Using 3-dimensional terahertz pulsed imaging to analyse automotive coatings

Summary

TeraView's 3D terahertz pulsed imaging (TPI™) technique is used to non-destructively and rapidly characterise the thickness and uniformity of coating layers on metal and polymer automobile structures. In addition, 3D TPI provides the unique ability to identify the presence of defects and to investigate their origins in multi-layered painted car panels.

Introduction

The colour of a car is one of its important selling features, so it should come as no surprise that the performance and quality control of multi-layer coatings in the automotive industry is a key issue. The painting of automobiles is also important for rust prevention, and waterproofing.

Today's industry standard is to apply several layers of paint to an automobile, see Figure 1. The first step is to give the body a primer coat by means of cathodic *electro-coating*; the principal purpose being anti-corrosion protection, and as surface preparation for the subsequent elements of the paint system. In this step, the coating particles are deposited onto the steel panels with the aid of an electric current in a cathodic electrocoat bath. Any coating residues are then rinsed off before the body moves on to the oven where the paint is baked at approximately 180°C. The second, *primer* layer is used to even out any irregularities and can be easily smoothed by sanding. As an intermediate coat between the cathodic electrocoat and the topcoats, the primer surface also provides stone chip protection and offers the cathodic electrocoat protection against ultraviolet (UV) radiation. The next functional layer is the *basecoat*. The task of the basecoat is to provide colour. Containing an extensive range of coloured pigments and effect substances, it plays a significant role in establishing the visual impression made by the painted body. The final layer applied to the car panel is the *clearcoat*. This layer has the functional role of sealing the previous layers. It has to withstand particular challenges such as resistance to sunlight and weather, but also to industrially generated chemicals and natural, biological influences (bird droppings etc.). Furthermore, the main focus in the clearcoat segment is on a very high scratch resistance even after aging.

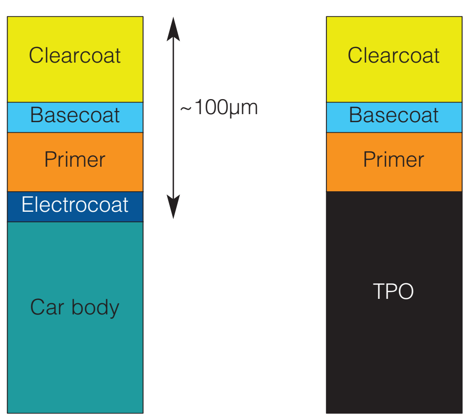


Figure 1.

Schematic diagram of the coating layers applied to automotive bodies. The image on the left is for a metallic car body, whilst the image on the right is for a sheet-moulded compound (SMC) part.

In addition to the painting of the metallic panels on an automobile, there is also much interest in the quality control of coatings on sheet-moulded compound (SMC) parts - the fibre-glass-reinforced thermoset panels used on bumpers and hoods, for example Thermo Plastic Olefins (TPO) panels. Although the paints used to coat plastic parts are similar to those applied to the rest of the car, SMC parts are difficult to paint as the paint layers do not readily adhere to the plastic substrate.

At present, commercially available thickness meters include ultrasonic gauges, eddy-current thickness monitors, and electromagnetic probes. All of these techniques are based on contact measurements. The suitability of alternative coating monitoring techniques is summarised in Table 1 (elements of Tablet 1 taken from Applied Optics, Vol. 44, No. 32, p. 6849, 2005). In contrast to these existing techniques, 3D TPI provides the additional quality control tests to automotive coatings:

- Non-contact remote measurement.
- Suitability for a variety of coating films and substrates.
- High precision and accuracy for thickness determination.
- The ability to measure the thickness of individual layers in multi-layered coatings.
- Measurement of the coating thickness uniformity distribution over an area.
- Identification of painting defects, and have the ability to determine the origin of the defect.
- Monitoring of wet-to-dry processes.

