Gatan KnowHow

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2k GIF — High Resolution Imaging

The Gatan Imaging Filter (GIF™) allows users to employ energy-filtered transmission electron microscopy to obtain valuable information in a spatially-resolved manner from inelastically scattered electrons. Among its many capabilities, the GIF can be used in compositional analysis to produce highly sensitive elemental and chemical maps from a large number of pixels in less than a minute.

Up to now, we have used CCD detectors with a lower number of pixels (typically 1024 x 1024). Recently we have incorporated a MegaScan CCD camera with 2048 x 2048, 24 μm² pixels into our GIF. More pixels offer an increased field-of-view for a given image resolution. Even in applications that do not require large data sets, bigger CCDs are beneficial for pixels can be "binned" (grouped together) into "super-pixels" to provide major performance gain and give better point-spread-function performance than single pixels.

To take full advantage of the increased number of independent image points, the new GIF also uses redesigned electron optics to provide improved performance in both the imaging and

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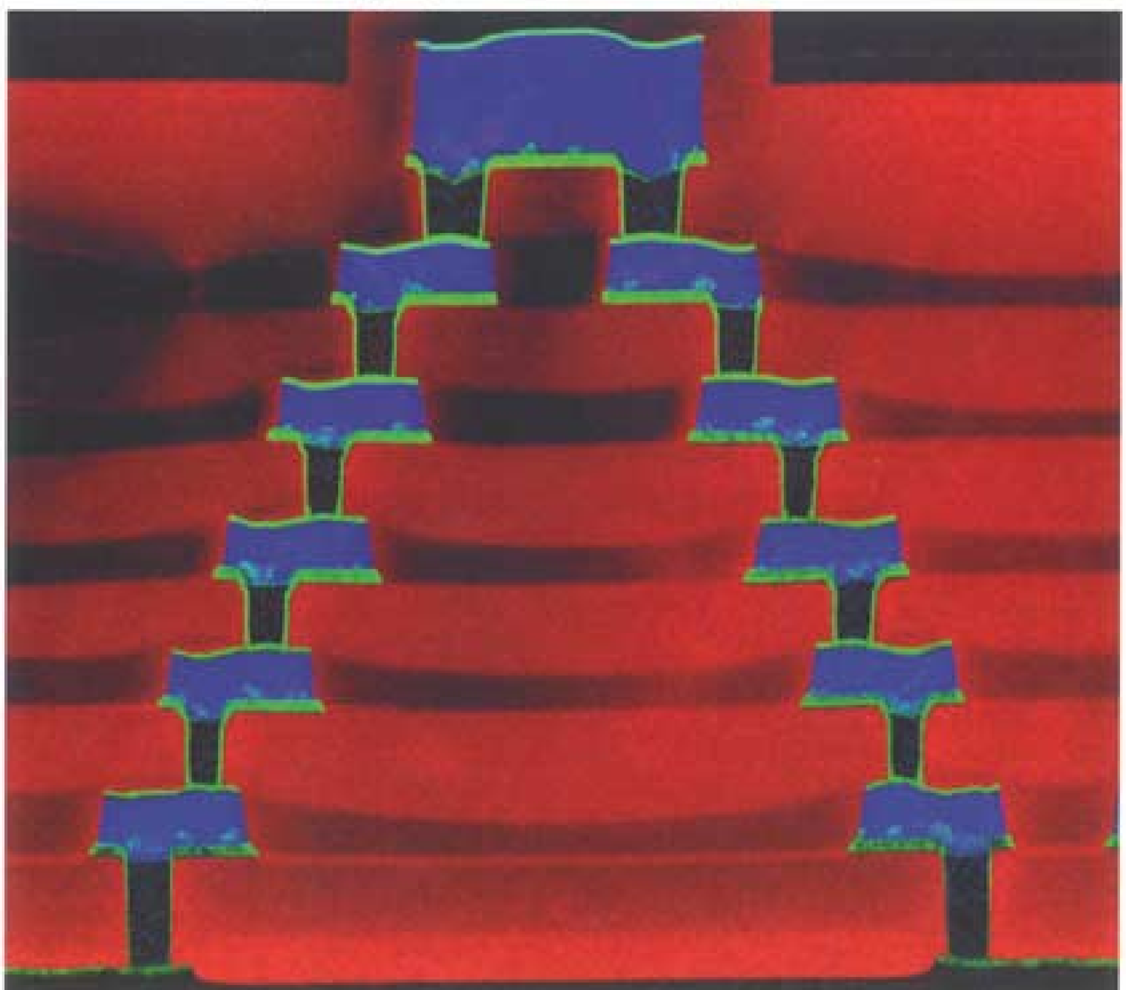


