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True-color 3D surface metrology for additive manufacturing using interference microscopy

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Abstract
Coherence scanning interferometry (CSI) is widely used for surface topography characterization. With the ability to measure both rough surfaces with high slopes and optical finishes, CSI has made contributions in fields from industrial machining to optical fabrication and polishing [1,2]. While the low coherence sources for CSI are typically broadband and suitable for color imaging, the metrology is usually preformed without regard for the color information [3]. We present color surface topography measurements from a CSI instrument designed to provide true color images in addition to areal surface topography of additive manufactured samples. The addition of color measurements enables contamination and defect detection along with blemish and discoloration identification.

Coherence scanning interferometry, metal additive manufacturing, surface topography, metrology, true color

1. Introduction

Additive manufacturing (AM) holds substantial promise for the fields of engineering and production. By providing the ability to selectively add material to a part as it is formed, the technique can produce novel part geometries that were previously beyond the capabilities of conventional, subtractive manufacturing. The new geometries and parts have applications in fields from biomedical implants to aerospace engineering [4,5]. However, while there are substantial advantages with AM, there are open challenges in improving the process. One such challenge is the ability to accurately assess the surface finish and identify defects; both of which are important areas for improving AM [6]. For this work we present novel measurements of AM samples that combine true color with surface topography. While foundational work has been done demonstrating the efficacy of coherence scanning interferometry (CSI) measurements of surface topography of additive manufactured samples [7], we present the first color topographies. These provide examples of discoloration and defects, providing more complete metrology feedback to the manufacturing process.

In the sections below, we describe the methodology used to acquire the measurements, along with the analysis and acquisition. We also describe the samples and the results from the measurements and possible future directions.

2. Methodology

2.1. Measurement System

We used a ZYGO Nexview™ system to generate the true color surface topographies. This microscope maps one million height points in a few seconds using CSI and specialized hardware to synthesize color images [1]. This instrument is capable of measuring topographies of highly complex surfaces characteristic of AM samples, overcoming many of the perceived limitations of interferometry for these surfaces [7-9]. The measurements relied on a 50× objective and 0.5× tube lens to resolve the sample defects and discoloration, and also to capture data from the high slope and rough surfaces. The single measurement field of view (FOV) with this configuration was 0.34 mm by 0.34 mm, with a spatial sampling of 0.33 µm and an optical resolution of 0.55 µm (given by the Sparrow criteria at an imaging wavelength of 570 nm).

2.2. Acquisition and Analysis

The main principle behind a coherence scanning optical microscope is the finite coherence length of a broad illumination spectrum. The light that illuminates the sample has a mean wavelength of about 570 nm and a bandwidth of 100 nm. This broad source bandwidth translates to a coherence length of a few micrometers. To measure the topography of a sample, the objective is scanned along an axis orthogonal to the nominal plane of the surface, and analysis of the coherence-limited interference fringes at each image pixel provides the height topography. Example measurements of AM samples are illustrated in Figures 4a and 5a.

In addition to surface topography, true color measurements are possible using CSI. As noted above, the 100 nm wavelength bandwidth covers much of the visible spectrum. Sequential illumination of the sample for each color channel (red, green and blue) provides the reflected intensity for these composite colors. The color information combines with the surface topography to give the true color results at best focus [3].

2.3. Samples

The two samples are respectively made of Ti-6Al-4V and Al-Si-10Mg. These materials both have good strength-to-weight ratios and high resistance to fatigue and corrosion [10,11]. This leads to possible application in both automotive and aerospace manufacturing [10, 11]. Furthermore, Ti-6Al-4V is a biocompatible material which enables biomedical applications [12]. These materials were selected to build two samples using laser powder bed fusion (LPBF). The Al-Si-10Mg and Ti-6Al-4V LPBF samples are shown in Figure 1a and 1b; both are cubes with a 20 mm lateral extent.

