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Terahertz Characterization of Roman Amphora Sherds

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Abstract—Amphorae frequently have a whitish skin that has been mistaken for a slip or painted layer over the otherwise pinkish ceramic. This skin is due to the simultaneous presence of calcite and NaCl in the clay, leading to depletion of red iron oxides near the surface. We demonstrate that terahertz time-of-flight tomography can provide a nondestructive, contactless means to measure the skin thickness on amphora sherds, finding a thickness of $\sim 50 \mu\text{m}$.

I. INTRODUCTION

Amphorae were used in bulk-commodity long-distance trade in the Roman Empire. A whitish skin [1] is often present. We measure the skin thickness w using terahertz (THz) time-of-flight (TOF) tomography. While [2-4] shows that the layer is a skin, surprisingly little is known quantitatively about its thickness on anything less than a mm scale [3].

The Baetican amphora sherds are shown in Fig. 1. A caliper measurement gives $w \sim 30\text{-}40 \mu\text{m}$. Clearly, nondestructive and noncontact techniques providing quantitative μm -scale resolution are called for.

II. RESULTS

THz TOF tomography experiments use a TeraView TPS Spectra 3000. The optical delay ΔT between successive echoes is determined by w and its refractive index n . The sherds were raster-scanned in the transverse x and y directions in $200 \mu\text{m}$ steps over the regions of the exteriors. We establish the optical thickness $w_{\text{opt}} = c\Delta T/2$ where c is the *in vacuo* speed of light. The actual thickness of the layer is $w = w_{\text{opt}}/n$. To reconstruct the sample from our measurement, *i.e.*, to recover the layer thickness w , we employ sparsity-based deconvolution (SD) [24,25,26], which in some cases can beat the naïve axial resolution limit and reconstruct samples with thin layers. Taking $n \sim 2$ [5], we find $w \sim 50 \mu\text{m}$.

B-scans based on such measurements are shown in Fig. 2. C-scans (not shown) enable us to acquire statistics for w .

III. CONCLUSION

We present nondestructive, noncontact measurements of skin thickness w in Roman amphora sherds by means of THz TOF tomography for the first time providing quantitative stratigraphic characterization. We find w to be $\sim 50 \mu\text{m}$ with a $5\text{-}\mu\text{m}$ standard deviation across the regions of the two sherds.

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Fig. 1. Amphora sherds (a) 1 and (b) 2. Black rectangles ($\sim 1 \times 1 \text{ cm}^2$) show areas studied. (c) shows sherd break exhibiting laminar fracture within the body fabric. (d) shows large fragment from same amphora from which the sherds originate. A craffito is seen in (d).

Fig. 2. (a) and (b) show binary B-scans with echo arrival time reconstructed by SD along cross section shown in regions in Fig. 1(a) and (b).