The image shows an application of the filter with an RGB composite image of titanium (green), oxygen (red), and aluminum (blue) elemental-distribution maps of a metal interconnect structure as used in modern semiconductor devices. The image's 1024 x 1024 independent "super-pixels" and 12 μm field-of-view clearly demonstrate the usefulness of the 2k CCD camera and the excellent performance of the new electron optics.

AutoFilter Software

Automatically characterizes and optimizes GIF electron-optical performance

Whether placed in-column or post-column, a TEM energy filter represents a significant expansion of the electron optics of a TEM system. As such, it is critical to the overall imaging performance of the energy-filtered TEM (EFTEM) system that the optics of the energy filter are precisely tuned and adjusted. Three classes of potential aberrations are particularly important to control: 1) image distortions, 2) chromatic imaging aberrations, which can blur filtered images taken at non-zero energy loss, and 3) spectrum aberrations at the energy-selecting slit, which result in non-uniform energy selection in filtered images.

The challenge in assessing and correcting these electron-optical defects lies in efficiently measuring them in a way that isolates the imaging properties of the energy filter from those of the TEM system as a whole. Gatan's new AutoFilter™ software package for EFTEM meets this challenge with intelligent tuning algorithms that harness two critical pieces of hardware integral to the Gatan Imaging Filter (GIF). This Gatan-exclusive, patent-pending technology helps ensure that you will always get the best results out of your Gatan EFTEM system, even if you aren't exactly the world's expert on energy-filtering electron optics.

The GIF hardware that enables AutoFilter to work its magic consists of: 1) an entrance aperture rod that includes a precision-fabricated 25-hole mask, and 2) a retractable, continuously adjustable, calibrated energy-selecting slit. Both of these devices are entirely under computer control, thus enabling the tuning procedures to run fully automatically.

Images of the mask, with its square 5 x 5 array of holes (Figure 1), permit filter-specific image distortions to be characterized to 4th order. With the addition of beam-energy variation, such images also allow filter-specific chromatic imaging aberrations to be measured to the same high order. By retracting the entrance mask and collecting an image while scanning the spectrum formed at the energy-selecting slit across one of its edges, the slit-plane spectrum aberration figure can be characterized to arbitrary order. The resulting "isochromatic surface" (Figure 2) directly shows the degree to which every pixel in an energy-filtered image is actually taken from precisely the same energy-loss range. Such automated measurements by AutoFilter provide the feedback needed by its tuning algorithms to automatically adjust the lenses of the energy filter to correct any detected imaging defects. By quantitatively tracking the imaged mask-hole positions (relative to the ideal square grid) while varying the relevant quadrupole and sextupole lenses of the GIF, AutoFilter precisely and efficiently corrects image distortions through 2nd order (Figure 1) and chromatic aberrations through 1st order, each in about 30 seconds. By tracking the 2-dimensional polynomial form of the isochromatic surface while varying the entrance optics of the GIF, AutoFilter quickly achieves isochromatic filtered imaging to within 1.5 eV over the entire image field (Figure 2), also in less than a minute.

Figure 1 - Image of 25-hole mask at entrance to GIF after full (2nd order) distortion tuning. Residual distortion ~1% RMS. AutoFilter tunes distortion by centering the imaged holes within target circles.