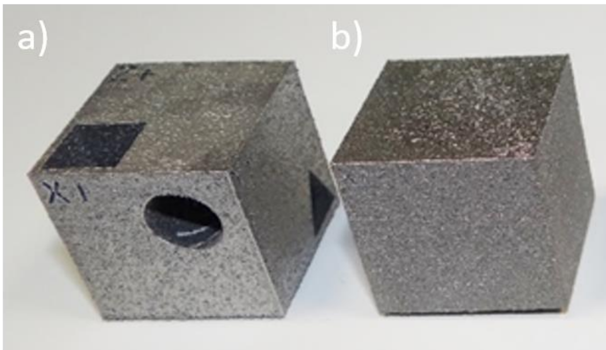

Figure 1. Pictures of the samples: (a) Al-Si-10Mg, (b) Ti-6Al-4V LPBF cubes. Both samples are 20 mm in lateral extent.

3. Results

The results for the true color measurements of the Ti-6A-4V and Al-Si-10Mg LPBF samples are shown in figures 2 and 3. In figure 2, the data for the Ti-6A-4V sample shows clear evidence of weld tracks and ripples [7-9]. These represent both micrometer level structures as well as more global features at the hundred micrometer scale. One of the benefits of color measurements is the clear discoloration as the weld ripples are tightly spaced, indicating a possible signal to feedback on the manufacturing process. In addition to the weld ripples, there are also several surface pores and protrusions from spatter or unmelted particles [7-9]. These are well resolved and can also help inform the manufacturing process.

Figure 3 shows the color measurement of the Al-Si-10Mg sample. In contrast to the Ti-6A-4V sample, this surface is far less ordered and exhibits very little evidence of spatter or pore defects. The overall color is more uniform, with differences largely from surface roughness and topography. Furthermore, there is no evidence of discoloration or localized blemishes.

In addition to the single FOV measurements presented in figures 4 and 5, we also present the combination of multiple measurements along the sample surface to create larger scale surface topographies. The results of both the surface topography and the true color measurements are displayed in figures 4 and 5. These are useful for larger sampling statistics in the context of defect identification and blemish inspection.

4. Summary

The challenges of metrology for AM samples come from the diverse surface topographies and structures. In addition to high slopes and large departures, it is necessary to capture additional information from blemishes and discoloration to help improve and control the manufacturing process. The combination of high-quality interferometric topographic measurements with true color imaging provides a unique metrology opportunity for AM materials.

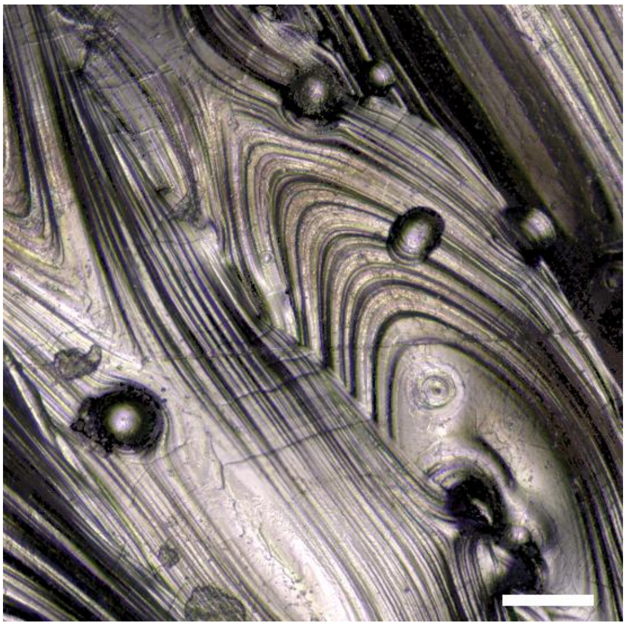

Figure 2. True color measurement for the Ti-6Al-4V LPBF sample. The measurement represents a single field of view for a 50× objective lens (NA 0.55, 0.34 mm × 0.34 mm field of view). The scale bar is 50 µm.

