Understanding and Optimizing EBSD Camera Settings

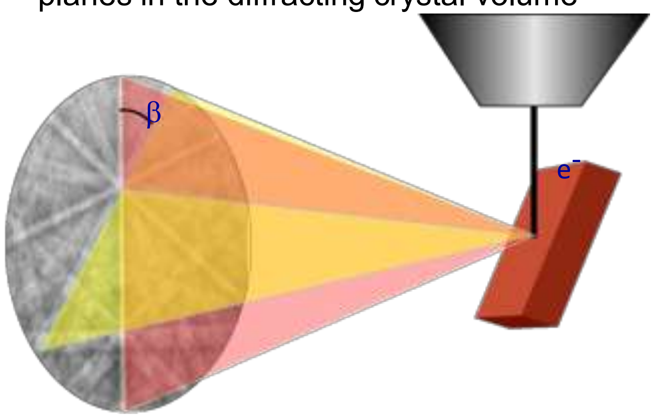
Presented by Shawn Wallace on July 14, 2016

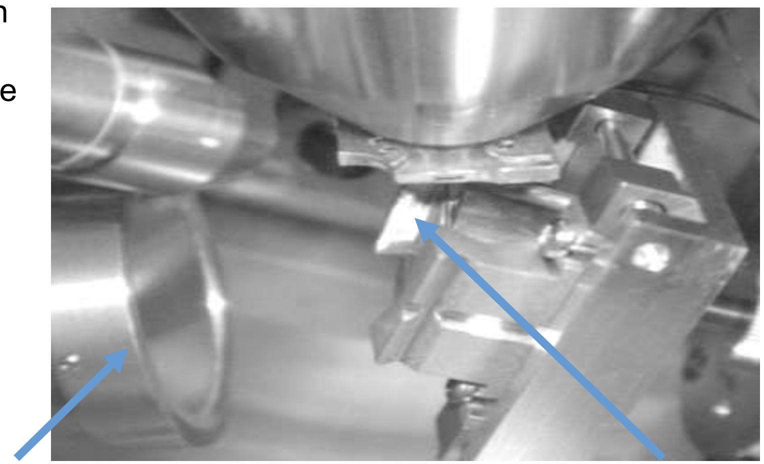
AMETEK
MATERIALS ANALYSIS DIVISION

EDAX
Smart Insight

EBSD Detector Geometry

- Specimen tilt ~70˚
- EBSD pattern projected on a phosphor screen and recorded by the EBSD detector
- Bands in the pattern represent reflecting lattice planes in the diffracting crystal volume





AMETEK MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

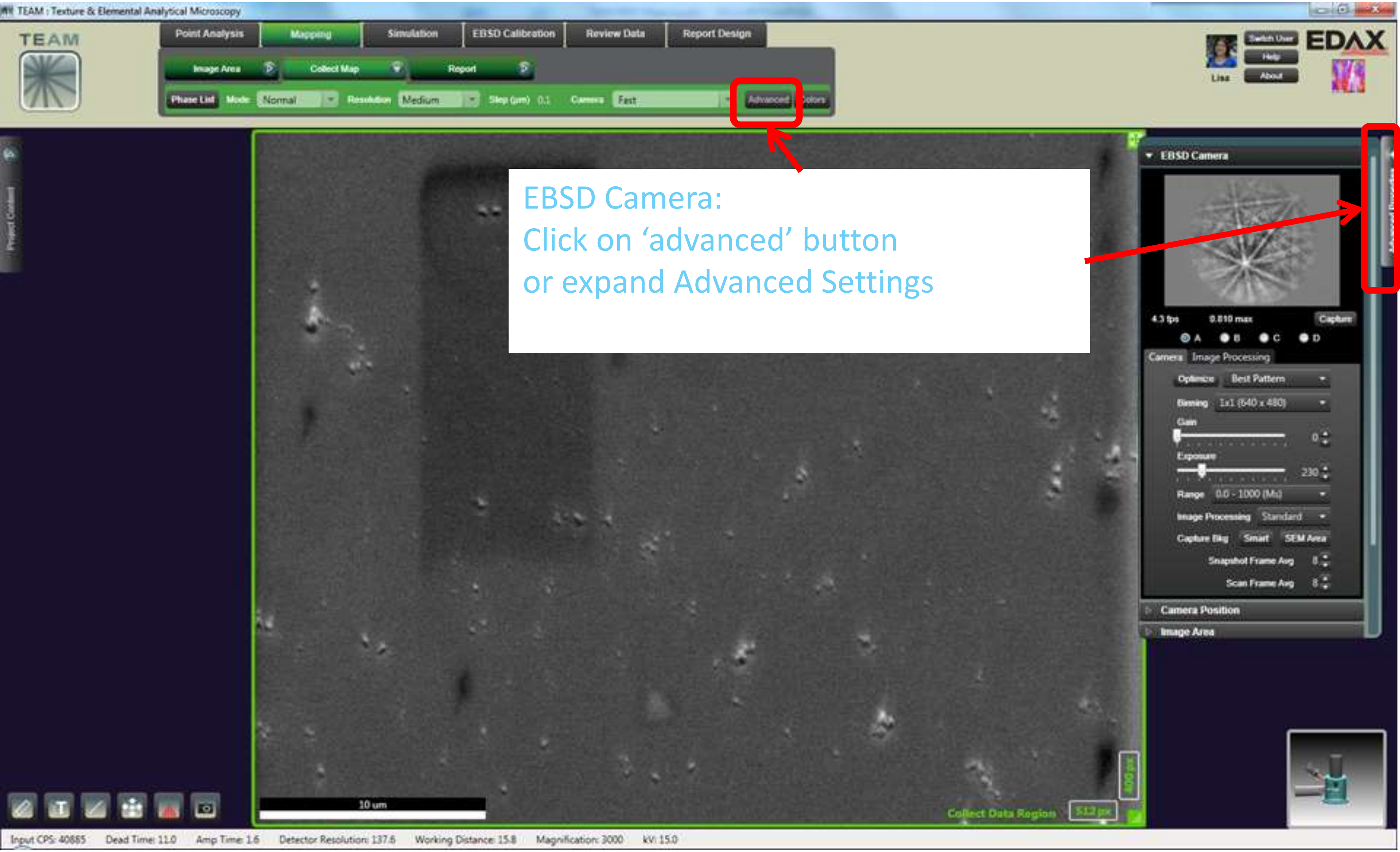
EBSD Detector Units

- Since 2001 EDAX has supplied two models of EBSD cameras.

DigiView
Max Speed: 200 IPPS
Max Resolution: 1392x1040

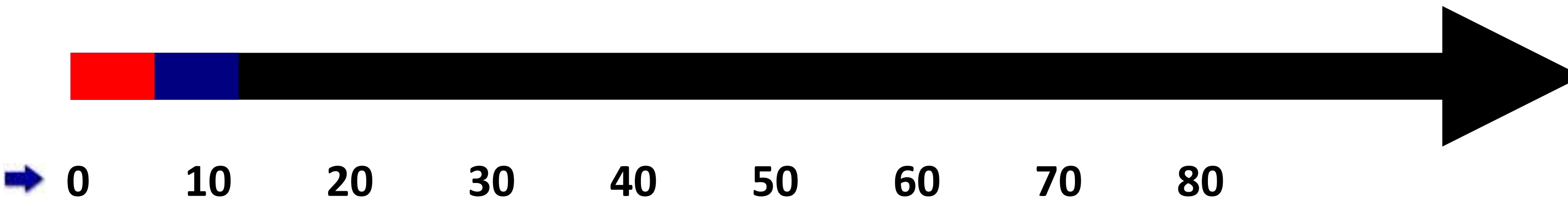
Hikari Super
Max Speed: 1400 IPPS
Max Resolution: 640x480

Camera Control



EBSD Camera:
Click on 'advanced' button
or expand Advanced Settings

Analytical Beam Currents



- An informal survey of SEM and EDS suppliers suggests analytical beam current conditions ranges from 1-100nA.
- The Hikari was designed to operate in the 100pA - 10nA range.
- The results shown here were all obtained with 5nA or less of current.
- Extremely high beam currents are <u>not</u> required for high speed collection of high quality data

AMETEK MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

What is my ultimate goal?

First question to always ask yourself is what is the purpose of the data I am collecting. Do I need high resolution patterns for HR-EBSD work or do I just need grain statistics?

The answer of this question leads to the next:

What quality level of the Pattern do I need to achieve my goal?

This question is really asking: How well/accurate can the Hough Transform find my lines on my patterns!

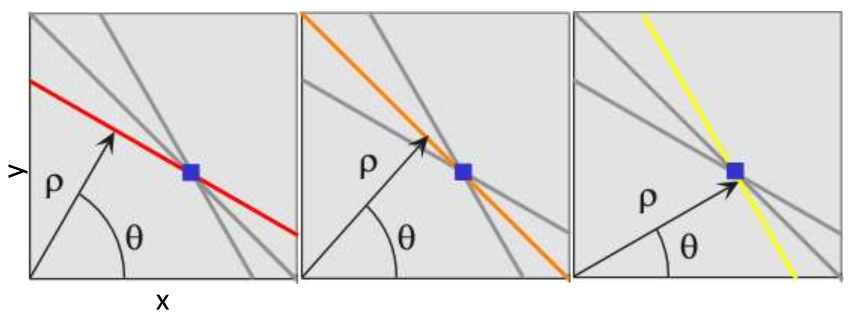
What does the Hough do?

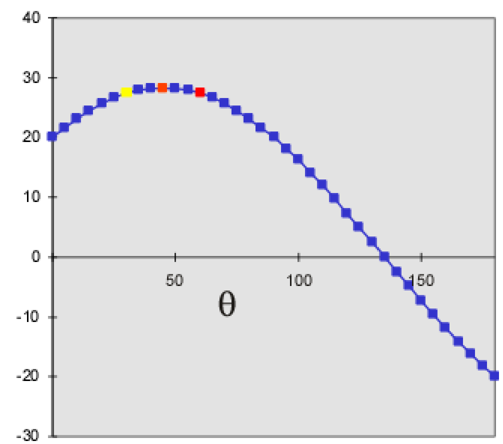
The Hough Transform is a way for the computer to detect lines.

Hough Transform

A given pixel in an image could belong to an infinite set of lines. A line can be parameterized by the Hough parameters r and q. Where q describes the angle of the line and r represents the perpendicular distance of the line from the origin. The relationship between the lines passing through a pixel at a coordinate in the image of *x*, *y* can be expressed as: r = *x*cosq + *y*sinq. This means a point in image space transforms to a sinusoidal curve in Hough space.

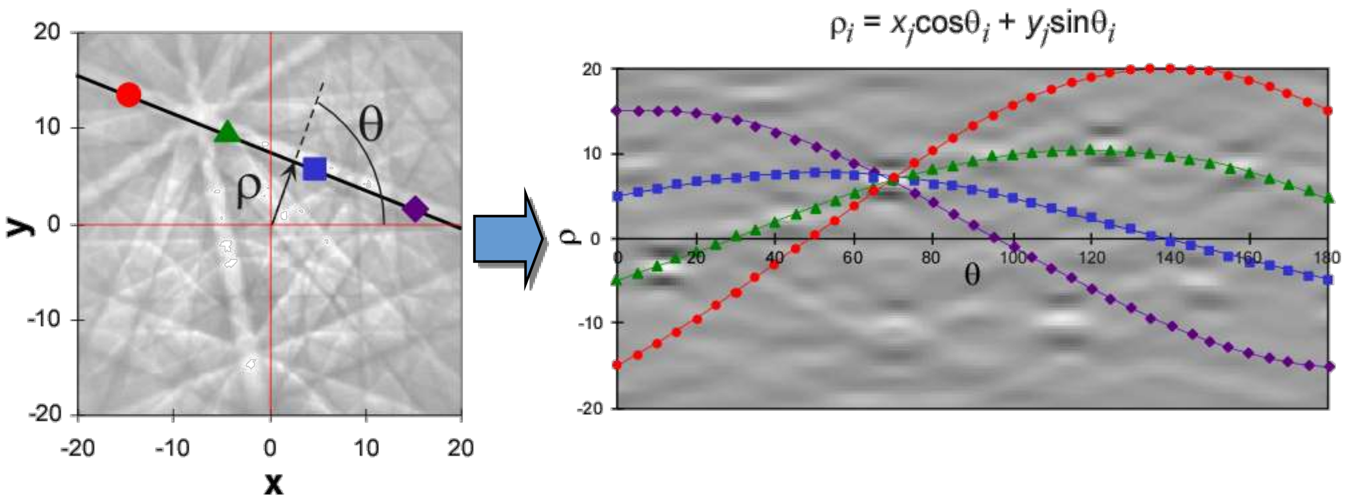
$$\rho_i = x\cos\theta_i + y\sin\theta_i$$





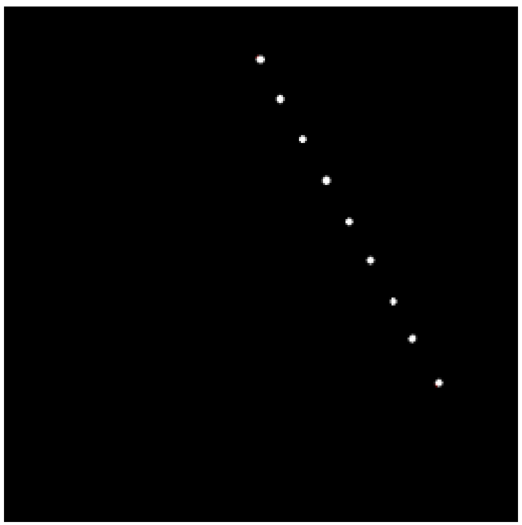
Hough Transform

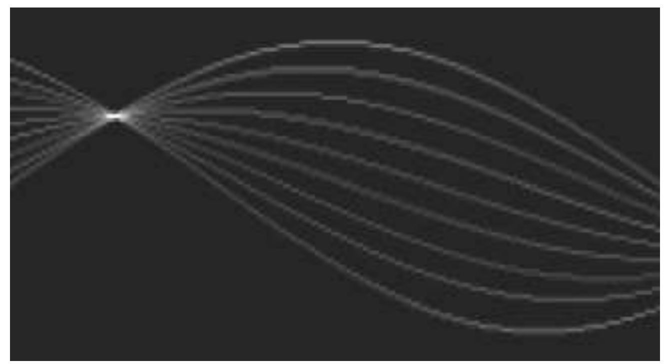
Consider 4 pixels along a line. For each pixel in the line, all possible r values are calculated for q's ranging in values from 0 to 180 degrees using the equation:
r = *x*cosq + *y*sinq. This produces 4 sinusoidal curves. This curves intersect at a point at a r, q coordinate corresponding to the angle of the line (q) and its position relative to the origin (r). Thus, a line in image space transforms to a point in Hough Space.