Requirement	Ultrasonic	Eddy-Current	Electro-magnetic	Teraview's 3D TPI
Non-contact	No	No	No	Yes
Suitability for various paint films and substrates	Yes	Partially	Partially	Yes
High precision for thickness determination	Yes	Yes	Yes	Yes
Individual thickness determination of multi-layered coatings	Partially	No	No	Yes
Detailed mapping of thickness distribution	No	No	No	Yes
Detection of defects and identification of origin	No	No	No	Yes
Monitoring of wet-to-dry process	No	No	No	Yes

Table 1. *Utility of techniques for monitoring automotive coatings.*

Figure 2.

Teraview TPI imaga 1000 imaging system (above and right).

Terahertz Pulsed Imaging

Studies were conducted using TeraView's TPI™ imaga 1000 imaging system (Figure 2). Based on TeraView's proprietary technology, this stand-alone system enables the user to rapidly image any object in 3-dimensions.

Terahertz pulses are incident on an automotive panel, and echoes or reflections from different buried layers (for instance at the clearcoat-basecoat interface) are measured at each point on the panel. Reflections or echoes arise in the terahertz reflected waveform whenever there is either a structural change in the object under test - leading to a change in the refractive index and/or absorption coefficient of the material. Images are generated via reflection of the raster-scanned terahertz spot. The system can scan an area of 25mm x 25mm in 20 minutes and exhibits a spatial resolution of 300 µm (at a frequency of 1 THz) and an axial resolution of 30 µm in air.

Figure 3.

Terahertz waveform reflected from a single point on an automobile panel. Peaks appear in the THz waveform whenever there is an interface in the object under test. By scanning the THz beam across the sample we can image in 3-dimensions – it is then possible to monitor the uniformity and thickness of each individual layer, and to identify defects.

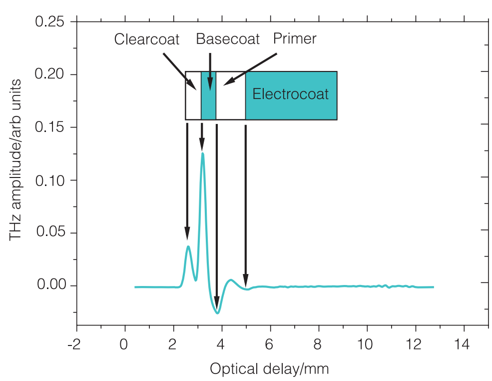
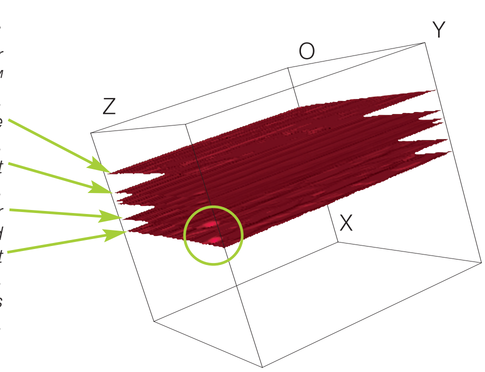


Figure 4.

Three-dimensional image of a car panel generated by the TPI™ technique.
layer 1 corresponds to the air/clearcoat interface,
layer 2 the clearcoat/basecoat interface,
layer 3 the basecoat/primer interface, and
layer 4 the primer/electrocoat interface.
The defect detected by TPI is circled in green.



Results and discussion

Metal Panels

For a test panel with a metallic substrate, four peaks in the terahertz waveform were typically observed, as shown in Figure 3, separated by a distance that is related to the layer thickness. The first peak in the terahertz waveform is due to the reflection from the outer surface of the clearcoat. The second peak is due to terahertz reflection from the subsurface interface between the clearcoat and the basecoat. The third (negative) peak is due to terahertz reflection from the interface between the basecoat layer and the primer layer. The fourth peak is due to the reflection at the interface between the primer layer and the electrocoat layer.

A 3D TPI image showing the location of the interfaces across a 50 mm area of a test panel is shown in Figure 4. In this Figure we can see that a defect is present at the interface between the electrocoat and the primer layer. This defect is not visible at the surface of the car panel, and is caused by a defect in either the electrocoat layer, or at the surface of the steel panel.

Figure 5.

