife holder and onto the stage at 6° clearance angle. The flywheel of the ultra-microtome is rotated to bring the sample towards the glass knife for cross-sectioning. The cross sectioned sample is collected in a small vial containing water because the ultrathin samples (approximately 900 nm thick) may otherwise stick to the surface of the vial and become brittle when being transferred to a FTIR microscope for paint analysis.

For IR image analysis, the cross sectioned sample is removed from the water using a wire loop attached to a small stick and a magnifying glass to view the sample. This procedure is straight forward. The cross sectioned sample is then placed on a Barium Fluoride (BaF<sub>2</sub>) disk, and the microscope is focused on the sample with an area selected that contains all four layers which ensures that IR transmission spectra of each layer is collected. The objective aperture of the IR transmission microscope was set to 50 x 50 microns, the spectral resolution was 4 cm<sup>-1</sup>, and the step size was assigned a value of 3 x 3 microns.

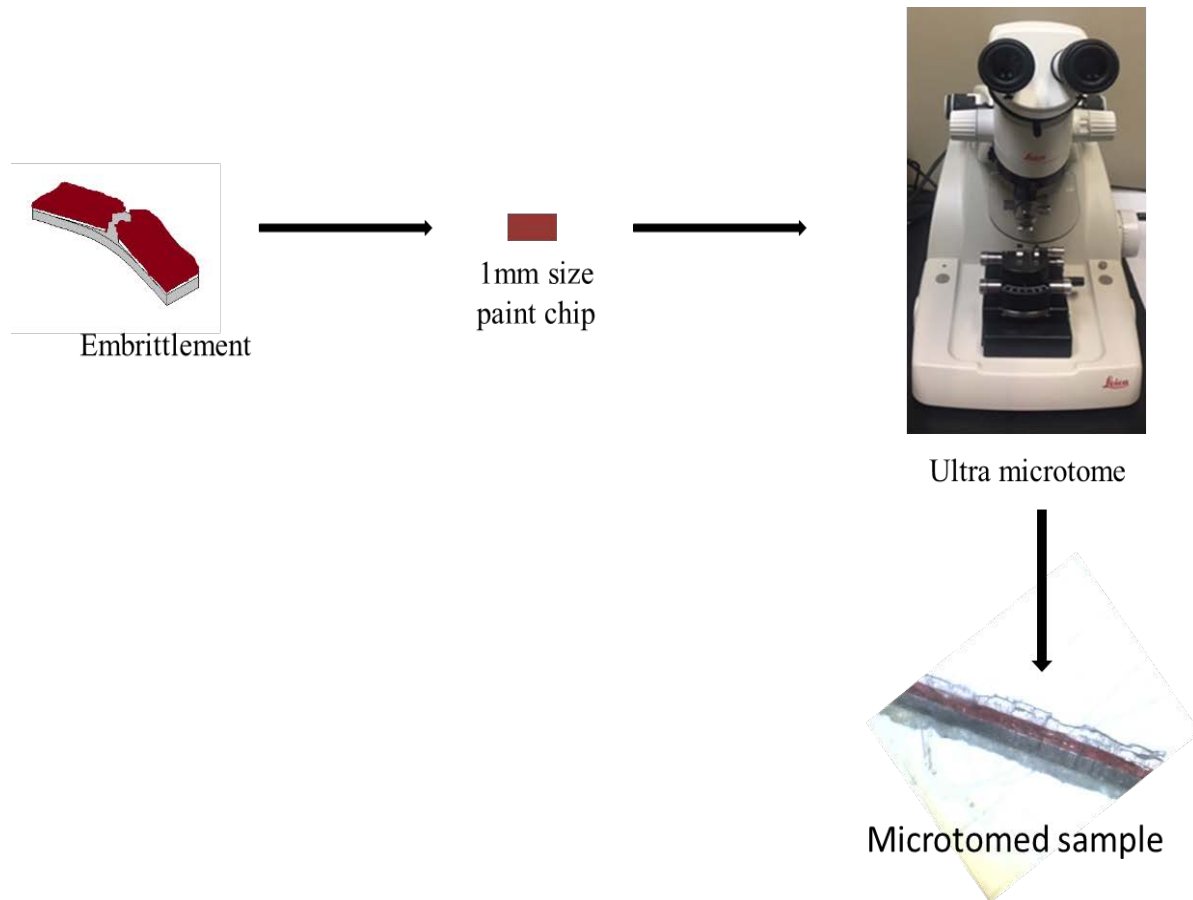


Figure 3.1. Schematic depicting the preparation of cross sectioned automotive paint samples for this study