Hough Transform

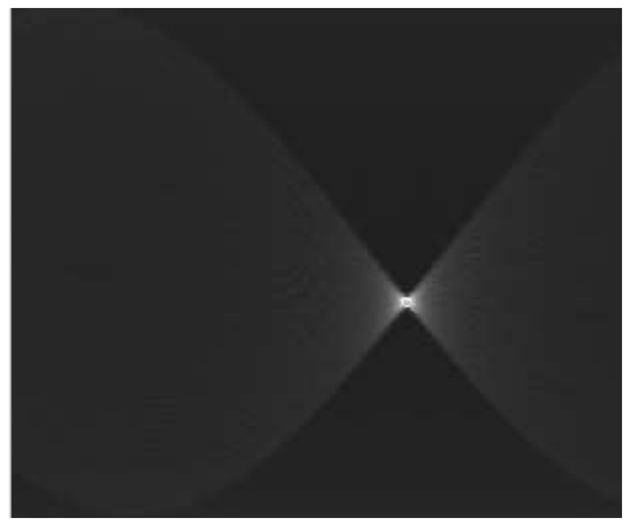
An entire image can be transformed into Hough Space by building an accumulator array H(r,q) where, for each pixel in the image, all possible r values are calculated for q's ranging in values from 0 to 180 degrees via the equation r = *x*cosq + *y*sinq. The intensity value of the pixel at *x*, *y* is then added to the bin in the array at each corresponding r, q. (Strictly speaking the Hough Transform only applies to binary images - this adaptation is the Radon Transform).





Hough Transform

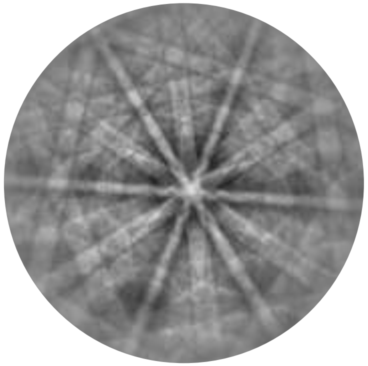
An entire image can be transformed into Hough Space by building an accumulator array H(r,q) where, for each pixel in the image, all possible r values are calculated for q's ranging in values from 0 to 180 degrees via the equation r = *x*cosq + *y*sinq. The intensity value of the pixel at *x*, *y* is then added to the bin in the array at each corresponding r, q. (Strictly speaking the Hough Transform only applies to binary images - this adaptation is the Radon Transform).

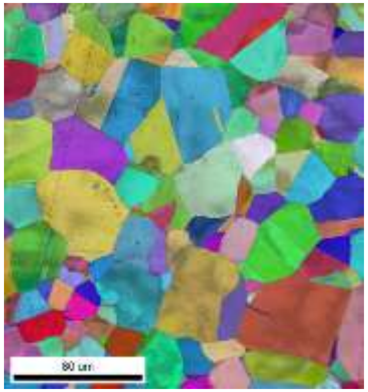


AMETEK® MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

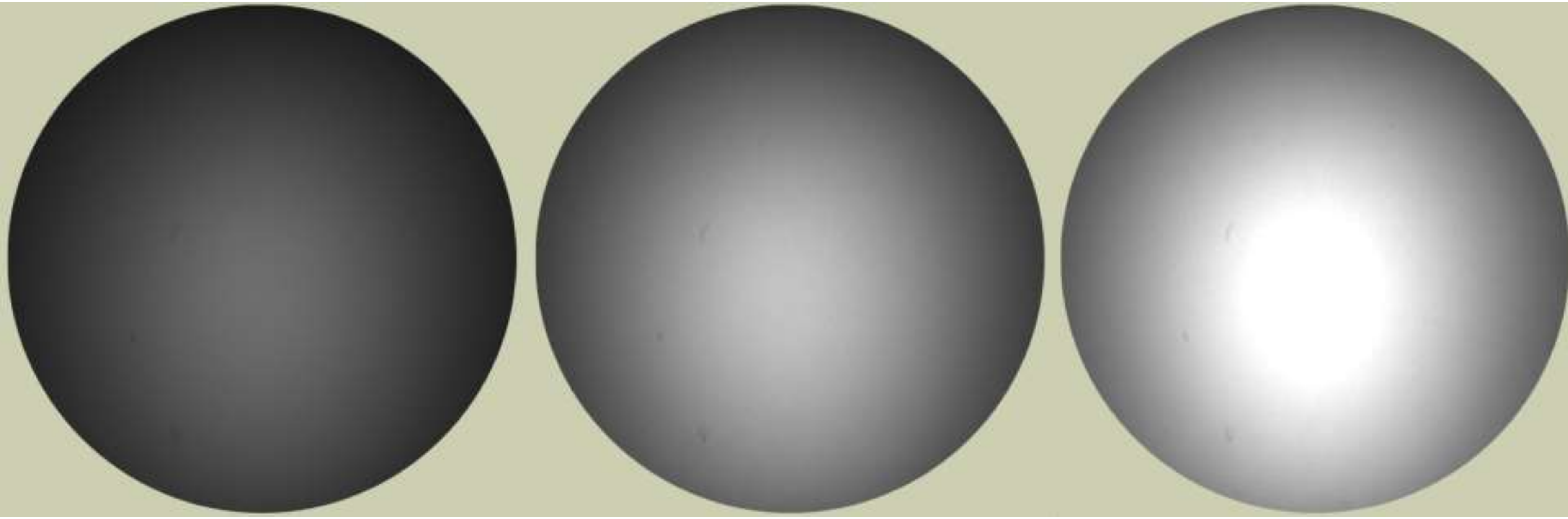
EBSD as Machine Vision





- One tool to maximize acquisition speed is reducing the pixel resolution of the captured and processed EBSD patterns.
- While visually less appealing, as long as acceptable for the Hough Transform, they provide accurate results.

Camera Signal Level

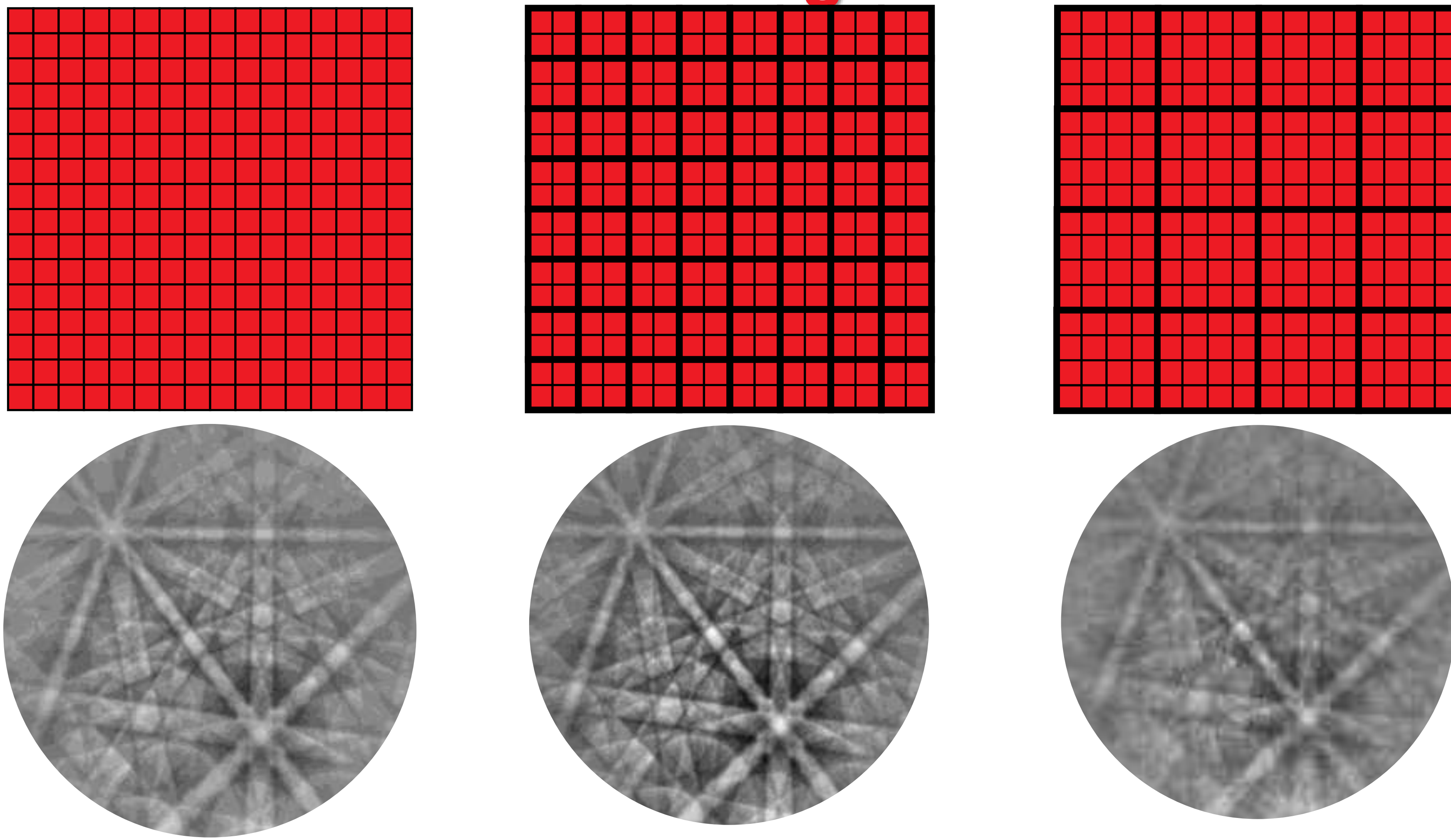


Under-saturated | Optimal | Over-saturated

The correct signal level produces a signal that is just below saturation.

Depending on the mode of operation, either gain or exposure time can be used to adjust the signal level.

CCD Binning – Match the Hough Binning



1024 x 1024 (1x1) | 512 x 512 (2x2) | 128 x 128 (4x4)

AMETEK MATERIALS ANALYSIS DIVISION

Binning the CCD makes the camera effectively more light sensitive leading to increasing achievable frame rates.

EDAX Smart Insight

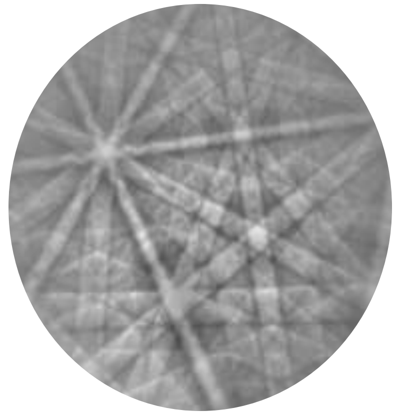
Camera Settings – Binning

Select the EBSD image resolution a.k.a. binning.