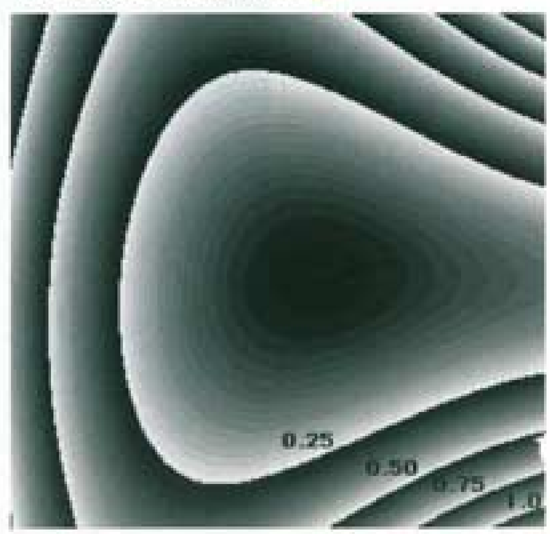


Figure 2 - Isochromatic surface measured by AutoFilter after it adjusted GIF 200 entrance optics for best 2nd order spectrum focus at energy-selecting slit. Labeled contours show deviations in energy (eV) relative to that at center of filtered images.

PECS

Applications for the Semiconductors

The Gatan Precision Etching and Coating System (PECS™) is designed to obtain clean, artifact-free, well-delineated etched specimens and these features have been demonstrated in a recent application where it was used to etch and coat an unencapsulated, state-of-the-art semiconductor.

The objectives were:

1. Observe the tungsten grain structure.
2. Evaluate step coverage.
3. Determine layer uniformity.
4. Ascertain etch profiles.

The semiconductor cross section was attached to a stub with mounting wax and mounted onto a standard polishing block. The sample was polished using conventional lapping techniques. Once the polishing was complete, the stub, with sample attached, was removed from the block and inserted directly into the PECS without removal and reloading of sample. The sample was etched for 5 min at 6 KeV with a normal (90°) beam angle and rotated at a constant speed of 30 rpm to ensure even etching along the cross-sectional surface. It was coated with Au/Pd for 30 sec in a working vacuum of approximately 1×10^{-5} Torr. The images were obtained on a Philips XL 30 field emission SEM courtesy of Materials Analysis Group of Sunnyvale, California.

You can see from Figure 1 that etching with conventional chemical processes does not bring out the tungsten grain structure and the step coverage, layer uniformity, and etch profiles could be more clearly delineated for analysis. Figure 2 shows a sample that has been etched and coated in the PECS and the grain structure and all other parameters are clearly defined. With the PECS, you do not get over etching as in chemical processes, will not introduce artifacts due to preferential etching, and will not have residues from polishing compounds, debris from cotton swabs, etc. It eliminates the need for chemicals and disposal considerations. You have more control over the etch rate and can easily have reproducible results. Specimen handling is greatly reduced with the PECS. The stage is configured to hold standard SEM stubs and eliminates the need to transfer the sample from the polishing stub to another holder. Etching and coating are performed in the same vacuum chamber and this eliminates additional handling of the specimen. The special airlock provides substantially increased sample through-put. Last but not least, the unit has very user-friendly features. ■

