Non-destructive Characterization of Automobile Car Paints using Terahertz Pulsed Imaging and Infrared Optical Coherence Tomography

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Abstract—**Terahertz pulsed imaging (TPI) and Optical Coherence Tomography (OCT) are two powerful techniques that can be used to non-destructively acquire high quality three-dimensional images from within scattering media. In this paper, we report experimental results of using TPI and infrared OCT for characterizing automobile car paints. We found that the individual layer thickness of all four layers of real-world car paint samples could be determined from TPI measurements whilst OCT measurements can only image the top two layers of the car paints albeit with a better image resolution. OCT is able to reveal additional information such as the shape and orientation of metallic flakes in the base coat of the car paints.**

I. Introduction

THE application of paint to a car body can be a complicated process. Expensive auto body paint is usually applied in at least four layer stages and includes clear coat, base coat and one or more primer coats as well as electrocoat layers. The result of these successive paint layers is a surface that exhibits complex light interactions, giving the car a smooth, glossy and sparkly finish. More importantly, these paint layers not only provide appealing colour effects, but also have important functions such as corrosion prevention and waterproofing. It is hence of great interest to characterize car paint properties including thickness and uniformity for the purpose of quality control and quality assurance.

Terahertz pulsed imaging (TPI) is a powerful noncontact technique for quantitatively characterizing individual layers of a multi-layered sample such as pharmaceutical tablets [1, 2]. Recently it has been demonstrated that TPI technology could be used for characterizing the paint layer thickness [3, 4] and drying process [3] of car paint samples. It has been shown that both the layer thickness and refractive index of each individual paint layer can be determined by comparing the experimentally measured THz signals with the numerically simulated ones [3, 5]. However, to accurately extract all eight parameters (four thicknesses and four refractive indices) from the measured THz signal is a computationally intensive process. Both the measurement accuracy and speed could be significantly improved if one could have some prior knowledge about one or more of the eight unknown parameters. Here we report the first experimental demonstration that the layer thickness of the top two coatings of real-world automobile paints can be quantified using infrared optical coherence tomography (OCT). The extracted layer thickness is in good agreement with that obtained using TPI. OCT is able to measure with better precision the layer thickness of the top two layers without the need for a numerical fitting procedure. On the other hand, TPI is able to measure the individual layer thickness of all four paint layers.

II. Materials and measurements

All THz measurements were performed using a TPI imaga 1000 system (TeraView Ltd, Cambridge, UK) [1, 4]. All OCT measurements were performed using an in-house spectral-domain OCT system which is based on a Michelson interferometer [6]. As shown in Fig. 1, a collimated light beam from the light source (Exalos, centre wavelength 850 nm and spectral bandwidth 50 nm) is divided into a sample arm and a reference arm using a broadband beam splitter (50:50). The back scattered light from the sample is collected using an achromatic lens and the collected light is subsequently recombined with the back reflected light from the reference. The resultant spectral interferogram is recorded using a spectrometer (HR 2000+, OceanOptics). The Fast Fourier transform (FFT) of the measured spectral interferogram provides the depth profile of a sample.

The samples used in this study are real-world car paints that have four coating layers on a metal substrate (clear coat/base coat/primer coat/electro-coat). One of the samples has metallic flakes in the base-coat whilst the other has a clear base coat (e.g., no metallic flakes in the base coat). In all OCT measurements 200 spectral interferograms were taken on each sample covering a length of 1 mm and the interval between each lateral pixel is 5 µm.

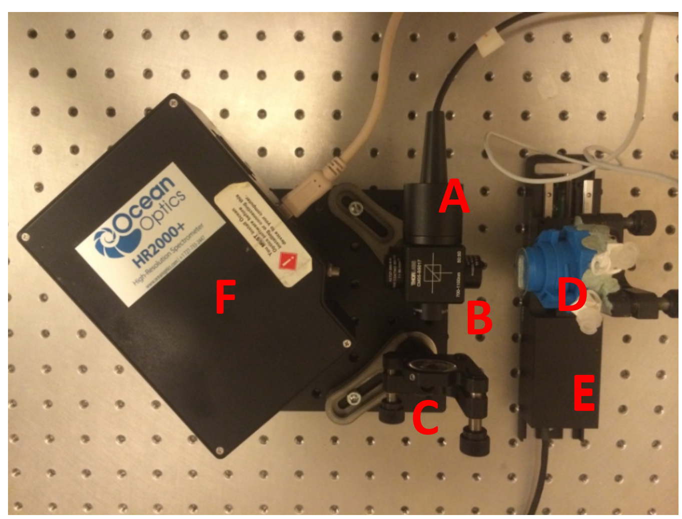

Fig. 1 Photograph of the in-house SD-OCT system. A: light source; B: beam splitter; C: reference reflector; D: sample; E: translation stage; F: spectrometer. The collimated light source is divided into reference and sample beams. The back scattered/reflected sample and reference beam recombine and interfere at the exit of the beam splitter. The interfered light beam is collected by a focus lens and recorded by a line camera based spectrometer.