To demonstrate proof of concept and evaluate the efficacy of the proposed cross sectioning procedure, an infrared image map of a one millimeter cross sectioned automotive paint chip was obtained. The paint chip used in this study was obtained from a 2002 Chrysler Jeep JBT manufactured in the Toledo, Ohio assembly plant. The infrared image was unfolded using an oblique transit to generate a line map of the spectral data. Both the starting point and endpoint for the transit was the unoccupied region of the BaF<sub>2</sub> disk adjacent to the cross sectioned paint sample.

Figure 3.2 shows an image of the cross sectioned paint chip (PDQ Number UAZP00421) from the 2002 Chrysler Jeep JBT on the BaF<sub>2</sub> disk. All four layers (clear coat, color coat, surfacer-primer, and e-coat) are visible and the borders between the layers are well defined.

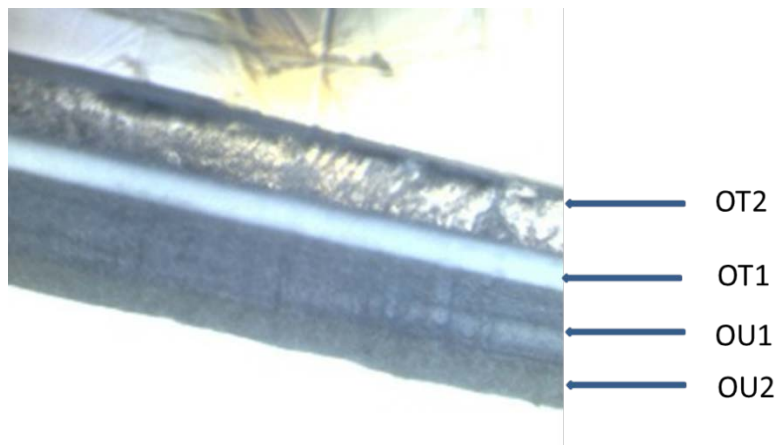


Figure 3.2. Cross section of a one millimeter paint chip (UAZP00421). OT2 = clear coat, OT1 = color coat, OU1 = primer-surfacer, and OU2 = e-coat. All four layers are visible and the borders between the layers are well defined.

The infrared spectra of the individual paint layers comprising the line map were reconstructed by alternating least squares. Comparing each reconstructed infrared spectrum against a Chrysler spectral library from the PDQ database, high quality matches were obtained for the clear coat, surfacer-primer and e-coat layers (see Figures 3.3 thru 3.5). Furthermore, each match was a top five hit. When the reconstructed infrared spectrum of the clear coat layer was searched against the Chrysler clear coat paint library from the PDQ database, the top hit corresponded to the same line, model and production year. For the reconstructed infrared spectra of the surfacer-primer and e-coat layers, the correct match was the second hit and fifth hit respectively. Although the infrared spectrum of the color coat layer was also reconstructed from the spectra comprising the line map, the large variation in its IR spectrum due to scattering by the pigments present in this layer precluded its use in a library search.