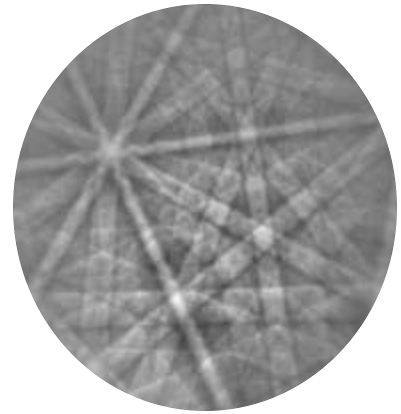
8x8 binning is typical for mapping, while 10x10 is used for the higher speeds

4x4 is sometimes used for EBSD-EDS mapping

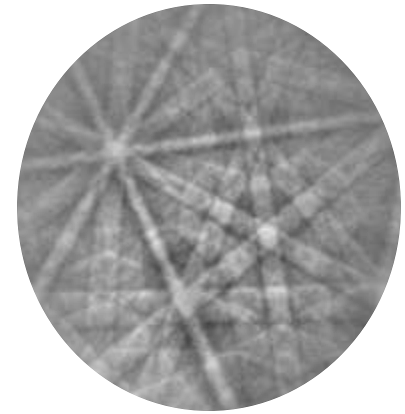
1x1 and 2x2 are typical for phase ID



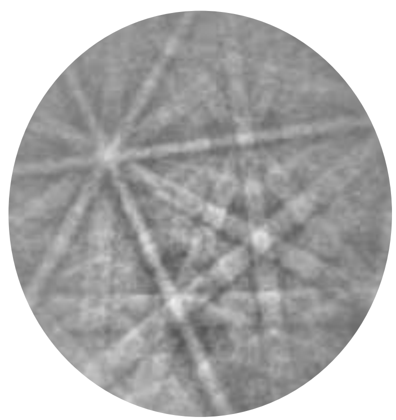
1x1 Binning
2 s



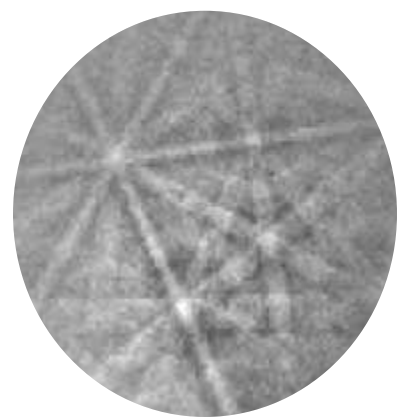
2x2 Binning
0.45 s



4x4 Binning
0.13 s



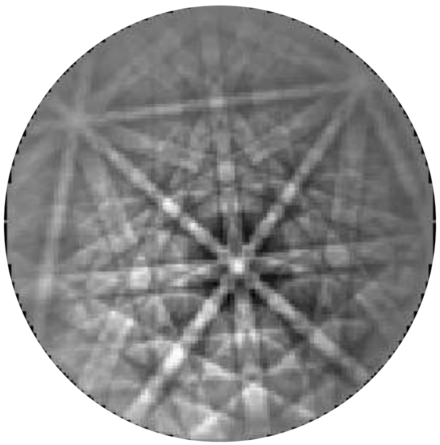
8x8 Binning
0.03 s



10x10 Binning
0.03 s

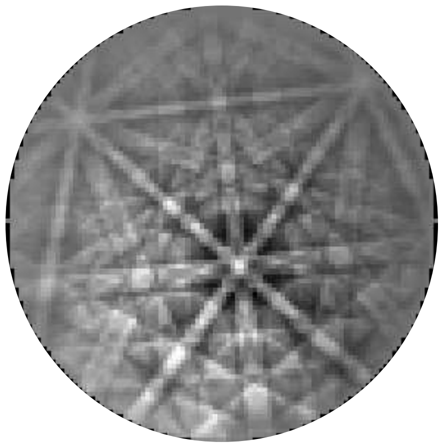
Values for DigiView

Camera Settings – Binning



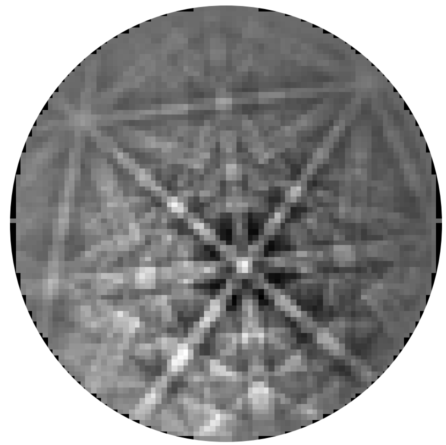
120 x 120

178 fps



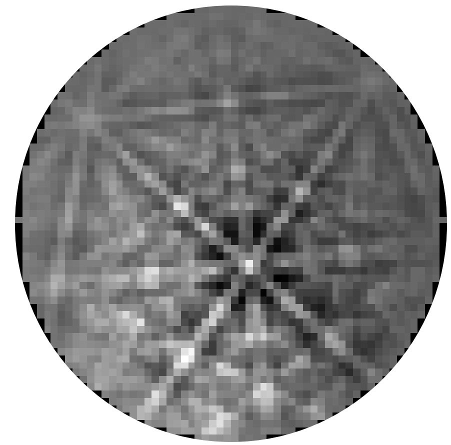
96 x 96

209 fps



80 x 80

240 fps



60 x 60

288 fps

At these scanning resolutions, the typical output frame rate (in frames per second) are shown here.

AMETEK MATERIALS ANALYSIS DIVISION

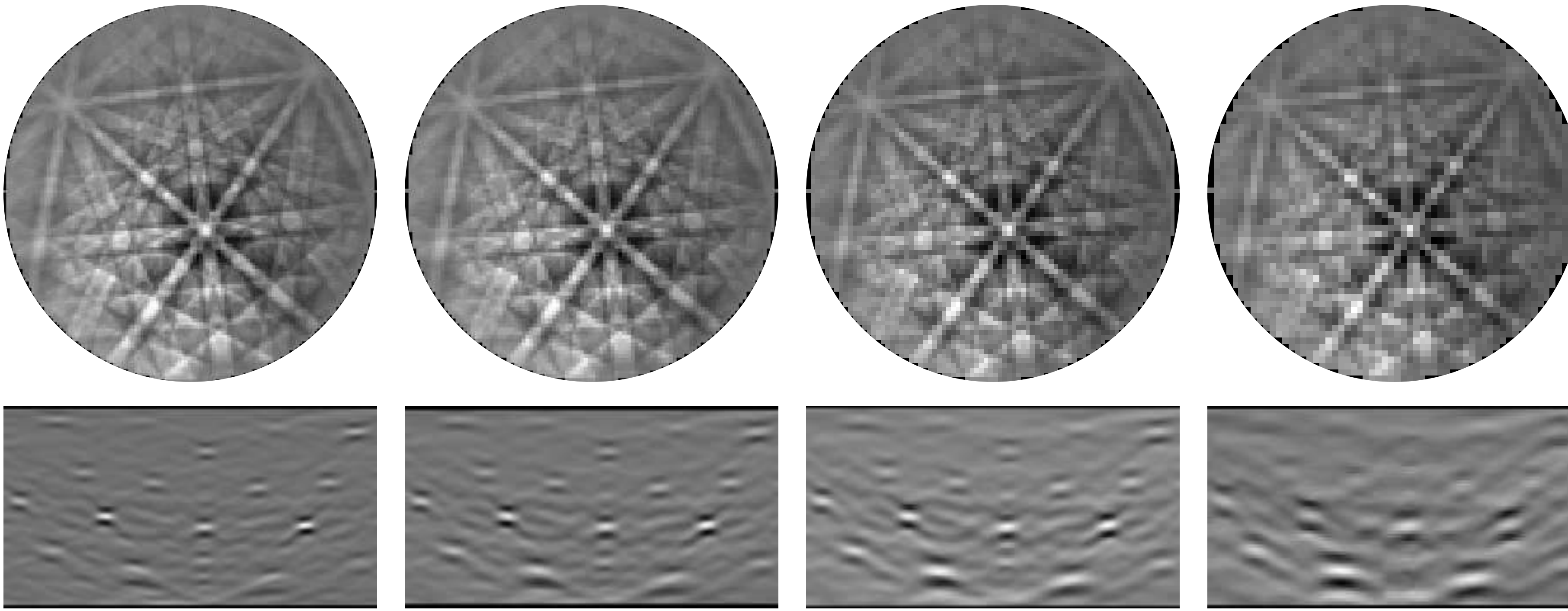
EDAX Smart Insight

Camera Settings – Binning

Binning Size	DigiView	Hikari
1x1	1392 x 1040	640x480
2x2	696 x 520	320x240
4x4	348 x 260	160x120
5x5	N/A	128x96
6x6	N/A	106x80
8x8	174 x 130	80x60
9x9	154 x 115	N/A
10x10	139 x 104	64x48
11x11	126 x 94	N/A
12x12	116 x 86	N/A
13x13	107 x 80	N/A
16x16	N/A	40 x 30

The CCD chip within the DigiView has a larger maximum resolution.

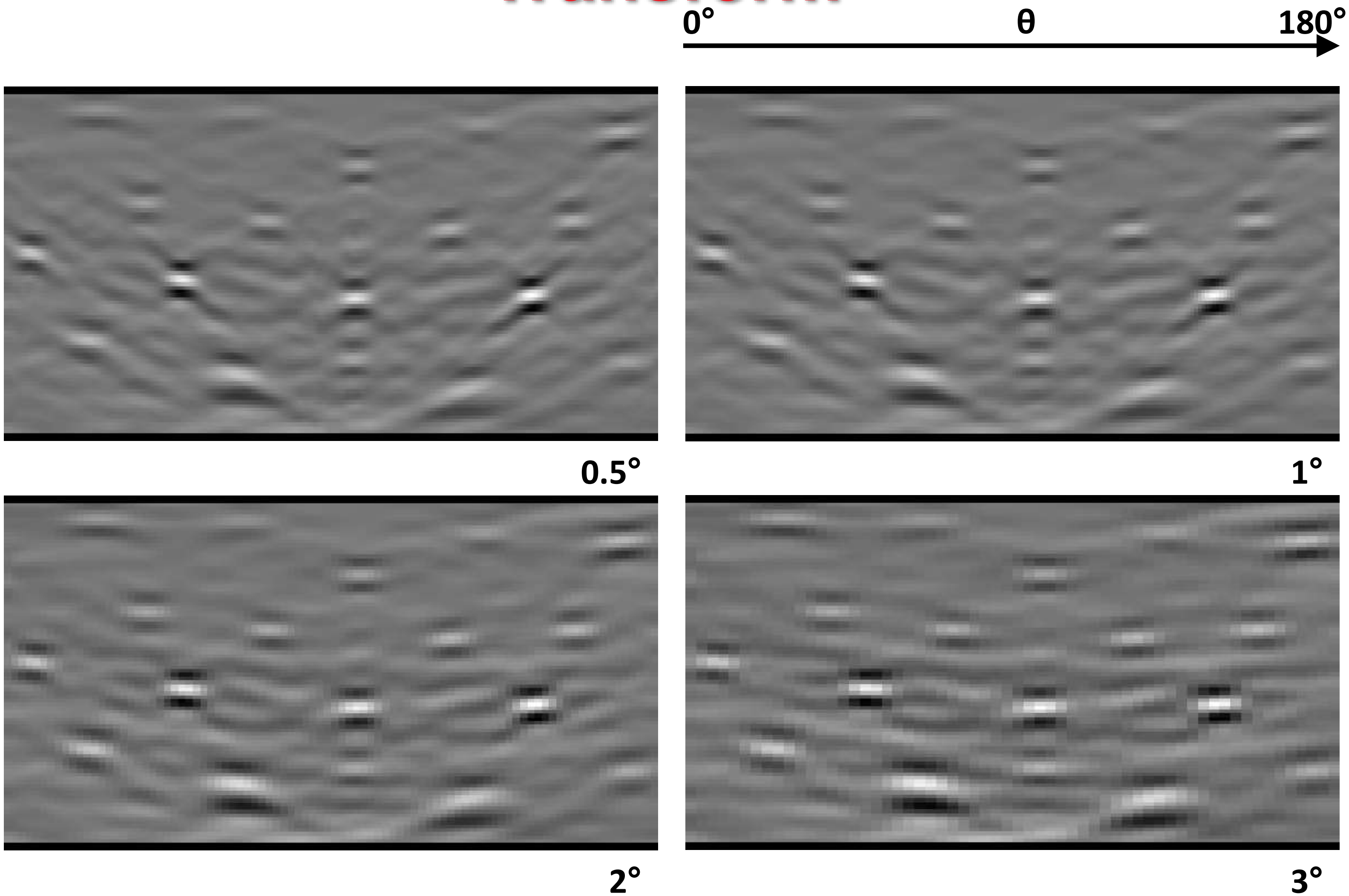
Camera Settings – Binning & Hough Transform



120 x 120 | 96 x 96 | 80 x 80 | 60 x 60

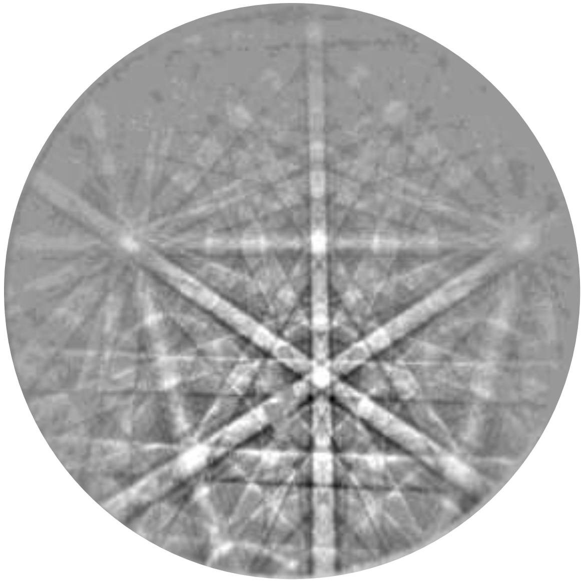
As your working image resolution decreases, so does the corresponding Hough Transform resolution (although they can have some independence).