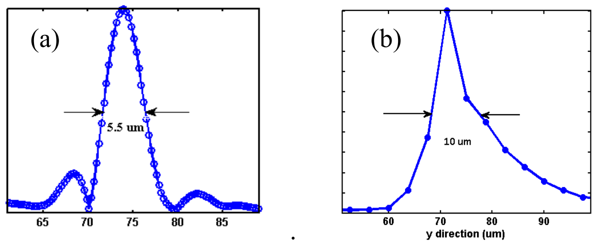

Fig. 2 (a) Main peak in the depth profile (b) power distribution of the focused sample beam at the focal plane. The axial resolution and lateral resolution of the SD-OCT system are determined to be 5 µm and 10 µm

III. RESULTS

The acquired OCT spectral interferograms were firstly converted into wavenumber space with equal wavenumber intervals. The FFT was then applied on the converted interferograms to generate the depth profiles that contain the inner structure information of the car paint samples. As shown in Figure 2(a), the achieved axial resolution determined by the full width at half maximum (FWHM) of the main peak in the depth profile is about 5 µm. The achieved lateral resolution is approximately 10 µm as determined by the FWHM of the focused beam profile.

Figure 3(a) shows a typical B-scan map of a car paint sample with a clear base coat, obtained using the OCT system. In the B-scan map, the clear coat and base coat are distinguishable from each other. However, the primer coat and electro-coat cannot be resolved using the OCT method probably owning to the strong absorption/scattering of these two coating layers in the optical frequency range. In order to calculate the coating thicknesses of clear coat and base coat, the measured OCT depth profiles were averaged. A peak finding method is then applied to find the locations of the peaks in the averaged depth profile. As shown in Figure 3(b), the layer thicknesses of the clear coat and the base coat were determined to be 87.4 µm and 17.4 µm, respectively. These numbers agree well with the reference measurement value of 87.9 µm and 18.0 µm, which was measured using TPI. Note that a refractive index of 1.56 and 1.63 was used for clear coat and base coat respectively.

Figure 3(c) shows the OCT B-scan map of a car paint sample with a base coat containing metallic flakes. It is clear that the obtained OCT B-scan map reveals additional features that are associated with the metallic flakes within the base coat layer. Figure 3(d) shows the averaged OCT depth profile. Due to the reflective nature of metallic flake, the metallic flakes reflected a large portion of the light power. Consequently the second peak (in Figure 3(d)) has a large amplitude (note that the y-axis is in logarithm scale). In addition, OCT has a much higher lateral resolution because of its relatively shorter wavelength as compared with TPI. Therefore, the OCT method could potentially be a powerful imaging method for studying the shape and orientation of the individual metallic flake within the base coat.

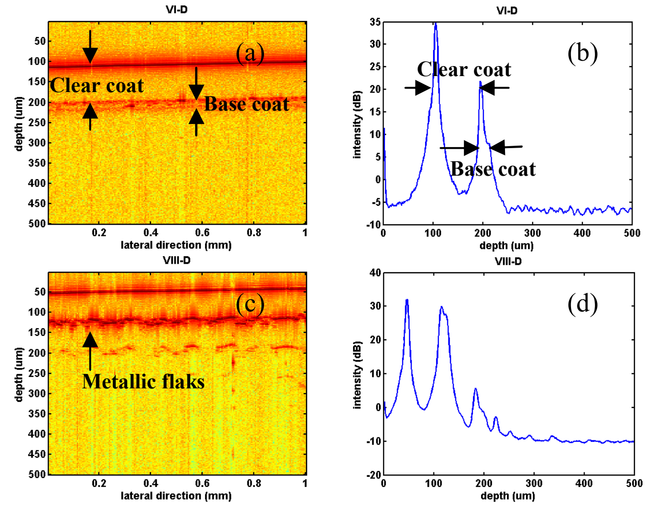

Fig. 3 (a) B-scan map and (b) the averaged OCT waveform measured on a car paint sample with a clear base coat. (c) B-scan map and (d) averaged OCT waveform with metallic flakes in base coat.

IV. Summary

In summary, both OCT and TPI have been used for non-destructive characterization of car paint samples. We found that OCT has higher spatial resolution for imaging the top two layers whilst TPI is capable of quantifying all four layers of the car paint sample. Furthermore, OCT is able to provide additional information of the sample such as the shape and orientation of metallic flakes inside the base coat.

Acknowledgements

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