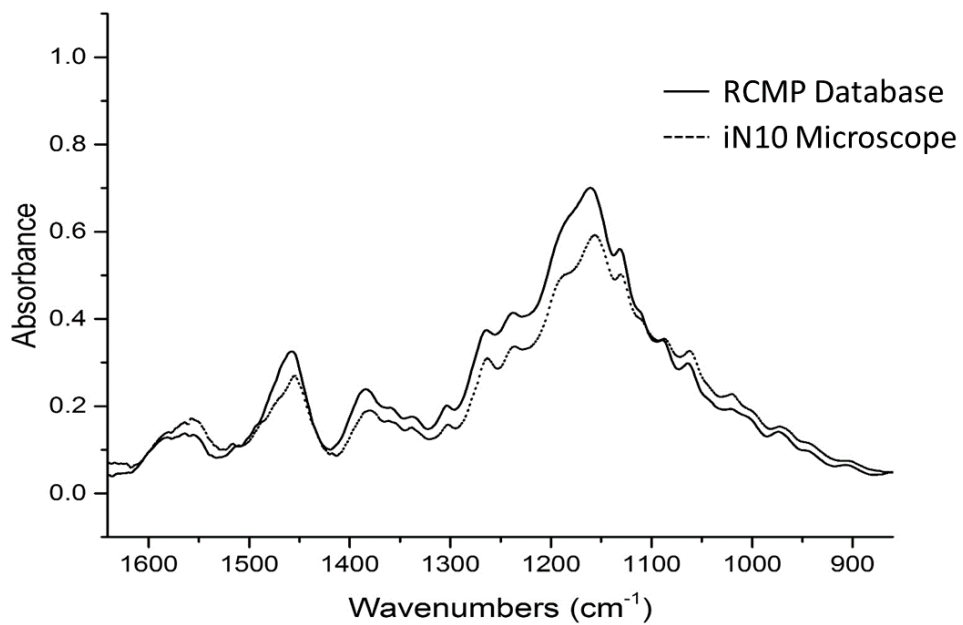


Figure 3.3. Comparison of the ALS reconstructed clear coat IR spectrum (dashed line) to the IR spectrum of the actual paint sample ((UAZP00421) in the Chrysler spectral paint library.

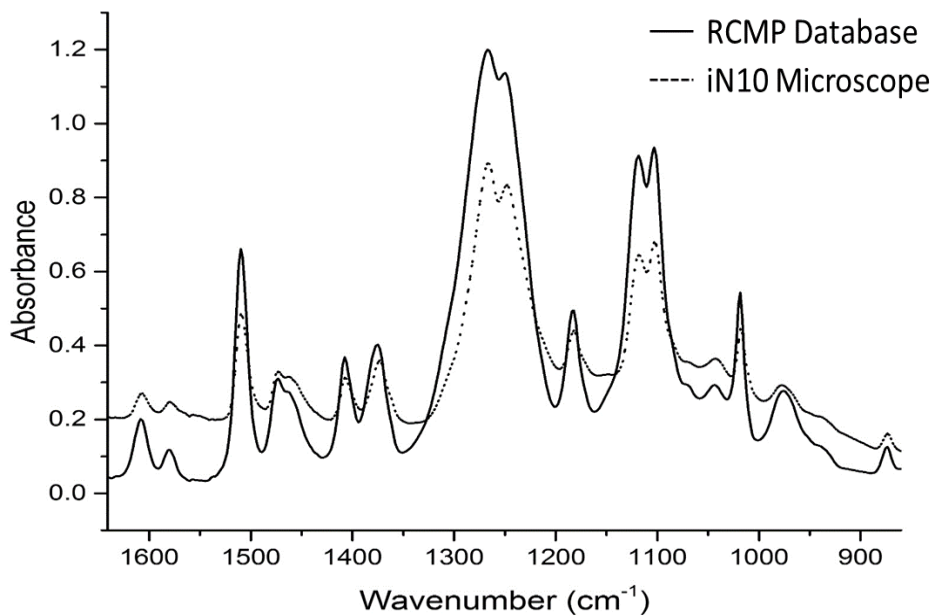


Figure 3.4. Comparison of the ALS reconstructed surfacer-primer IR spectrum (dashed line) to the IR spectrum of the actual paint sample ((UAZP00421) in the Chrysler spectral paint library.