Camera Settings – Binning & Hough Transform

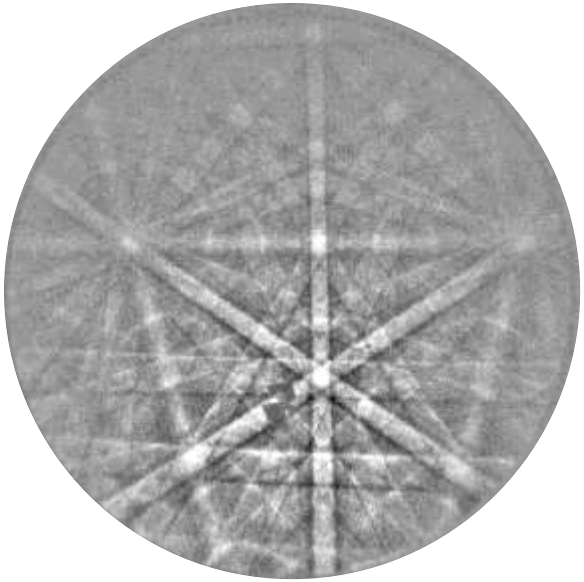


One can also adjust the theta step size

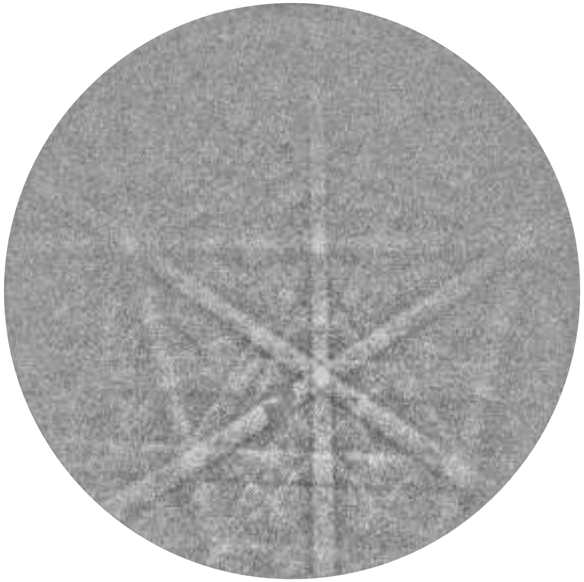
Camera Settings – Gain



0% Gain



50% Gain

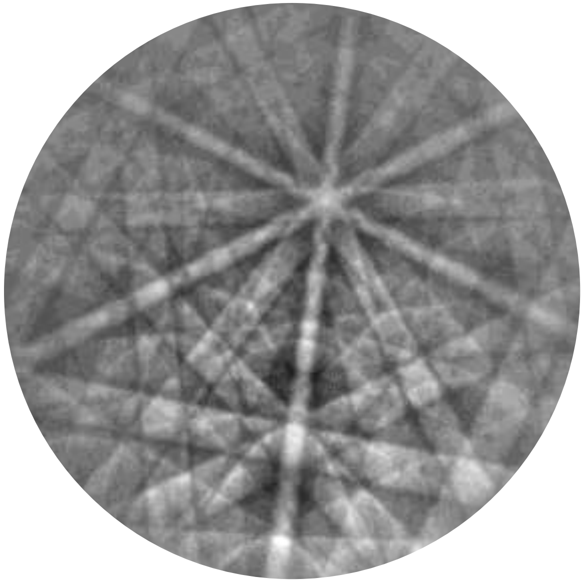


100% Gain

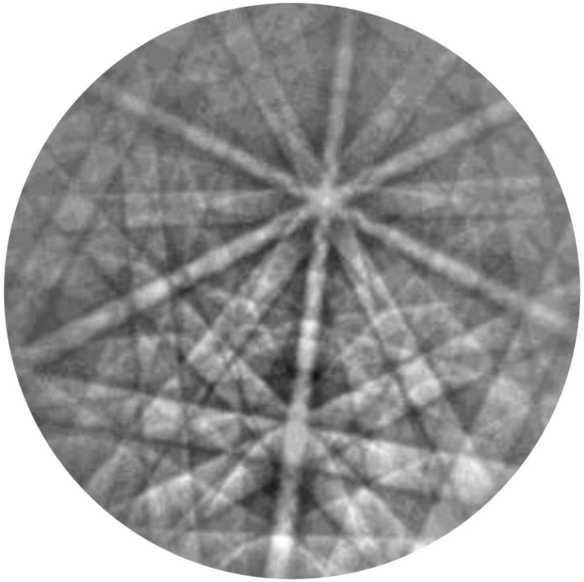
Increasing gain increases noise. Higher gain often allows faster image collection.

Microscope Conditions

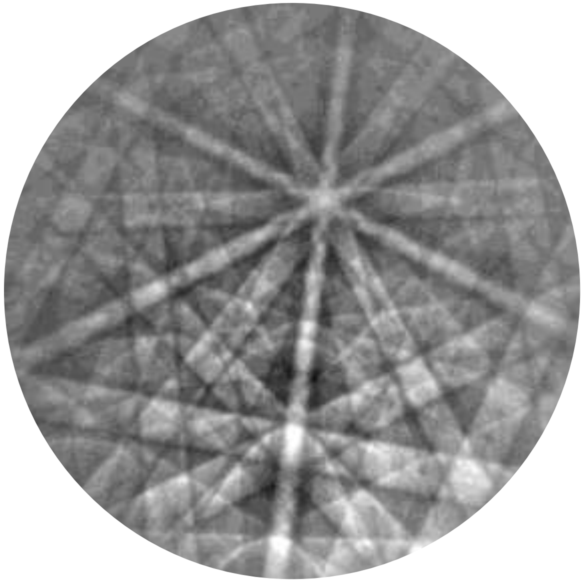
Probe Size (FE vs. LaB_6 vs. Tungsten)
Operating Conditions (**Current**, Voltage, Vacuum)
Video Settings (Exposure, gain, contrast & brightness)



0.6nA Beam Current
4.62 Seconds



2.4nA Beam Current
1.56 Seconds



9.45nA Beam Current
0.6 Seconds

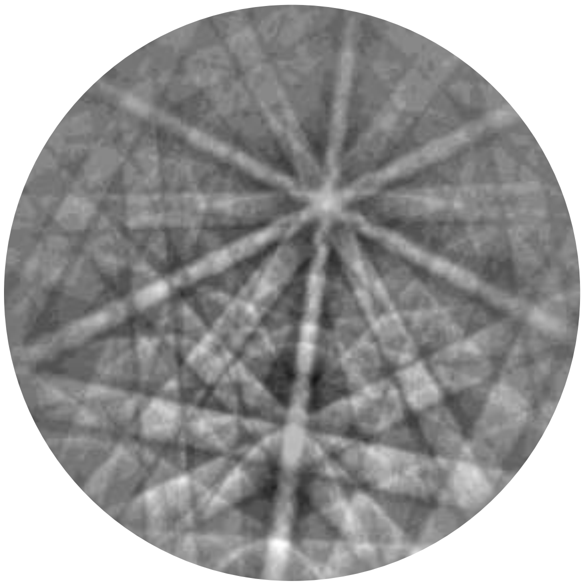
SEM conditions also play a role. As beam current goes up, exposure time goes down. By keeping the camera gain constant, pattern quality doesn't change much though.

AMETEK MATERIALS ANALYSIS DIVISION

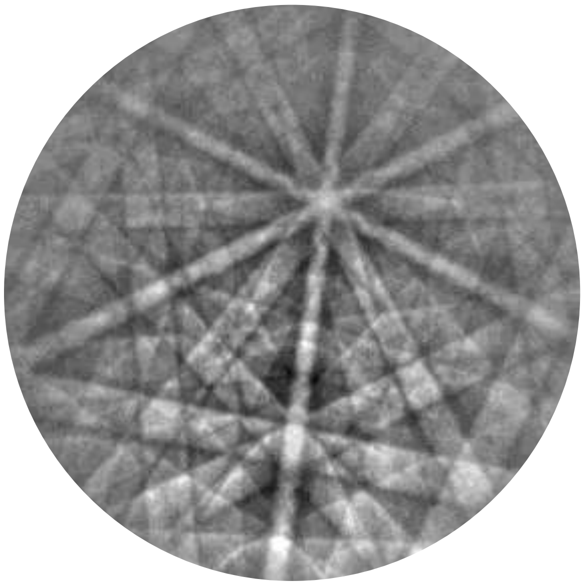
EDAX Smart Insight

Microscope Conditions

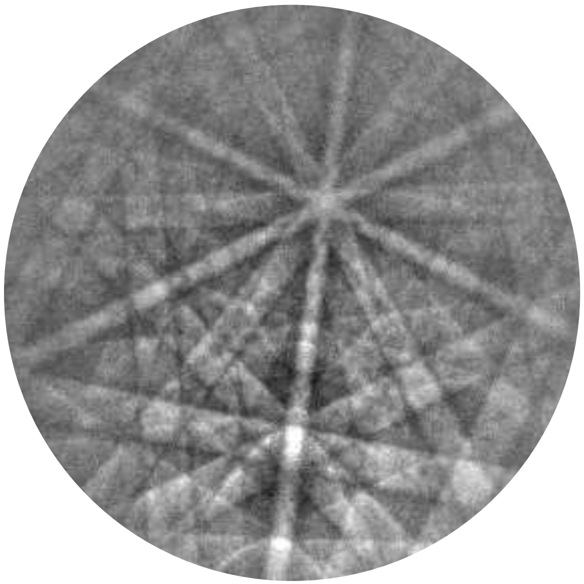
Probe Size (FE vs. LaB_6 vs. Tungsten)
Operating Conditions (Current, Voltage, Vacuum)
Video Settings (Exposure, **gain**, contrast & brightness)



Minimum Gain
2.76 Seconds



Mid-Range Gain
0.55 Seconds



Maximum Gain
0.15 Seconds

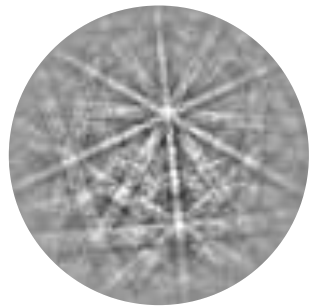
Three different camera gain settings are used. As gain goes up, exposure time goes down, however, the signal to noise ratio decreases.

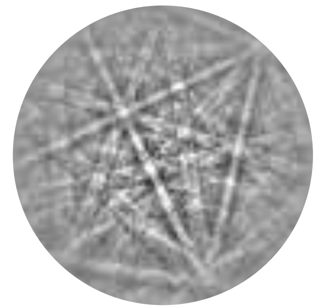
AMETEK MATERIALS ANALYSIS DIVISION

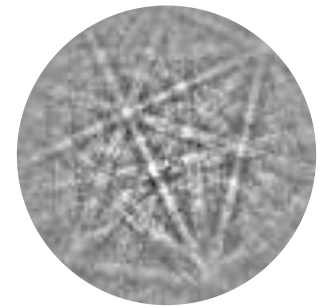
EDAX Smart Insight

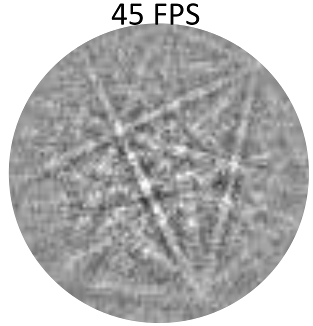
Faster EBSD Mapping

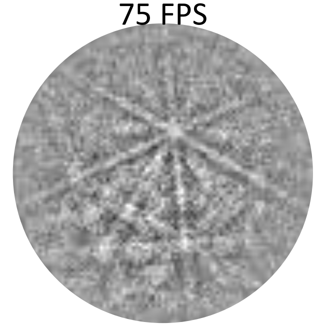
- Faster camera speeds are obtained by increasing camera gain.
  - 17X Faster between 0 and 25 gain
- This also increases image noise and decreases signal to noise level (S/N) in patterns.

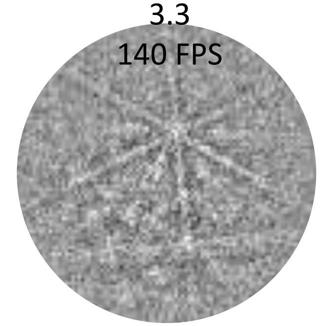

Gain 0 – Noise ≈ 1.9
45 FPS


Gain 5 – Noise ≈ 2.5
75 FPS


Gain 10 – Noise ≈ 3.3
140 FPS

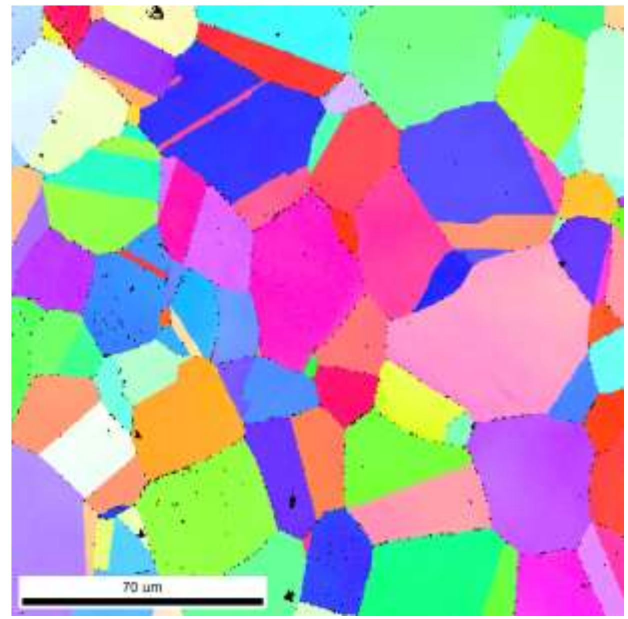

Gain 15 – Noise ≈ 4.6
260 FPS


Gain 20 – Noise ≈ 6.7
478 FPS


Gain 25 – Noise ≈ 9.7
783 FPS

5x5 Gain 30 Noise ≈15

Gain 30 – Noise ≈ 15



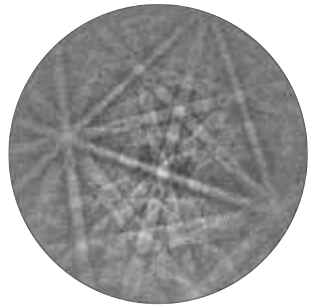
- While visually it is difficult to observe the EBSD pattern, this quality can be analyzed with > 99% accuracy.
- This is a best case scenario

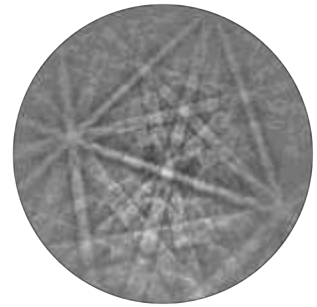
AMETEK MATERIALS ANALYSIS DIVISION

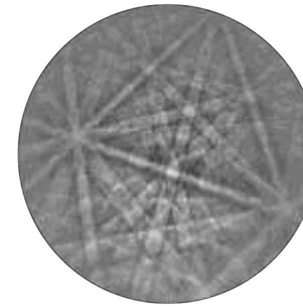
EDAX Smart Insight

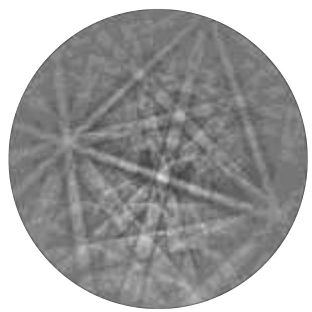
Frame Averaging

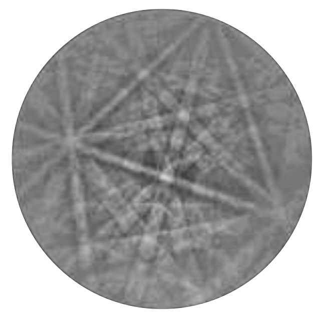
- Frame averaging improves the S/N in pattern.
- However because multiple frames are averaged, the overall acquisition time is slower than the camera frame rate.