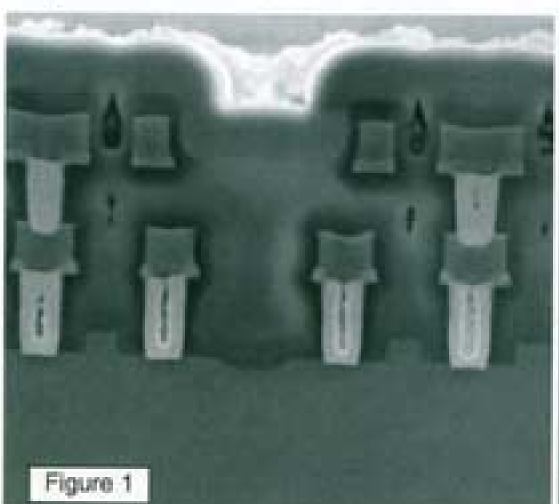


Figure 1

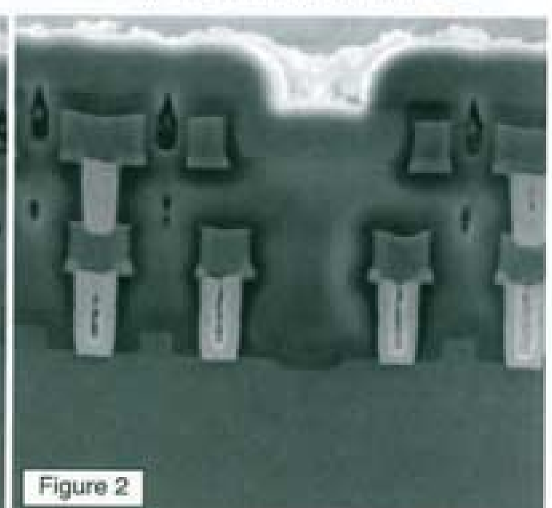
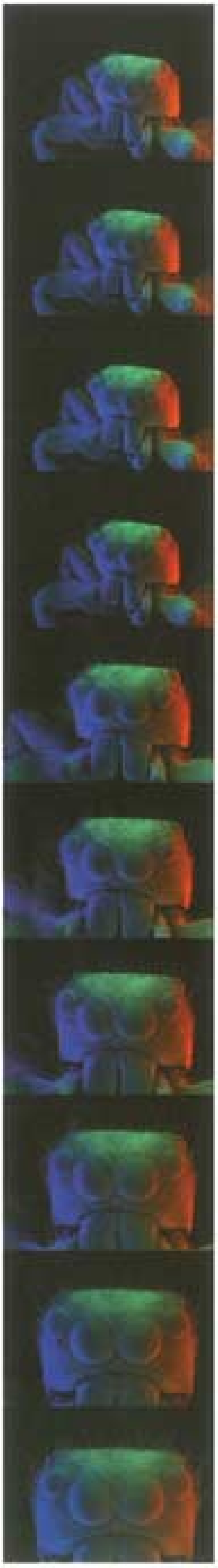


Figure 2



DigiScan and IMAX

Recently, scientist/photographer, David Scharf, was commissioned to create motion picture animation sequences using an SEM for the IMAX 3D movie entitled "4 Million Houseguests." IMAX 3D is an extension to the traditional format that allows the audience to see three-dimensional images on a huge projection screen (up to 7 stories high) with the aid of special viewing glasses. The goal of this SEM movie project was to produce high-resolution, 3D, color, movie-sequence views through microspace of microscopic creatures and objects.

