High-Speed EBSD Mapping with the Velocity™ EBSD Camera Series

Introduction

In the 25 years that Electron Backscatter Diffraction (EBSD) mapping has been commercially available, the adoption of new technology has continually enabled faster acquisition rates for more efficient data collection. Initial analog video cameras were limited to operating rates of 30 frames per second and were often frame averaged to collect at speeds of one pattern per second. The first digital CCD-based cameras were introduced at about 40 patterns per second. The first high-speed CCD-based cameras were introduced at 200 patterns per second and were continually improved to reach speeds of 1,500 patterns per second. The recent introduction of the Velocity™ Plus EBSD Detector, utilizing a high-sensitivity and low-noise CMOS imaging sensor, again provided a significant improvement of collection speeds to 3,000 indexed patterns per second. Now, with the latest Velocity™ Super EBSD Detector, data collection speeds up to 4,500 indexed points per second are available.

To make these fast acquisition speeds practical and useable, the entire Velocity™ EBSD detector and system has been optimized for performance. This includes a customized for EBSD CMOS-based camera, a custom-designed lens for highest sensitivity, and optimized software for indexing speed and performance. The results of this design are shown in Figure 1. This image shows an EBSD Image Quality (IQ) greyscale map combined with a colored Inverse Pole Figure (IPF) map (this map type will be subsequently referred to as an IQ + IPF map), where the colors correspond to the crystallographic orientation aligned to the sample surface normal direction, collected from an Inconel 600 superalloy at 3,000 indexed points per second. The beam current used for this acquisition was 11 nA, which demonstrates the high-sensitivity of the Velocity™ system, which combined with the 99.6% indexing success rate, also shows that the system is fast and accurate.

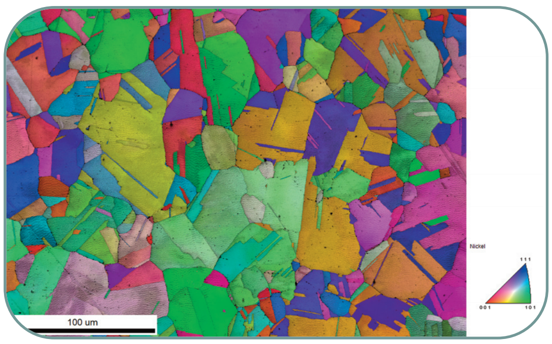

Figure 1. EBSD IQ + IPF map from a Ni superalloy collected at 3,000 indexed points per second at 11 nA with 99.6% indexing success.

The Velocity™ EBSD System is available in two configurations: the Velocity™ Plus, with a collection speed up to 3,000 indexed points per second, and the Velocity™ Super, with a collection speed up to 4,500 indexed points per second. To enable this collection speed, the Velocity™ Super has a dedicated high-speed mode designed for the fastest collection speeds. Beam currents of 25 nA or higher are necessary to achieve these collection speeds with 99% indexing success on standard samples, although lower currents can be used if this indexing success is not required. Figure 2 shows an IQ + IPF map from an additively manufactured Inconel 718 alloy collected at 4,500 indexed points per second with a 98.2% indexing success rate using a beam current of ≈30 nA. This orientation information helps users to understand the solidification rates and mechanisms during the additive manufacturing process. These microstructures can contain information both over a large area and with fine detail. The high-speed collection capability of the Velocity™ Super is ideal for characterizing these 3D printed structures.

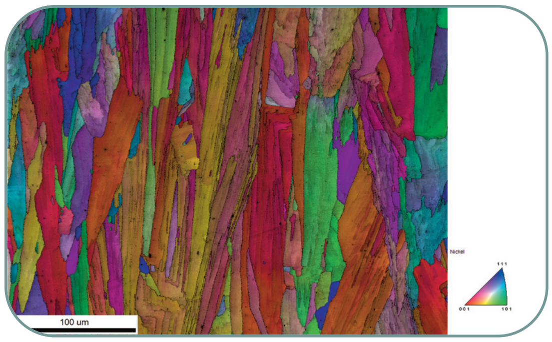

Figure 2. EBSD IQ + IPF map from an additively manufactured IN718 alloy collected at 4,500 indexed points per second.

One advantage of the Velocity™ CMOS-based EBSD detectors is that the EBSD pattern resolution used for high-speed collection is 120 x 120 pixels. In comparison, the Hikari CCD-based detector uses a 30 x 30 pixel pattern for 1,500 points per second acquisition and has an acquisition speed of around 500 patterns per second at a comparable 120 x 120 pixel image resolution. Because of this, the Velocity™ detector can be used on a range of materials (both in terms of material state and crystal structure) without having to optimize either the indexing or band detection settings.

Smart Insight

In the following examples, the Velocity™ was set up to acquire patterns at 3,000 points per second and was indexing around 2,500 points per second using the default Hough parameters with the EDAX TEAM™ software and a beam current of ≈30 nA. The ability to achieve these high collection speeds without specific optimization, which requires a higher level of operator knowledge, allows users to get more real performance on their instruments with a shorter learning curve compared to traditional detectors.