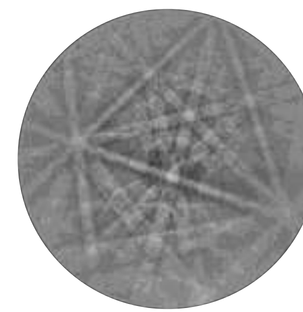

1 Frame


1 Frames Averaged

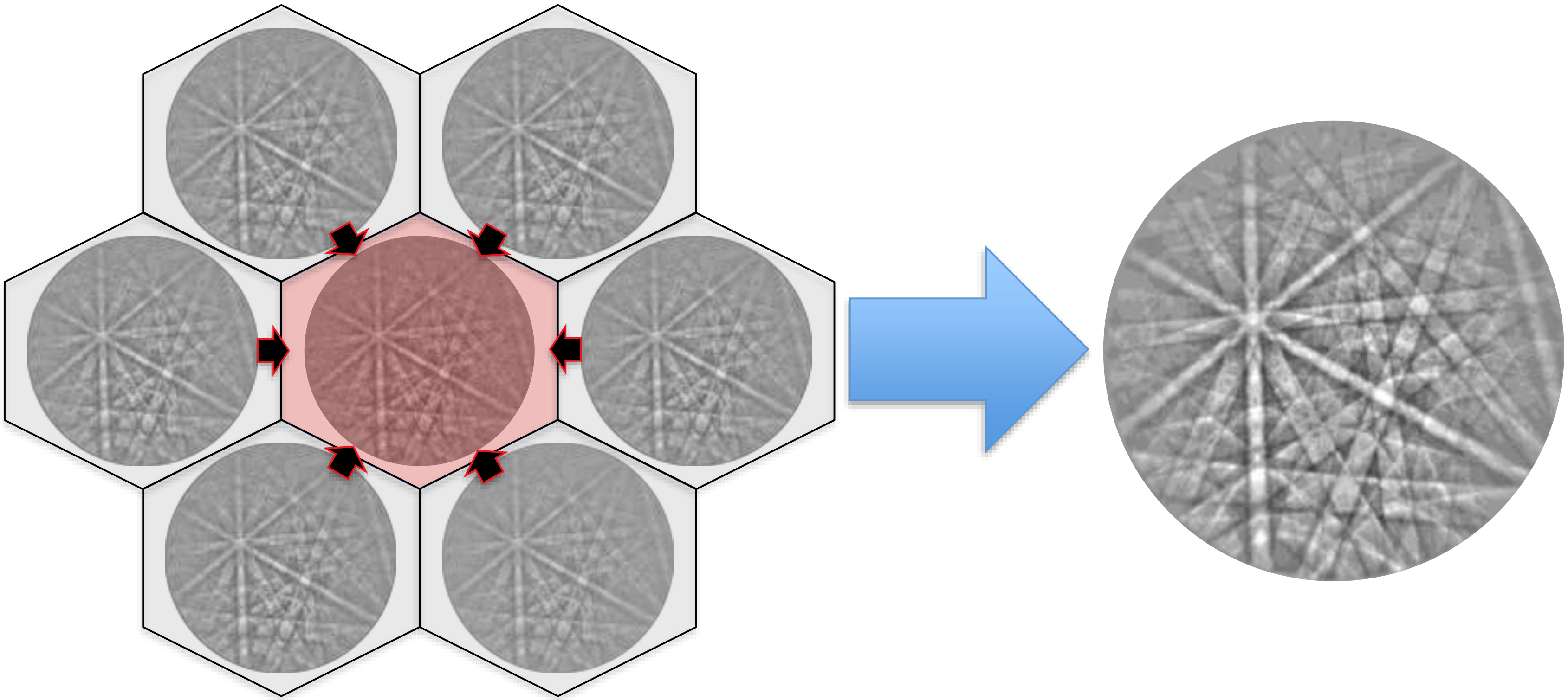

2 Frames Averaged


4 Frames Averaged


7 Frames Averaged


10 Frames Averaged

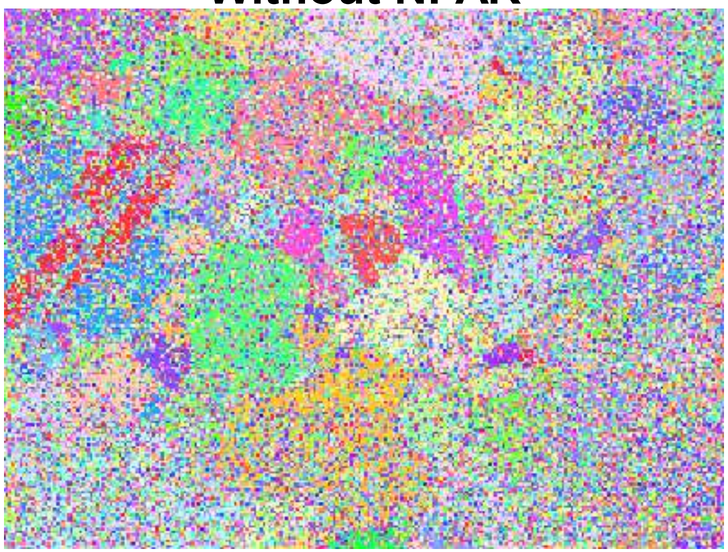
NPAR – Neighbor Pattern Averaging and Reindexing



A new approach to improving S/N while maintaining acquisition speeds

NPAR Indexing Performance

Without NPAR



11% Indexing Success

With NPAR

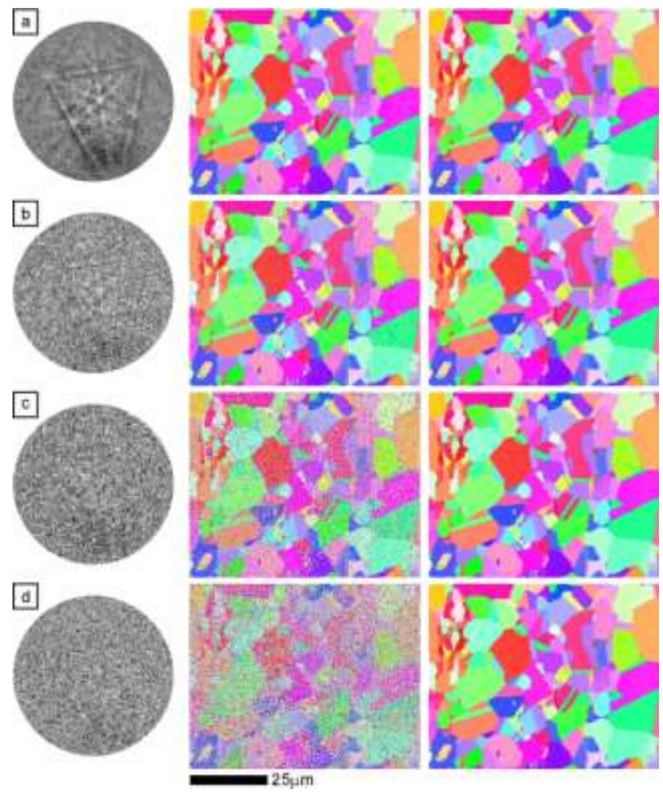
96% Indexing Success

AMETEK MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

Indexing as a Function of Noise and NPAR

- Effects of EBSD pattern noise on indexing and NPAR performance were systematically studied.
- Gain was increased to introduce more noise and reduce indexing success.

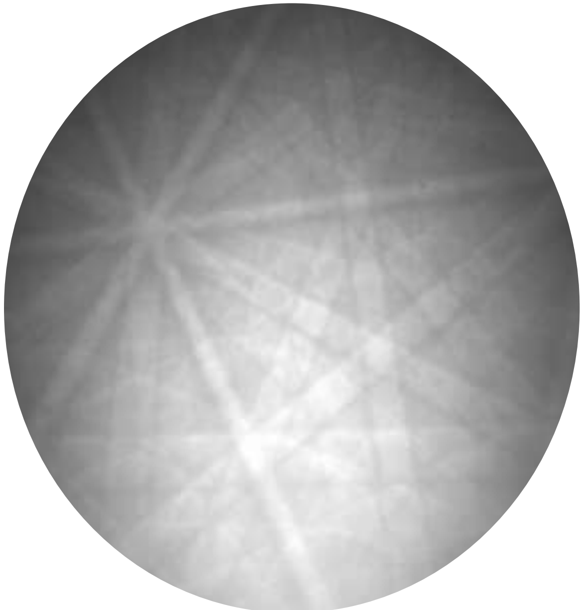


Camera Settings – Recommended

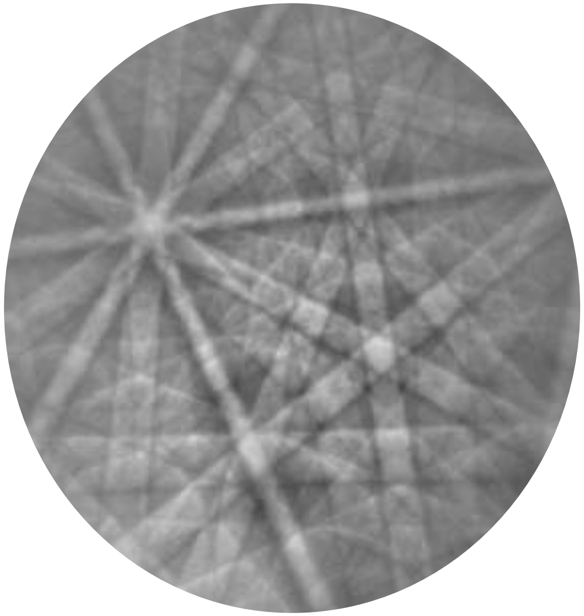
- For standard mapping, 8x8 binning on the DigiView and 5x5 binning on the Hikari will produce approximately 70pps and 200pps respectively.
- For simultaneous EBSD+EDS collection, check EDS count rate to make sure enough EDS counts are collected. This is very dependent though on what you are trying to do with the EDS information. Often times I operate a lower gain or higher resolution/lower binning sizes because I want to operate more slowly for more counts.
- For phase ID, 2x2 binning on the DigiView and 1x1 on the Hikari will give high resolution patterns that takes about 1 sec.

Image Processing – Background Subtraction

Background subtraction enhances the overall EBSD pattern, increases the contrast level, smoothes the inherent intensity gradient, and helps improve band detection.



Without Background Subtraction



With Background Subtraction

AMETEK MATERIALS ANALYSIS DIVISION

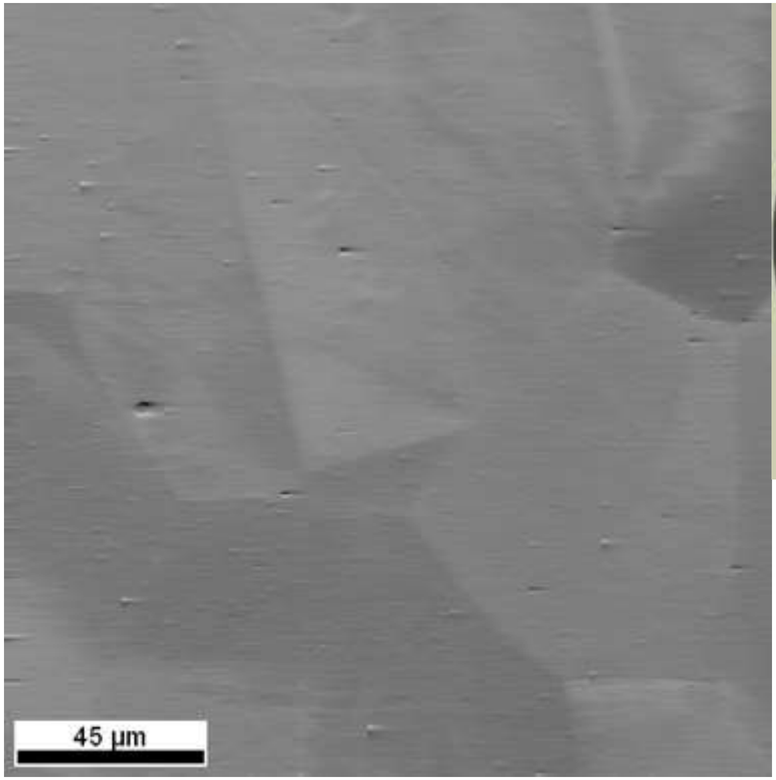
EDAX Smart Insight

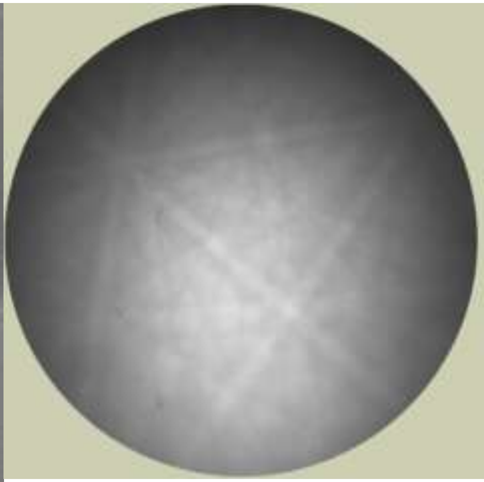
Image Processing – Background Subtraction

Prior to collecting a background, the SEM magnification must be selected appropriately.