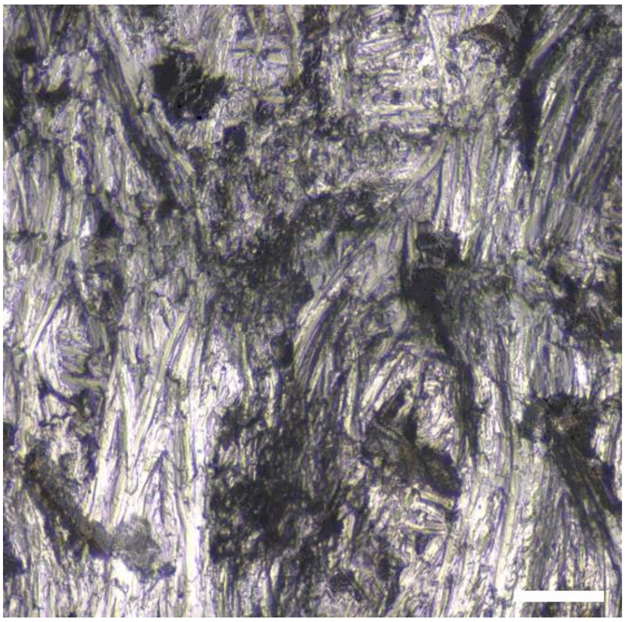

Figure 3. True color measurement for the Al-Si-10Mg LPBF sample. The measurement represents a single field of view for a 50× objective lens (NA 0.55, 0.34 mm × 0.34 mm field of view). The scale bar is 50 µm.