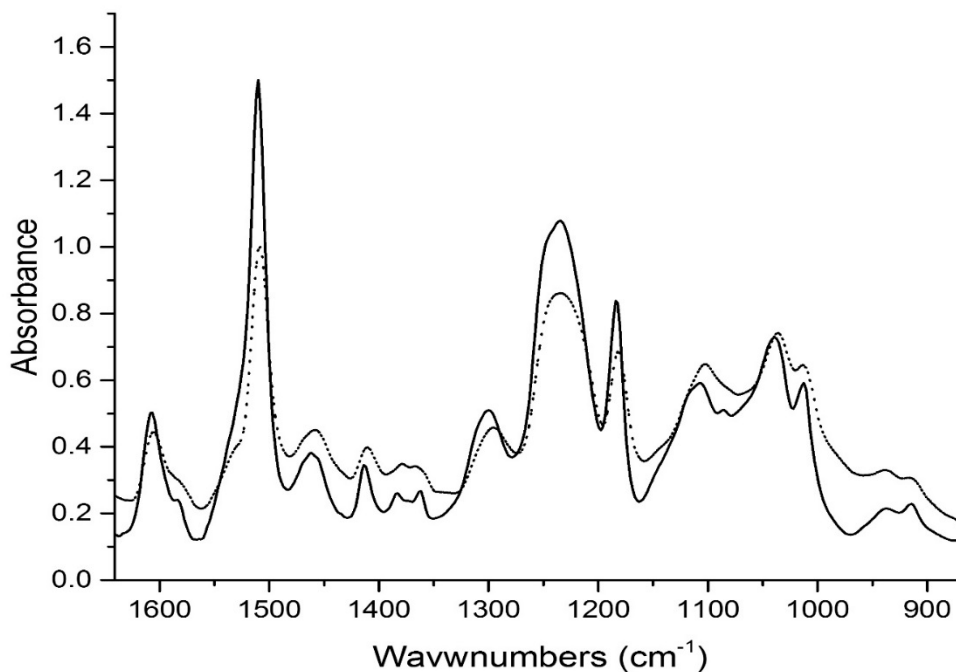


Figure 3.5. Comparison of the ALS reconstructed e-coat IR spectrum (dashed line) to the IR spectrum of the actual paint sample (UAZP00421) in the Chrysler spectral paint library.

### 3.2 Analysis of Automotive Paint Smears

A second thrust of this honors thesis was the development of an infrared spectroscopic method to characterize paint smears (e.g., abraded or deformed clear coats, clear coat and color coat layers mixed together, or clear coat, color coat, surfacer-primer, and e-coat layers mixed together) as a result of paint transfer from an automobile substrate to a substrate. Realistic paint smears are difficult to analyze because of the mixing of the various layers of the automotive paint. Furthermore, changes in the chemical structure of the polymer comprising each layer in the smear may occur because of the heat generated by the collision in turn inducing the paint transfer. To this end, a standard Charpy impact tester [35] was used to simulate a collision between two

vehicles in regards to paint transfer. The automotive paint sample used for the paint transfer experiment was obtained from the PDQ database and was a 2001 Chevrolet Tahoe (UAZP00435) manufactured in Arlington, TX. The automotive substrate used in this simulation experiment to collect the paint transfer was placed on the stage of the infrared microscope (see Figure 3.6). Setting the aperture at 150 x 150 with a step size of 5 x 5 and the number of scans at 128, the infrared microscope (operated at  $4\text{cm}^{-1}$ ) was initially set to reflection mode. This allowed us to preview the infrared spectra of the smear and to visually select points on the substrate for ATR analysis. After selection of the desired points, the operation of the infrared microscope was switched to the Tip-ATR mode. Using germanium as the crystal for attenuated total reflection, the pressure applied to the smear was 15psi. Representative infrared spectra of the points selected in each region of the paint sample that were user designated when the microscope was operated in reflection mode were collected.