A significant number of grains must be imaged.

This magnification is dependent on the grain size of the material of interest.



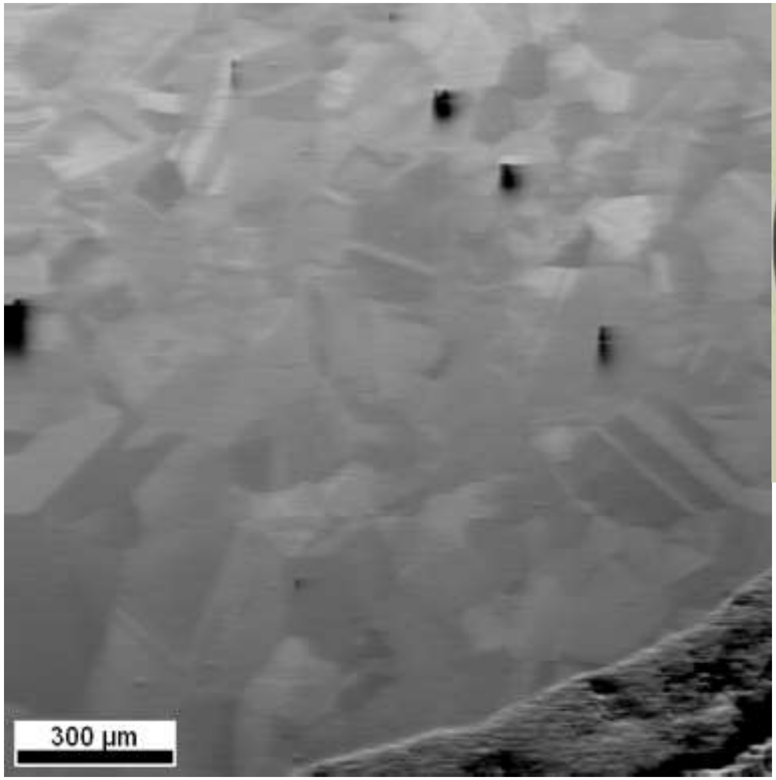


1,000X Mag

Image Processing – Background Subtraction

For this material, with an average grain size of 40 microns, imaging at 125X produces no latent EBSD pattern.

The SEM should raster at a fast rate, preferably TV rate, to avoid any latent background EBSD patterns.



125X Mag

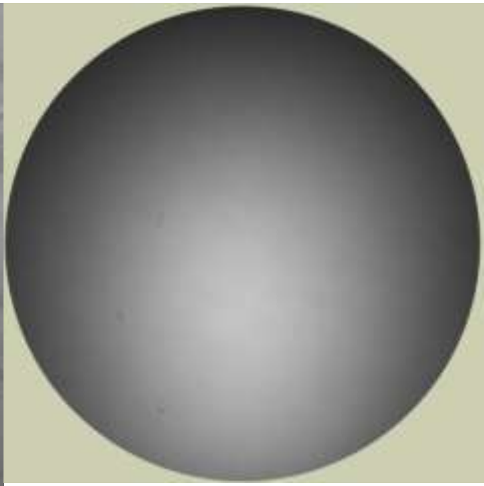
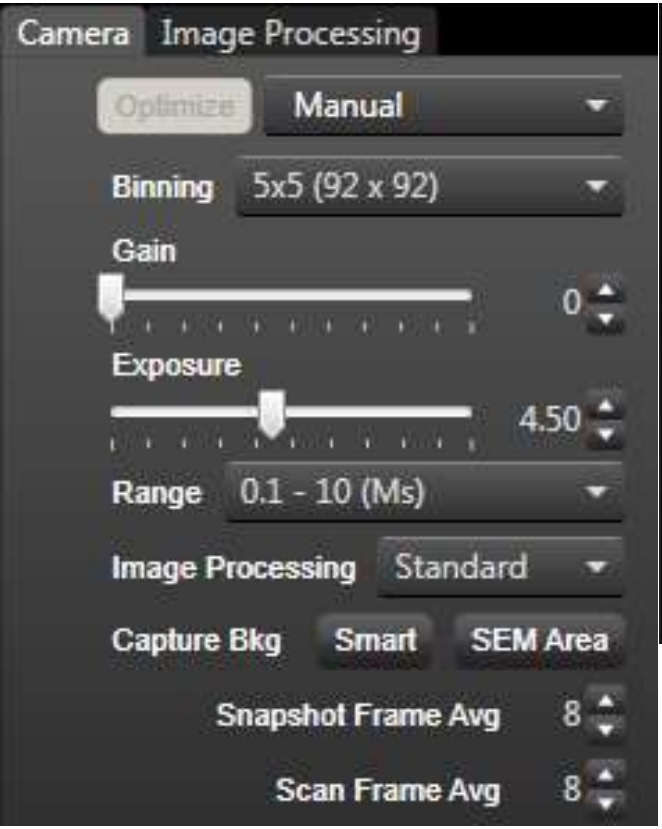
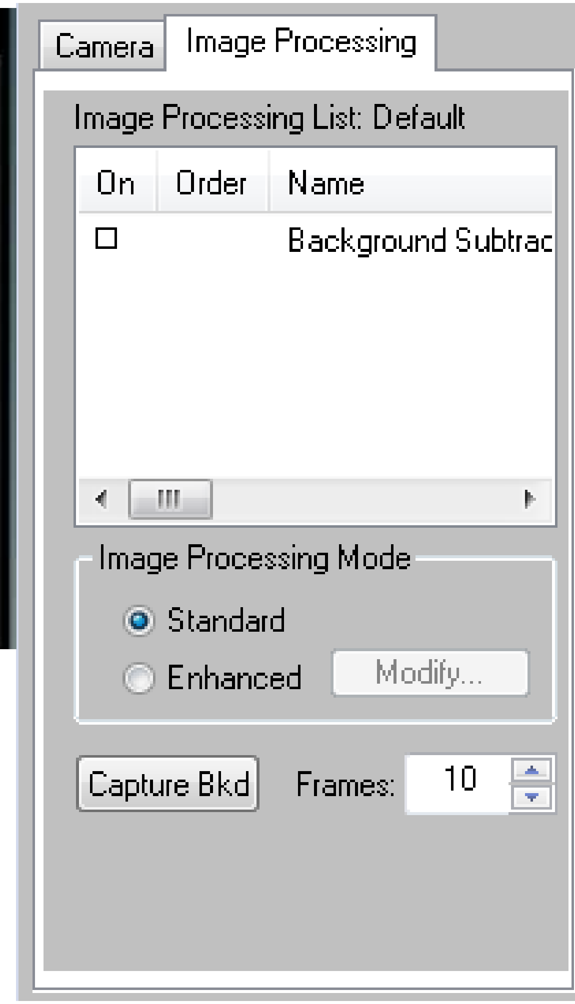


Image Processing – Background Capture





The capture button activates the background collection process. No patterns should be visible.

Smart background will drop the magnification before capturing.

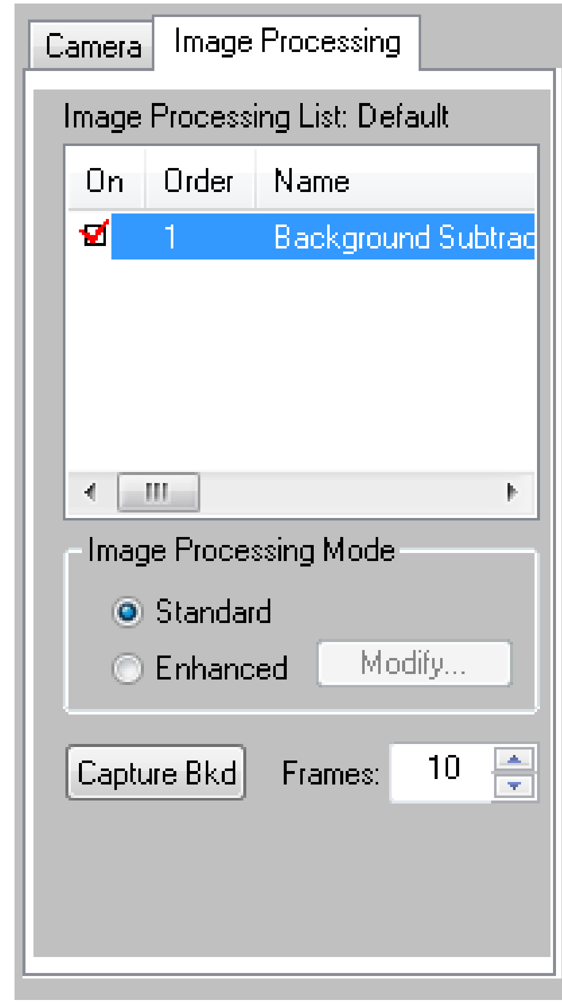
Image Processing – Background Subtraction

To apply the background:

TEAM: select Standard or Enhanced from the Image Processing Mode dropdown menu

OIM: check on background subtraction

The background correction is now applied to both the live and captured images.



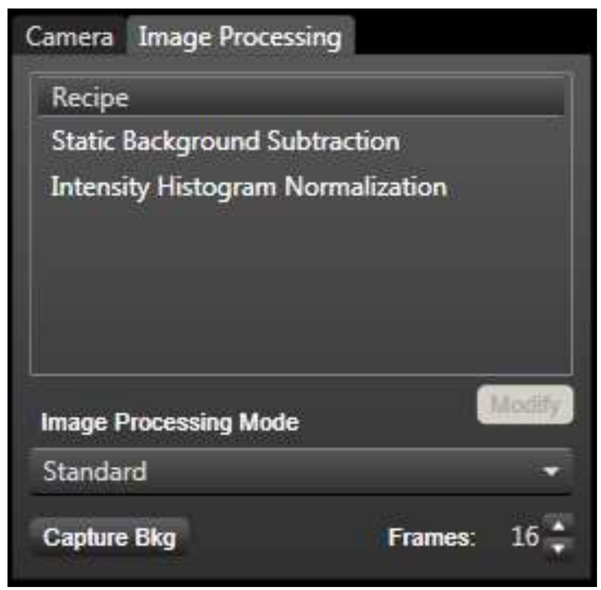
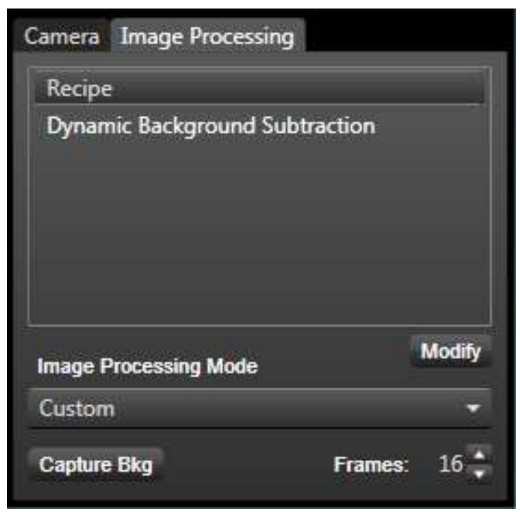


Image Processing – Dynamic Background Subtraction

For single crystals, extremely large grained samples, or rough-surfaces the Dynamic Background Subtract option can be used.

While this doesn't produce the same contrast, the band detection and mapping results are similar.



