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Terahertz Non-Destructive Thickness Characterization of Optically Thin Wüstite Layers on Steel

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Abstract— Terahertz imaging is a relatively new technique for nondestructive evaluation. Compared with the destructive micro-cut technique that provides information along the line of cut only, THz imaging nondestructively provides a global mapping of a sample. Hence, this technique has been applied to characterize coated materials and composite laminates. In this work, we characterize optically thin wüstite layers on steel leveraging signal-processing techniques.

I. INTRODUCTION

Monitoring coating thickness (paints, polymers, and oxides) on steel is a way to characterize the sample quality. A common approach is cross-section imaging, which is destructive as it requires the sample to be cut.

Terahertz (THz) imaging has attracted considerable interest as a noninvasive, noncontact, nonionizing and nondestructive evaluation method to characterize various nonmetallic materials with single- or multi-layered structures.

Specifically, the work focuses on thickness characterization of wüstite layers on steel based on a two-step process: (1) measuring the sample with pulsed THz reflectometry and (2) advanced signal processing to extract detailed features about the sample that are not immediately evident in the signals collected in the first step. Three wüstite films of thickness 28.5, 13.4, and 5.1 μm were provided by ArcelorMittal.

Three innovative approaches, frequency-wavelet domain deconvolution (FWDD)¹, sparsity-based deconvolution (SD)² and autoregressive spectral extrapolation (AR)³ are applied to demonstrate the structural properties of samples with different thicknesses.

II. RESULTS

Fig. 1 FWDD deconvolved signal for films of different thickness.

Figure 1 shows that, after applying the FWDD method, only one pulse can be identified in the signal reflected by the samples, implying that the optical thickness of the oxide layer

on steel substrate is beyond the capability of the FWDD algorithm.

When applying the SD approach, however, an additional small echo, originating in the wüstite/steel interface, can be seen clearly as shown in Fig. 2. The layer thickness can be estimated from the time delay between the two peaks, to be 28.4 μm , 12.8 μm and 9.6 μm , respectively. It is thus clear that the thickness of the thinnest layer cannot be accurately characterized with SD.

Fig. 2 SD deconvolved signals for films of different thickness. Two peaks corresponding to the top and bottom interfaces of the wüstite layers are clearly observed. The second peak corresponds to the wüstite/steel interface.

AR is a model that exploits the data in high-SNR regions to estimate the components in low-SNR regions. The results of AR are illustrated in Fig. 3. The thicknesses of all samples could be successfully measured.

Fig. 3 AR deconvolved signals for the three different films. Two interfaces are observed in all cases.

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