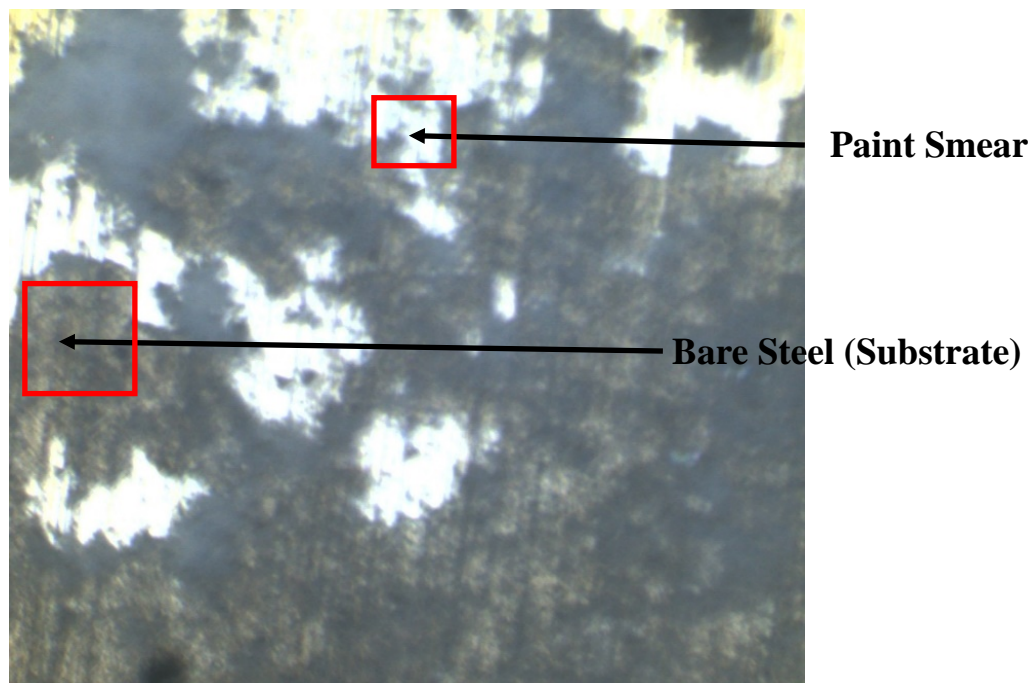


Figure 3.6. Camera image of the automotive paint substrate used in the paint smear simulation experiment.



The infrared spectra at the selected points were collected and submitted to ALS for analysis. Two paint layers were successfully reconstructed from the ALS analysis: the clear coat and the e-coat layers. Comparing each reconstructed infrared spectrum against a General Motors spectral library from the PDQ database, high quality matches could be obtained for the clear coat and e-coat layers (see Figures 3.7 and 3.8). When the reconstructed infrared spectrum of the clear coat layer was searched against a General Motors clear coat paint library from the PDQ database, the third hit corresponded to the same line, model and production year as UAZP00435. For the reconstructed infrared spectra of the e-coat layer, the correct match (same model and line) was the sixth hit. The library search results were also encouraging because a smear could be successfully matched against automotive paint obtained from an intact chip.