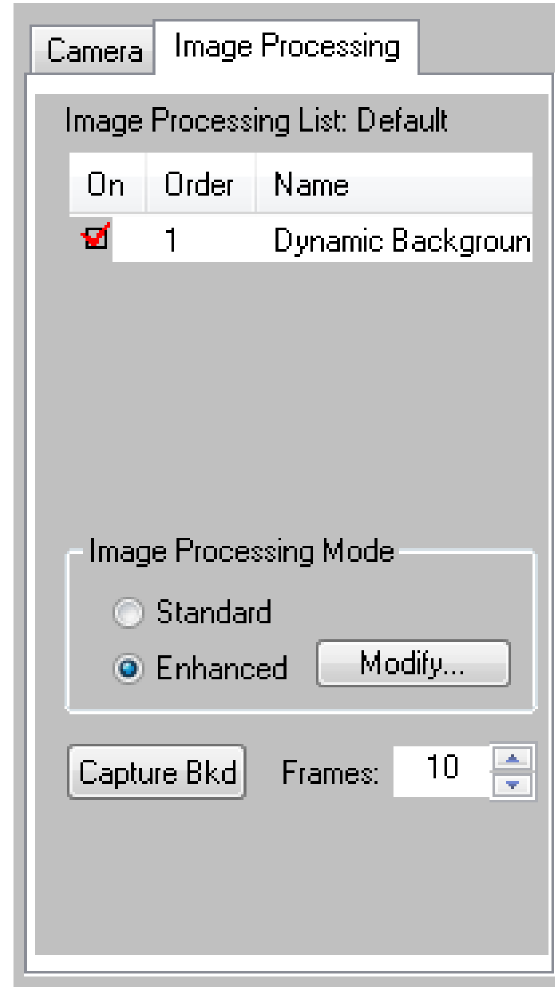
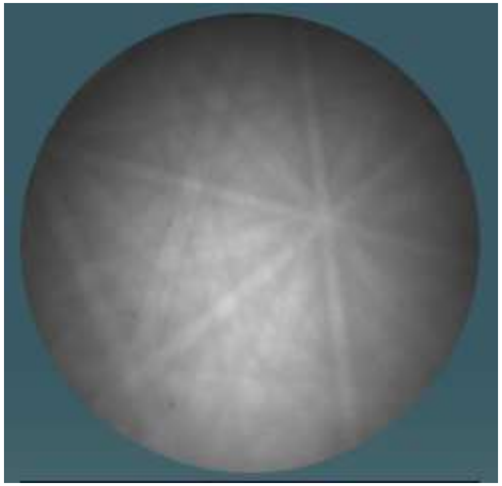


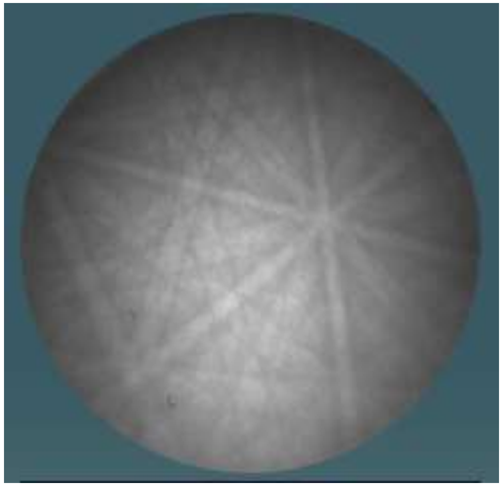
Image Processing – Dynamic Background Subtraction

Increasing the number of filter passes improves the resulting EBSD pattern quality.

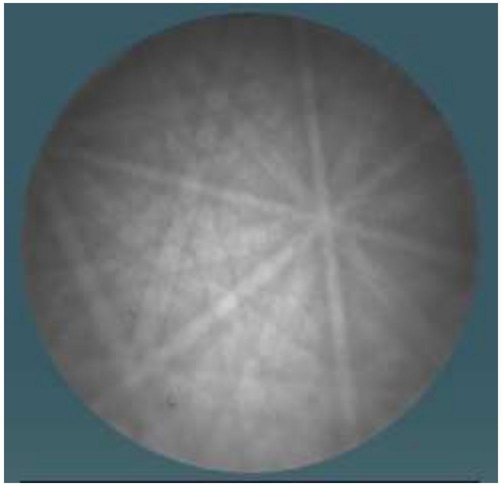
There is a time penalty associated with each filter pass however.