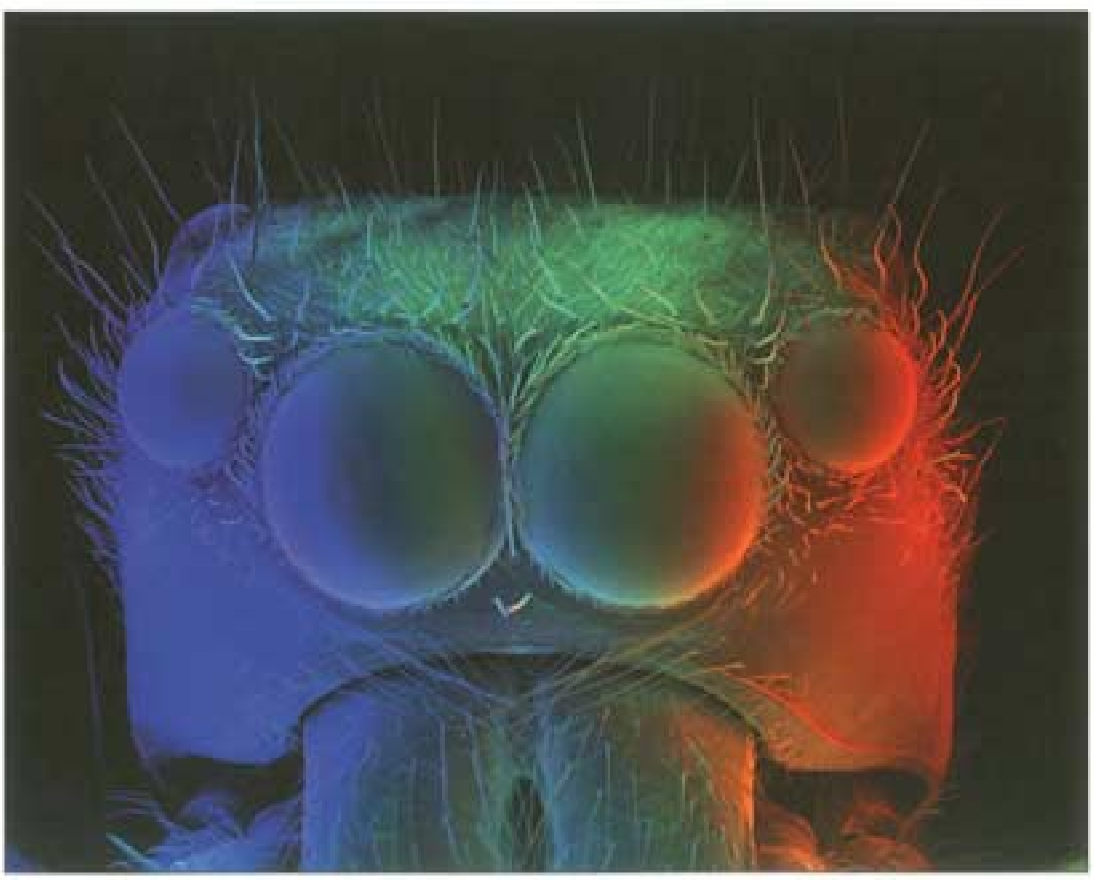
David's SEM images are well known and have appeared both on the covers and inside numerous journals and magazines. In 1993, he developed a patented system called the Multi-Detector Color Synthesizer (MDCS) for acquiring color images in the SEM. The MDCS uses multiple secondary-electron detectors arranged around the sample stage to collect signals that are mixed to produce color SEM images. For the last several years, David has been using a Gatan DigiScan system with Digital Micrograph to collect images on his vintage ETEC AutoScan.

The DigiScan is a device that produces digital images on an SEM or STEM. The DigiScan is ideal for connecting to the MDCS because the signals coming from the detectors' processor can easily be combined into an RGB format and viewed as a color image during acquisition.

To generate the 3D effect, a LEO StereoScan 440 was chosen to collect stereo pairs of an image for each movie frame. This system was outfitted with an MDCS and a DigiScan. Most of the software necessary for acquiring the movie data was written in Digital Micrograph scripting language.

In order to create images with pixel resolution and low noise necessary for IMAX motion pictures, a stop-frame animation technique was employed—similar in principle to that used to produce cartoons. After the entire movie sequence was acquired, the files were copied to Digital Linear Tape and sent to IMAX where they were recorded to film and edited.

"Four Million Housguests" is currently showing at several IMAX theaters around the USA. This is the first time that colored, high-resolution, 3D SEM image sequences have been created for motion pictures. ■



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spectroscopy modes. Some lenses are now magnetically rotatable to allow precision spectrum alignment with the energy-selecting slit and to provide more accurate image alignment with the CCD. Octupole elements now correct for third-order chromatic aberrations. Finer control of the lens-current power supplies better addresses the higher alignment requirements of the larger CCDs. As a result of these improvements, the electron optics of the GIF has negligible geometric and chromatic aberrations. The remaining image distortions are under 1% and total chromatic aberration are less than a single pixel.

These newly incorporated enhancements take full advantage of the latest developments in automated filter tuning and make the GIF more straightforward to align and easier to operate. ■