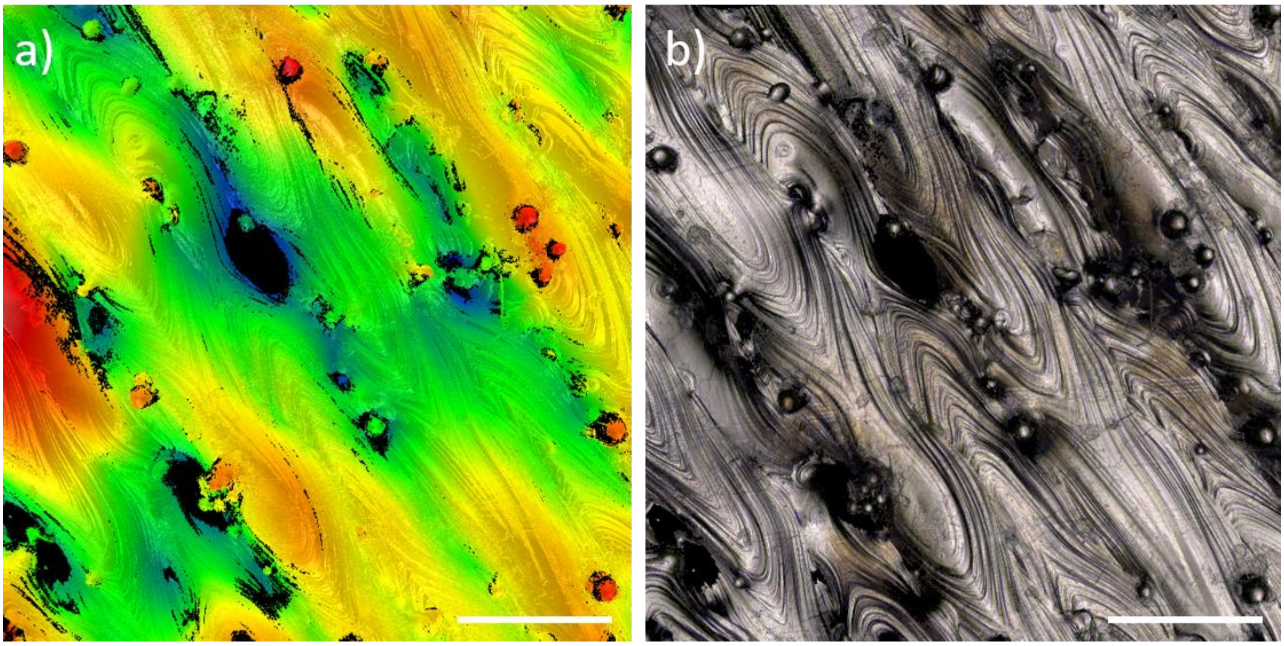

Figure 4. a) Surface topography the Ti-6Al-4V LPBF cube displayed in false color. The color scale gives the surface height, the scale is linear from -60 µm to +60 µm b) True color measurement combined with the surface topography. This is a stitched image with a 1 mm by 1 mm field of view with a 50x objective lens (NA 0.55, 0.34 mm × 0.34 mm single measurement field of view). The lateral scale bar is 250 µm.

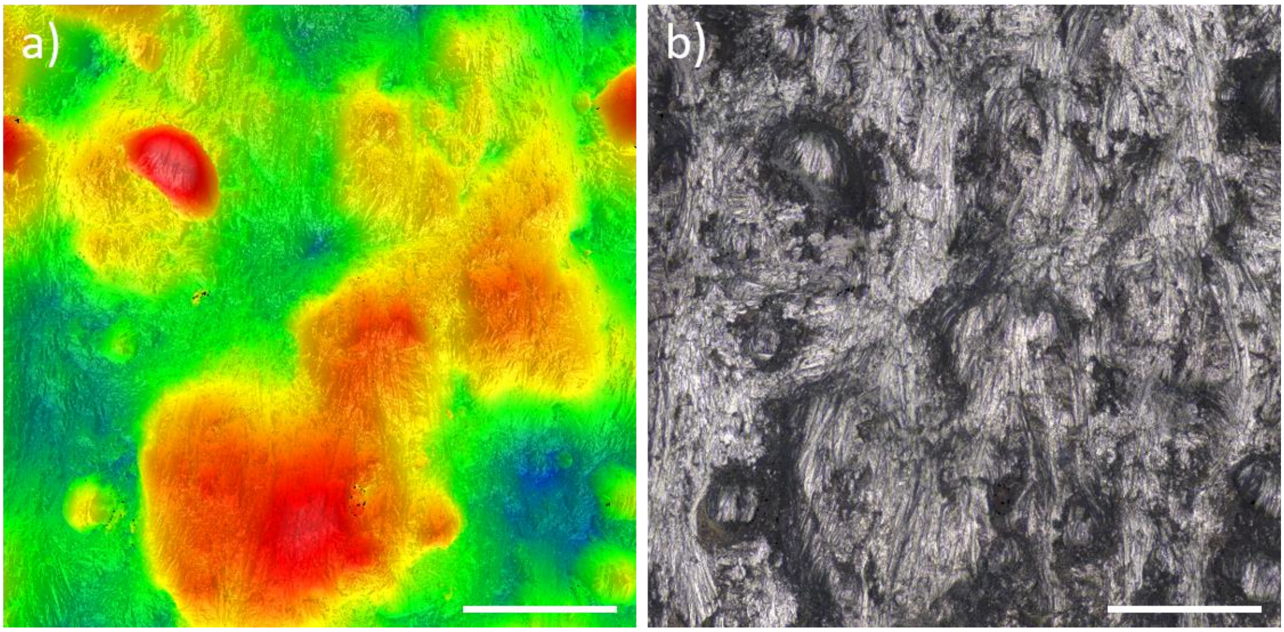

Figure 5. a) Surface topography the Al-Si-10Mg LPBF cube displayed in false color. The color scale gives the surface height, the scale is linear from -60 µm to +60 µm b) True color measurement combined with the surface topography. This is a stitched image with a 1 mm by 1 mm field of view with a 50× objective lens (NA 0.55, 0.34 mm × 0.34 mm single measurement FOV). The lateral scale bar is 250 µm.

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