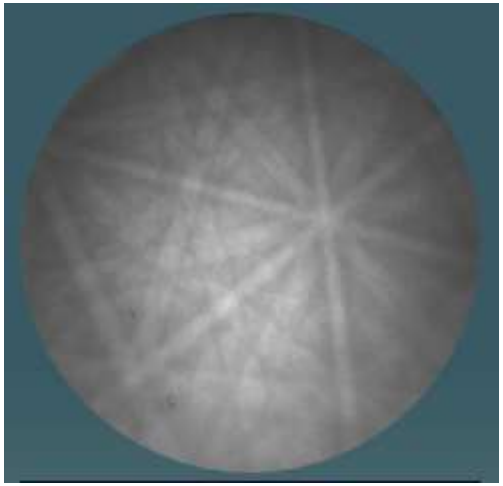
Filter passes: 0



Filter passes: 2

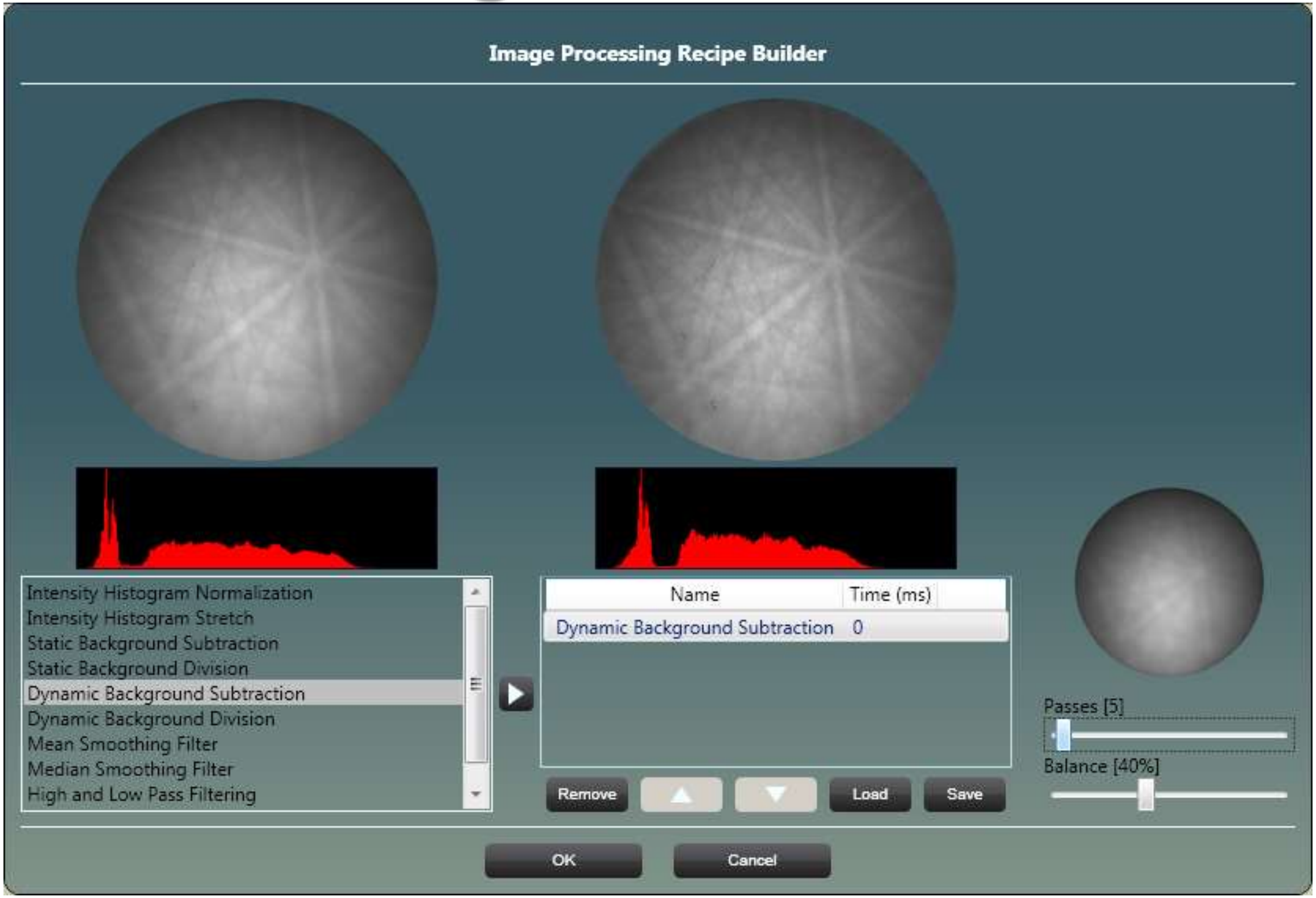


Filter passes: 10



Filter passes: 40

Image Processing – Dynamic Background Subtraction

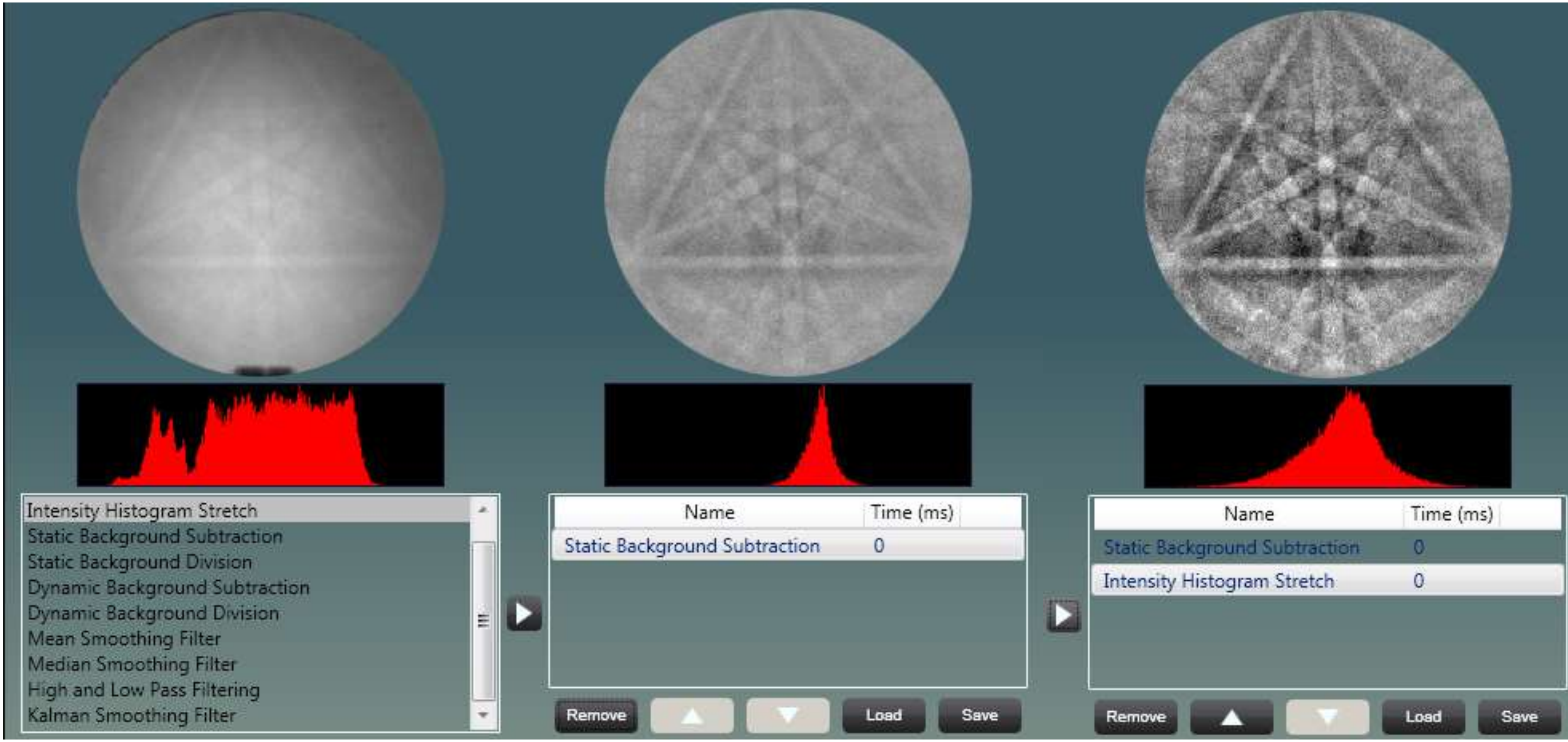


AMETEK
MATERIALS ANALYSIS DIVISION

EDAX
Smart Insight

Image Processing – Histogram Stretch

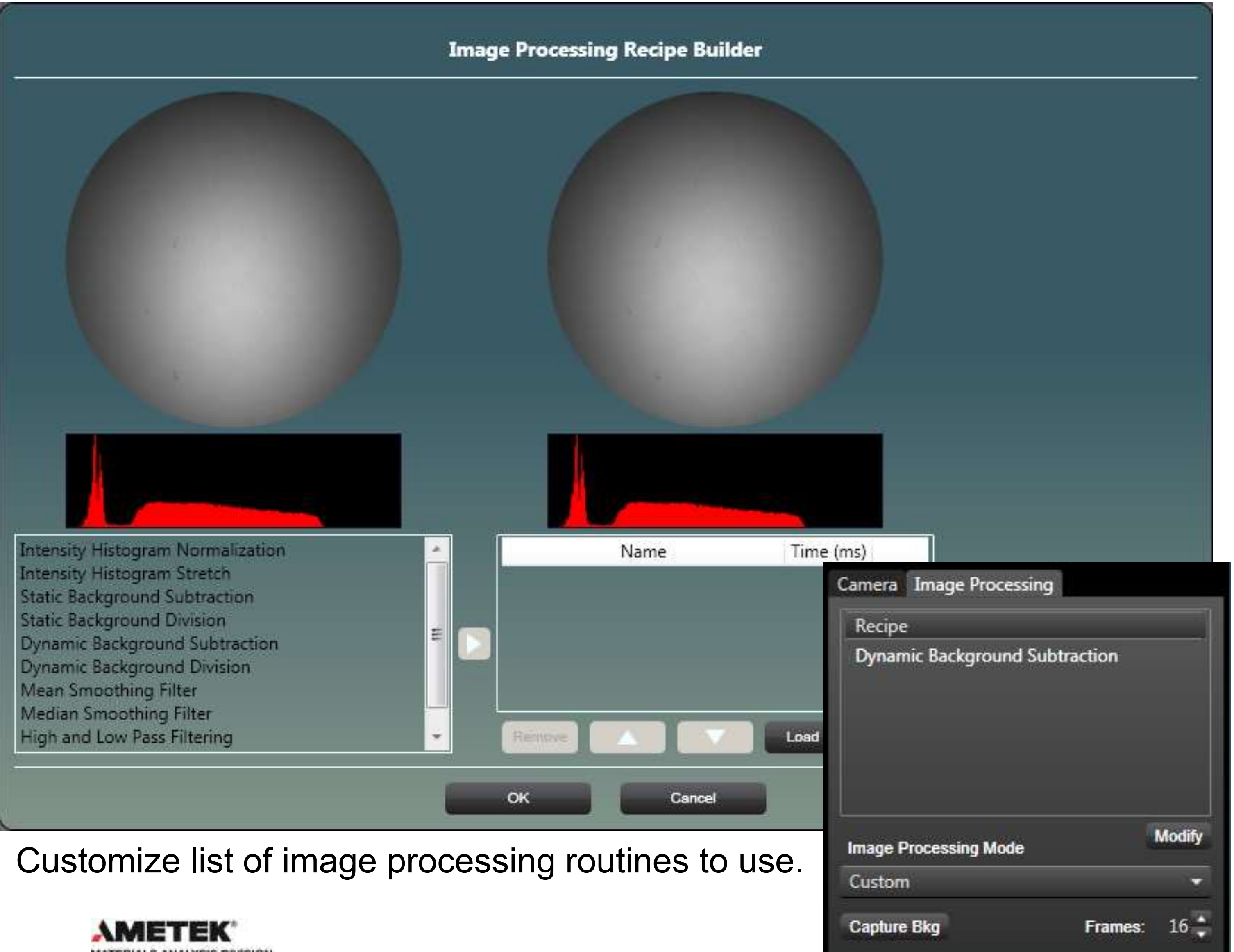
- **Intensity Histogram Stretch**
  - Improve the Brightness and Contrast

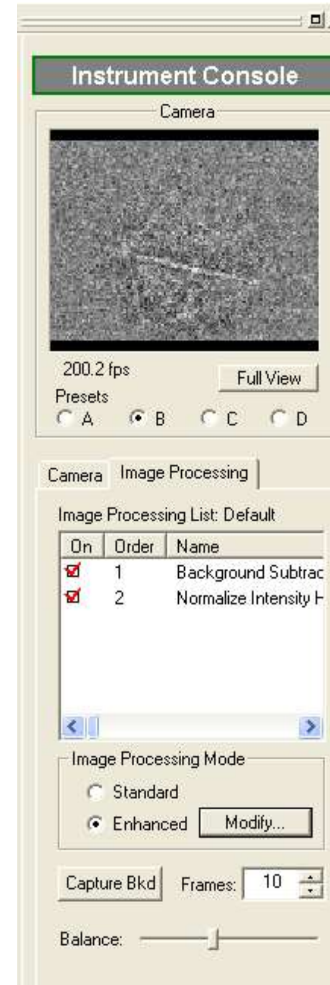


AMETEK® MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

Image Processing Routines





Customize list of image processing routines to use.

AMETEK MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

Band Detection Troubleshooting

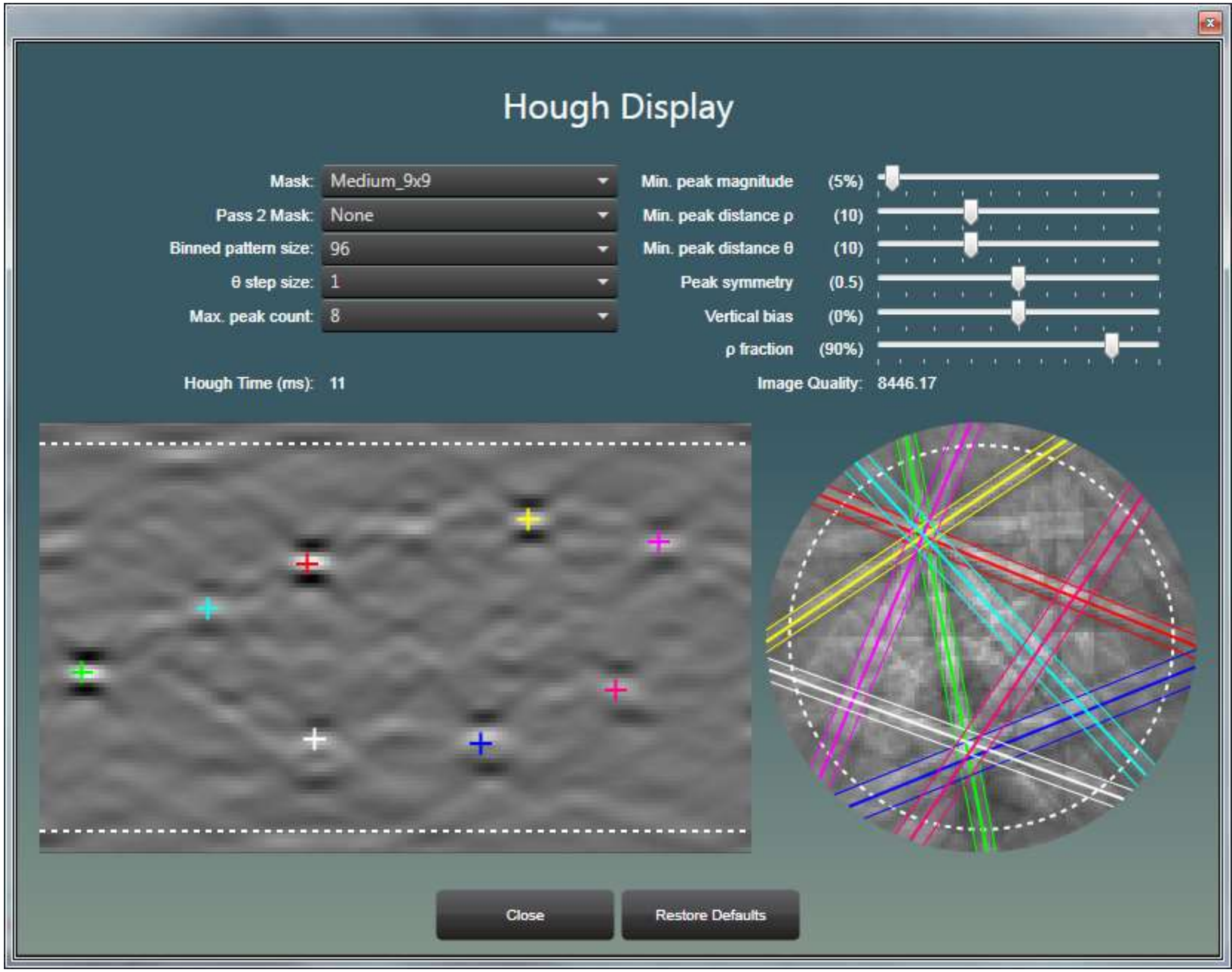
If the detected bands do not match actual bands, try adjusting the Rho Fraction (sometimes edge artifacts can be detected) down until reaching 75%.

If the band appear wider than what is being detected, try using the Large (13x13) mask size. Conversely if they appear narrower, use the Small (5x5) mask.

Sometimes a particular orientation is difficult. Try capturing a differently oriented pattern and try again.

You can also try using the Frame Average function on the camera control window to remove noise from the pattern.

If this doesn’t work, then try improving the pattern quality, either by decreasing the gain on the camera (and corresponding increasing the camera exposure) or increasing the SEM beam current and/or voltage (and recapturing the background).



AMETEK MATERIALS ANALYSIS DIVISION

EDAX Smart Insight

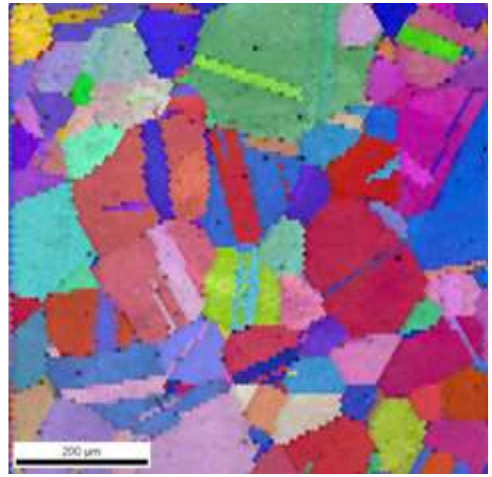
Step Size Selection

Typically dividing the grain size by 10 yields a nice balance between number of points per grain and total number of grains.

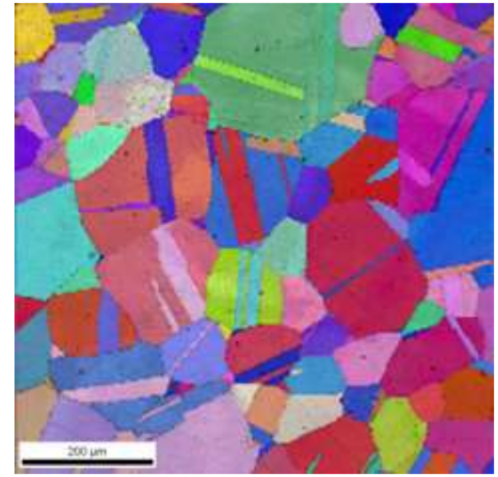
For this material (SS 316L), the average grain size is 40μm.

Dividing by 5 (8μm steps) is good for fast demo scans.

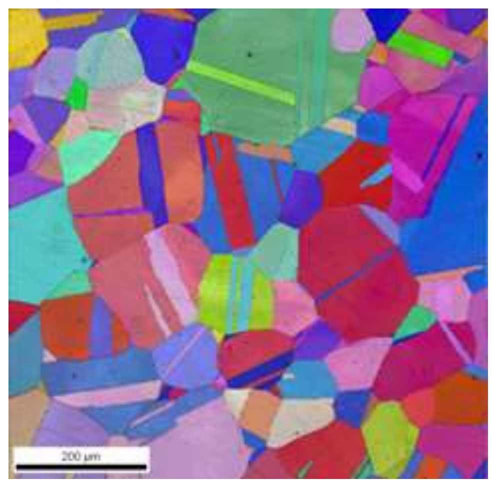
For longer time periods, you can either go with a prettier picture with smaller steps or look at a larger area and more grains (only 200 or so were sampled in this area).



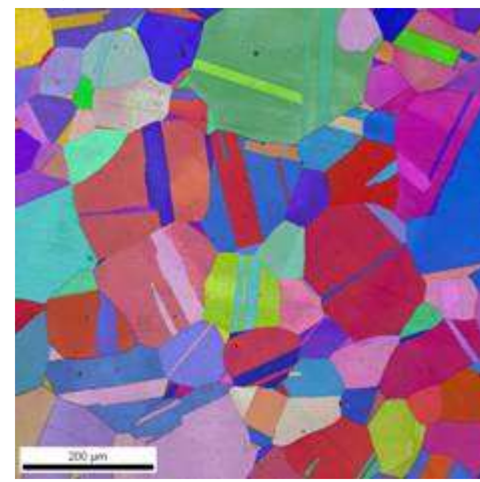
8μm steps, 2.4 min



4μm steps, 9.4 min



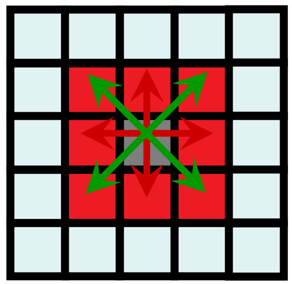
2μm steps, 37.4 min

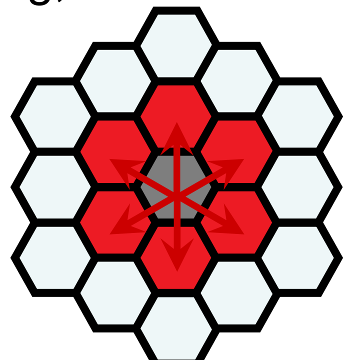


1μm steps, 2.5 hrs

Hexagonal Scanning Grid

- In traditional SEM imaging and EDS mapping, the standard analysis grid has always been square.





- Such a square grid is not optimal for EBSD analysis as it does not provide a constant point-to-point distance between all adjacent measurements.
- This may produce artifacts in the determination of the grain shapes and statistical analysis of triple grain junctions
- Using hexagons instead allows an optimum measurement density of an area and precise grain boundary reconstructions.
- At high resolutions (small step sizes), the hexagonal scanning grid also allows the precise EDS coverage to identify submicron grains using phase cluster analysis.

Additional Resources from EDAX

- Read our blogs at www.edaxblog.com
- For movies go to the EDAXNews Channel on YouTube https://www.youtube.com/user/EDAXNews
- Find our posts on LinkedIn and Twitter
- Register for webinars at
- http://www.edax.com/Events/Microanalysis-Web-Seminars.aspx
- For additional information, contact us at info.edax@ametek.com

AMETEK
MATERIALS ANALYSIS DIVISION

EDAX
Smart Insight

EDAX®

Smart Insight

AMETEK®

MATERIALS ANALYSIS DIVISION

edax.com