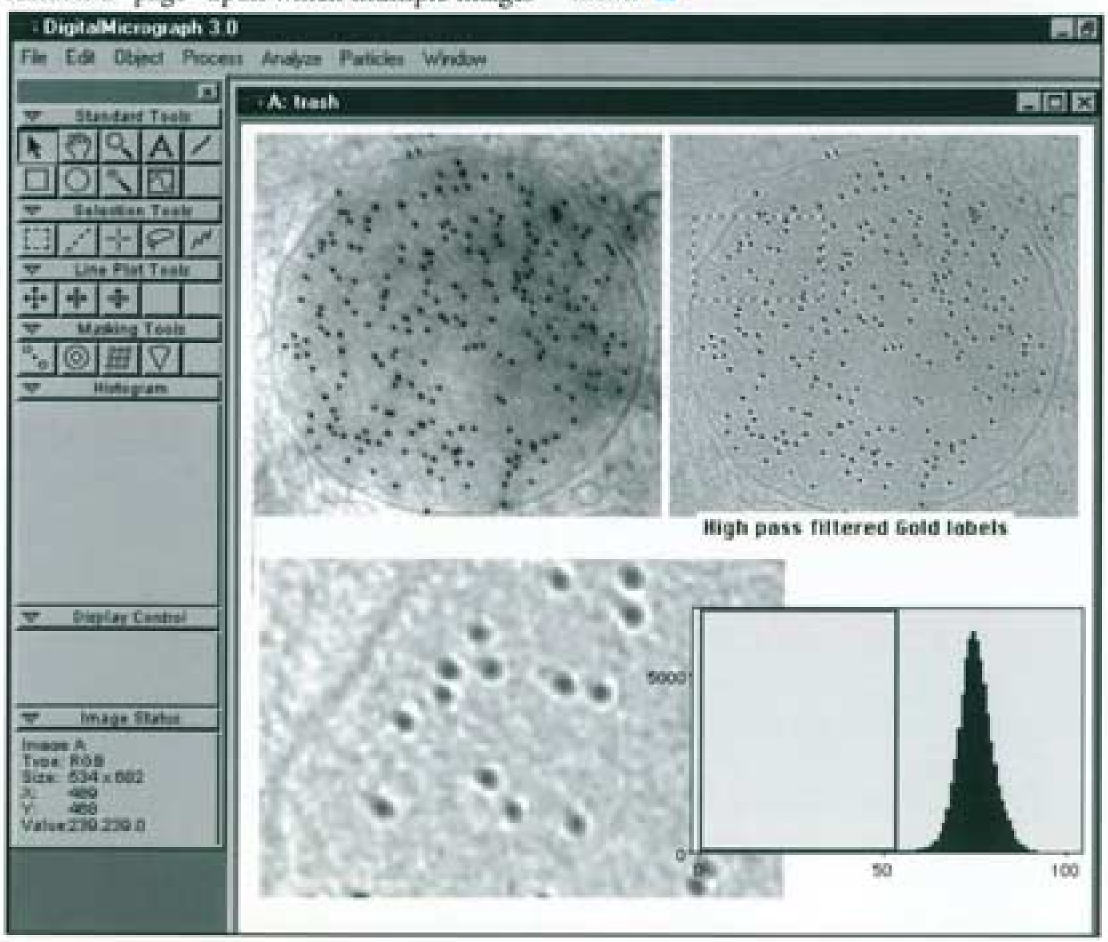
DigitalMicrograph

New –DigitalMicrograph on the PC!

DigitalMicrograph 3.2 is the upgrade to the versatile DigitalMicrograph 2.5. It is available on both Macintosh and PC platforms. DigitalMicrograph 3.2 for the PC is designed to run on Windows 95 and NT operating systems.

DigitalMicrograph 3.2 has many new features such as improved image display and manipulation, extended plug-in support, and expanded interfaces with other applications. The new image "document" in DigitalMicrograph 3.2 features a "page" upon which multiple images can be manipulated and attached just as easily as annotations. New page-layout capabilities allow images to be stretched to fit the page more precisely. Multiple display types, such as raster, spreadsheet, surface plot, and a new display type, the surface model, can be placed on the same page. Zoom is enhanced to allow for continuous zooming. The scale bar can be adjusted to display a specific linear value and the actual display size of the scale bar itself can be varied.