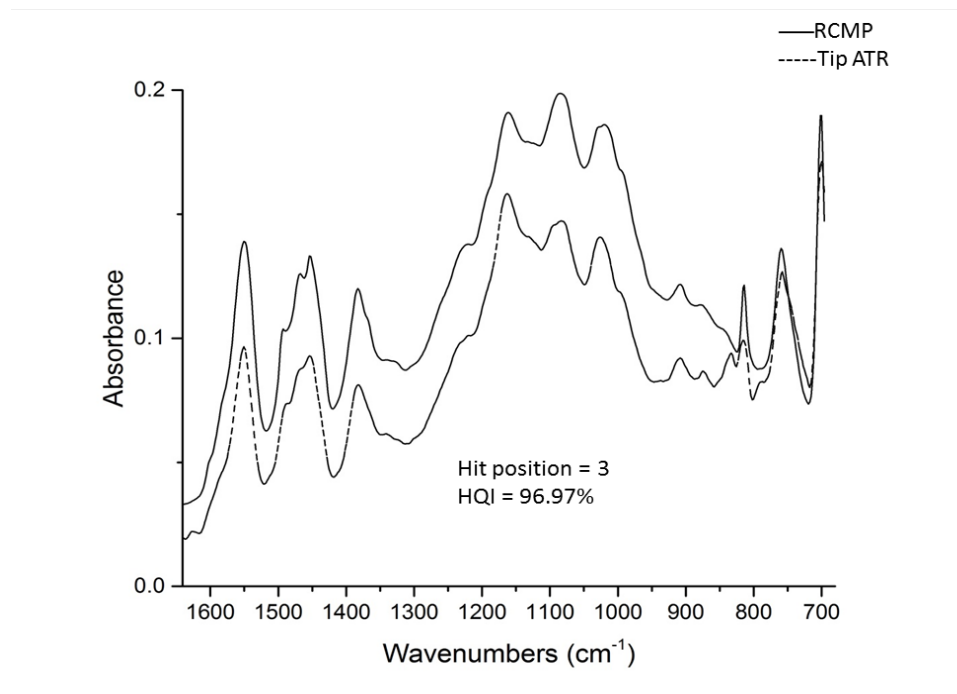


Figure 3.7. Comparison of the ALS reconstructed clear coat IR spectrum (dashed line) to the IR spectrum of the actual paint sample (UAZP00435) in the General Motors infrared spectral paint library.

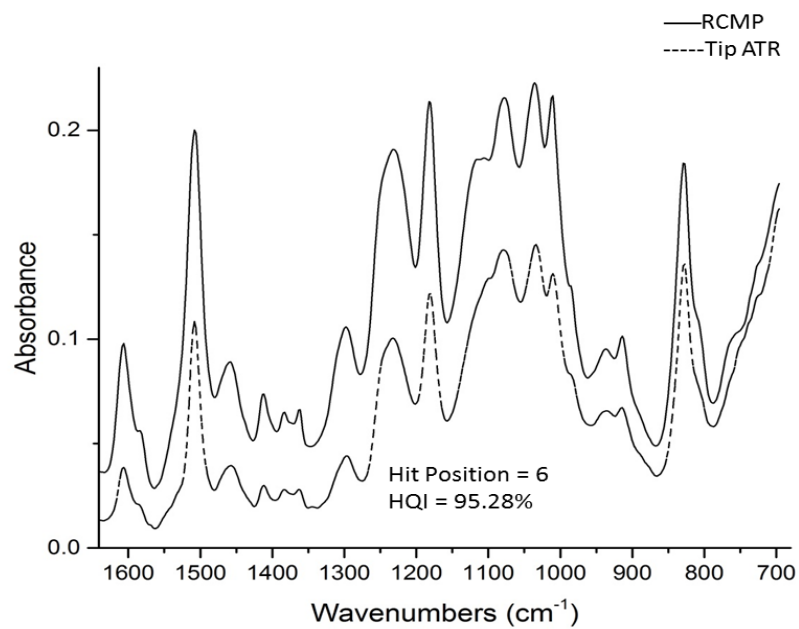


Figure 3.8. Comparison of the ALS reconstructed clear coat IR spectrum (dashed line) to the IR spectrum of the actual paint sample (UAZP00435) in the General Motors infrared spectral paint library.

## **Chapter 4**

### **Conclusion**

IR spectra of the clear coat, surfacer-primer, and e-coat layers were collected in a single analysis from a multi-layered automotive paint chip using a transmission FTIR imaging microscope. Decatenation of the spectral image as represented by a line map was achieved using ALS. The successful spectral reconstructions of each layer allowed us to quantify the discrimination power of the original manufacturer's automotive paint system by way of a library search.

The research described in this honors thesis will serve to quantify the general discrimination power of automotive paint comparisons involving both paint chips and paint smears and further efforts to succinctly communicate the significance of this evidence to the courts. This research will also ensure that analytical techniques used by paint examiners in forensic laboratories will remain current with respect to modern automotive paint systems.

The research project described in this honors thesis is directly targeted to enhance current approaches to forensic automotive paint analysis through decreased data collection times as compared to current practices and to aid in evidential significance assessment, both at the investigative lead stage and at the courtroom testimony stage. Direct impact on over 75 local, state, and federal forensic laboratories that are currently using the PDQ database in the United States is anticipated. There will also be direct impact on international forensic laboratories using the database, including the Forensic Laboratory Services Division of the RCMP, the Centre of Forensic Sciences in Toronto, Canada, the ENFSI network of European forensic science institutes, the Australian Police Services, and the New Zealand Police Services. The research described in

this report is an international collaborative effort between the Lavine research group at Oklahoma State University and Mark Sandercock of the RCMP.

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