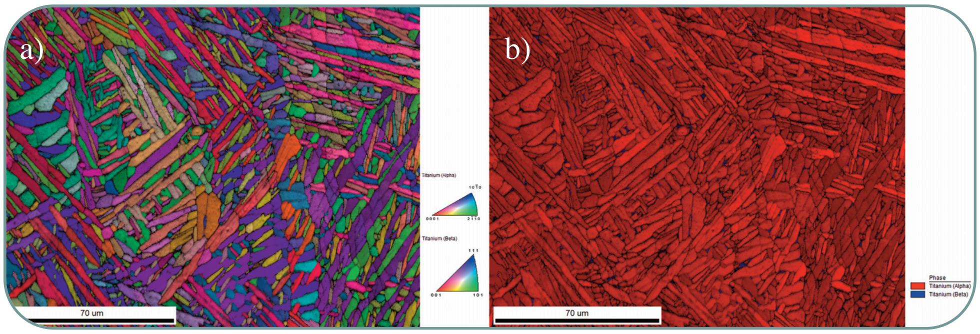

Figure 5. EBSD (a) IQ + IPF map and (b) IQ + Phase map from an additively manufactured titanium sample.

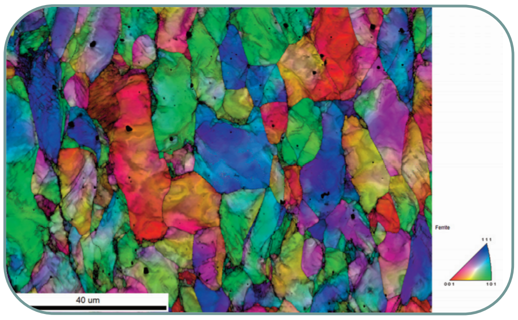

Figure 3. EBSD IQ + IPF map from a deformed ferritic steel sample.

Figure 3 shows an IQ + IPF map from a deformed ferritic steel sample. The deformation is visualized through the subtle changes in color within the individual grains. The orientations within a grain change as much as 30°, but the precision of the measurements at these conditions allows detection of the small rotations within the microstructure. There are more defects within the crystal lattice in a deformed material, which results in EBSD patterns that are less sharp. This can reduce band detection efficiency and indexing performance. However, with this example, an indexing rate of 98.3% was achieved. This shows that deformed materials can be measured at high speeds with the Velocity™ .

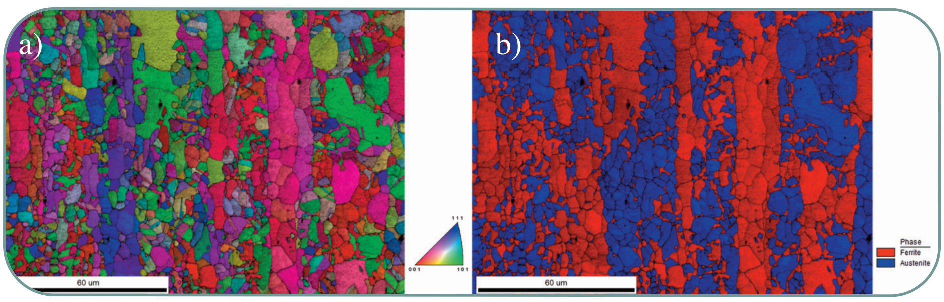

Figure 4. EBSD (a) IQ + IPF map and (b) IQ + Phase map from a duplex phase steel sample.

All these examples have been single phase materials. When analyzing multiple phases, the system needs to determine both the correct phase for a given EBSD pattern and the correct orientation. This increases the computational requirements for the data collection process. Figure 4a shows an IQ + IPF map from a dual-phase (BCC Ferrite and FCC Austenite) steel sample and Figure 4b shows an IQ + Phase map, with an indexing success rate of 97.3%. These phases are clearly resolved, and the orientation is correctly determined. These types of steels are used in severe environments to resist corrosion and understanding the phase distribution helps to optimize performance.

These examples have all had cubic crystal structures, which have a high degree of symmetry. This increased symmetry reduces the scope of the orientation determination process. Figure 5 shows results from an additive manufactured titanium medical implant. Figure 5a shows the IQ + IPF map, and 5b shows the IQ + Phase map, with an indexing success rate of 94.3%. This sample is primarily alpha titanium, which has a hexagonal crystal structure. There are also small pockets of beta titanium, which has a BCC crystal structure. This beta phase is what is retained as the titanium cools during the additive manufacturing process. Specific orientation relationships measured here confirm the phase transformation mechanism. Measuring the size and fraction of the beta phase can give insight into the cooling rates within the material.

Conclusion

These examples show that the Velocity™ cameras can provide high-quality data collected at high-speeds with reasonable beam currents without the need for expert level software optimization. This makes the Velocity™ practical for traditional EBSD scans, but also ideal for 3D serial sectioning and in-situ experiments, where minimizing acquisition time is very important.

MATERIALS ANALYSIS DIVISION