Two-dimensional cross section through the test panel where no defect is present (left), and two-dimensional cross section through the test panel where a defect is present (right). The defect is circled green in this image.

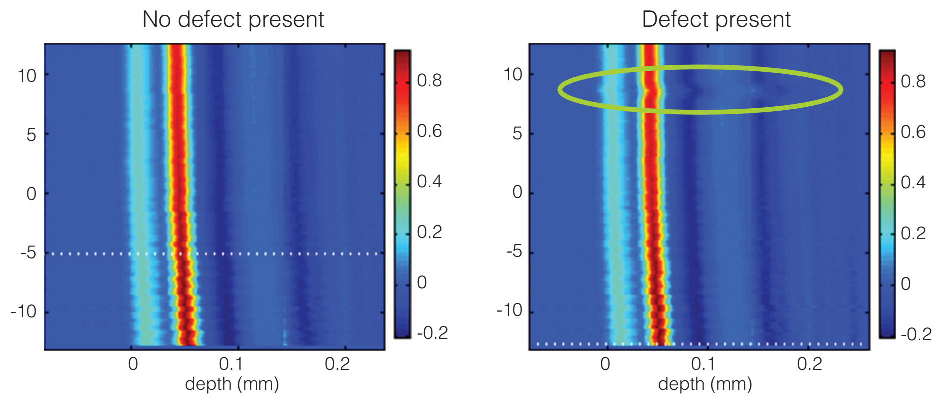


Figure 6.

Terahertz image of a 2" square from the test panel. The terahertz image is rotated such that we are looking from the back surface of the electrocoat layer. In this image three defects are detected, as circled. However only the defect circled green is detectable from the front surface by visual inspection. The defects circled blue are not apparent from visual inspection.

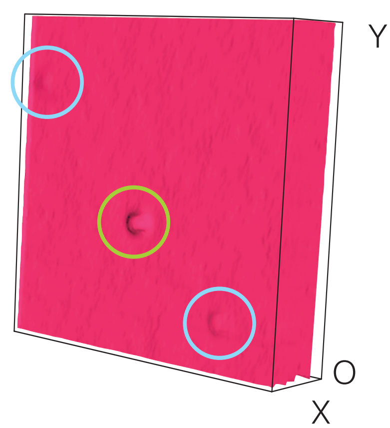
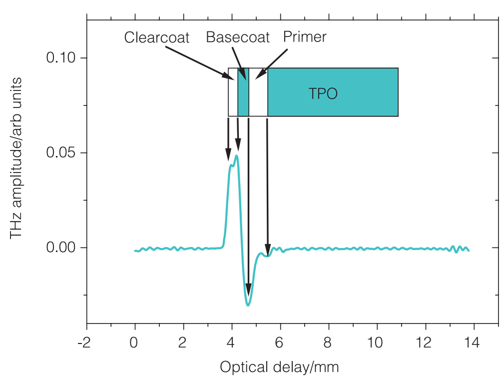


Figure 5 shows two 2D cross-sectional view through the 3-dimensional image generated in Figure 4. As shown, 3D TPI clearly determines the thickness of each of the individual layers present through a non-contact method. Furthermore, in the image on the right, in addition to determining layer thickness, 3D TPI identifies a defect in the electrocoat.

Figure 6 shows additional defects that are detected 3D TPI. Only one of these defects is observed from visual inspection.

Figure 7.

Typical terahertz pulse of the test panel with a sheet-moulded compound (SMC) TPO substrate.



Plastic Panels

For a test panel with a TPO substrate, four peaks in the terahertz waveform were typically observed, as shown in Figure 7, separated by a distance that is dependent on the layer thickness. The first peak in the terahertz waveform is due to the reflection from the outer surface of the clearcoat. The second peak is due to terahertz reflection from the subsurface interface between the clearcoat and the basecoat. The third (negative) peak is due to terahertz reflection from the interface between the basecoat layer and the primer layer. The fourth peak is due to the reflection at the interface between the primer layer and the TPO substrate.

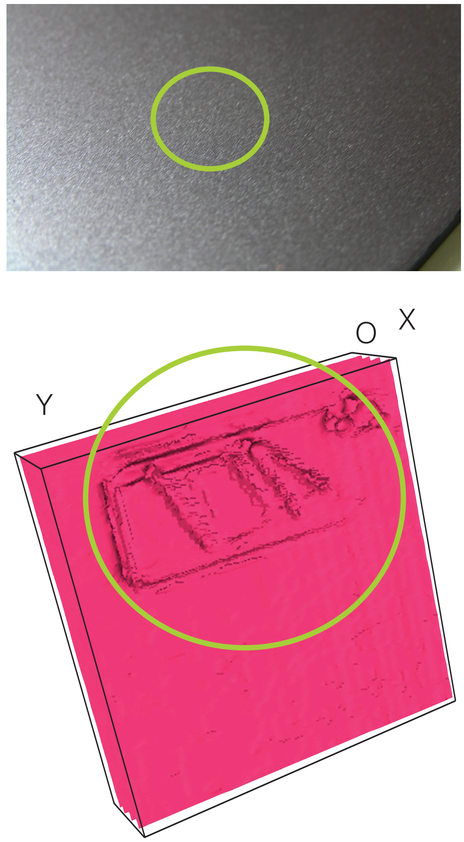


Figure 8.

Photograph (top right) and 3-dimensional terahertz image of the TPO substrate test panel (below right). The THz image is rotated such that we are looking at the panel from the rear surface. The 3D TPI™ detects a defect (circled green) that cannot be seen by visual inspection.

A 3-dimensional image showing the location of the interfaces across a 2" area of a plastic test panel is shown in Figure 8. In this Figure we can see that a defect is present at the interface between the TPO substrate and the primer layer. This defect is not visible from very close inspection of the panel (by holding the panel at a very high angle to the eye). Figure 9 shows two 2-dimensional slices through the 3-dimensional image generated in Figure 8. The image below left has no defect present – here we can clearly monitor the thickness of the multiple layers through a non-contact method. Furthermore, in the image on the top left we can monitor the thicknesses of the multiple layers, and also at the same time visually identify the defect in the test panel. From inspection of Figures 8 and 9 we can see that the defect is the result of a bubble between the TPO substrate and the primer layer i.e. the primer layer has not adhered to the plastic in this region.

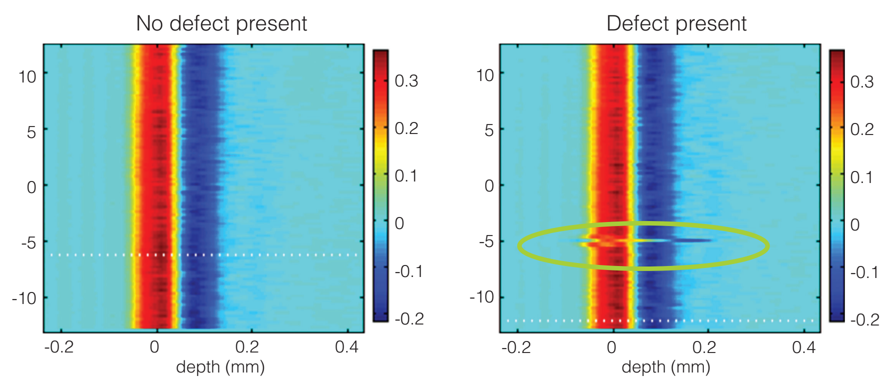


Figure 9.

2-dimensional cross section through the plastic substrate test panel where no defect is present (left), and 2-dimensional cross section through the plastic substrate test panel where a defect is present (right). The defect is circled green in this image. The defect is the result of a bubble between the TPO substrate and the primer layer i.e. the primer layer has not adhered to the plastic in this region.

Conclusions

TeraView's 3D terahertz pulsed imaging (TPI) technique can be used to non-destructively and rapidly characterise the thickness and uniformity of coating layers on automobile assemblies. Furthermore, 3D TPI provides the unique ability to identify the presence and to investigate the origins of defects in multi-layered painted car panels with both metallic and plastic (sheet-moulded compound (SMC) parts) substrates.

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