DigitalMicrograph 3.2 for the PC currently supports plug-ins for the MultiScan and the BioScan cameras. Eventually it will support many types of plug-ins to allow for easy extension of DigitalMicrograph through Gatan, third parties, or ones own software development. ■



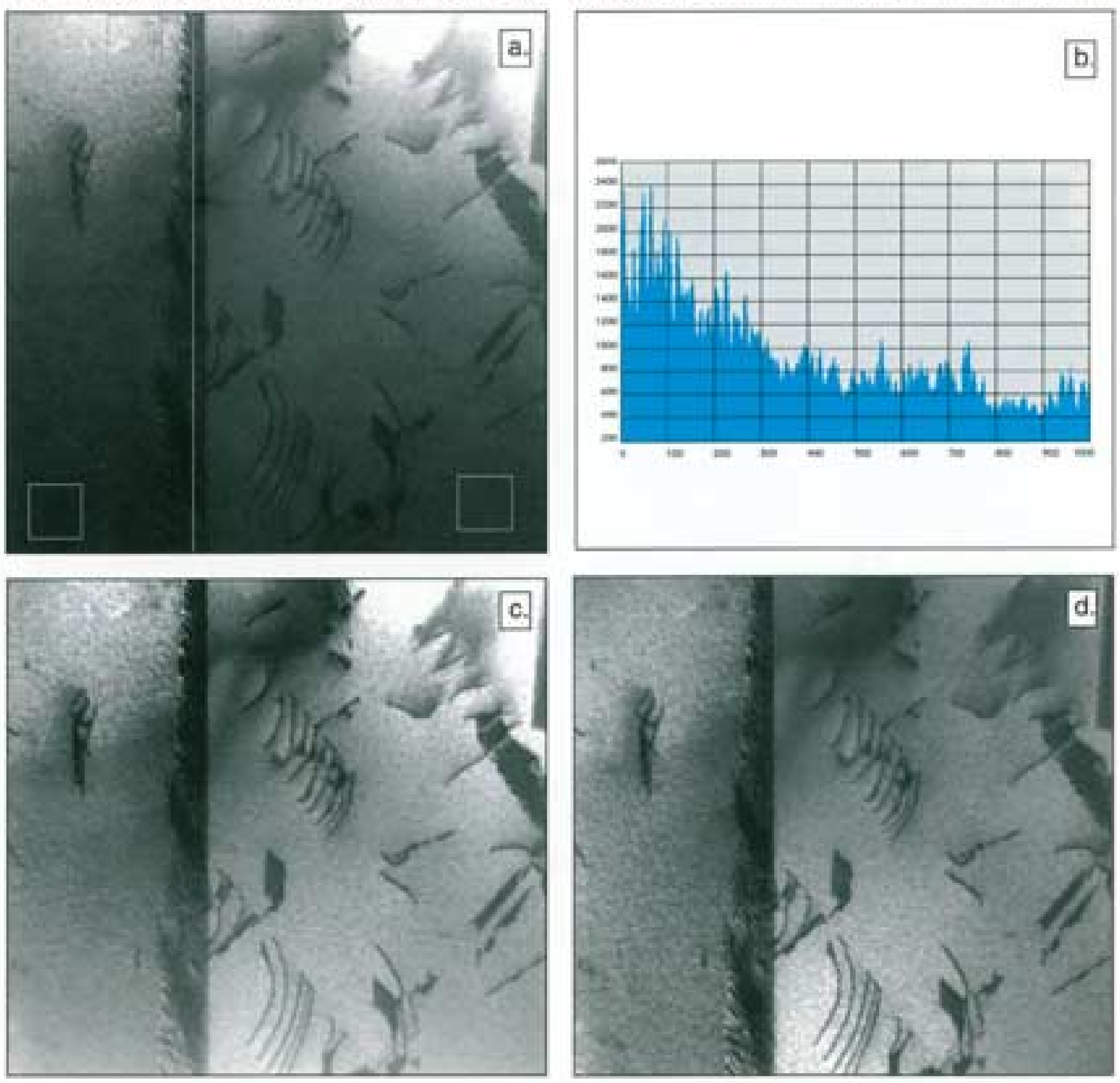
Plane Dodging with DM

Dodging–the practice of sweeping a mask across a sheet of print film during the printing process allows a photographer to compensate for uneven lighting or bring out selected features in a scene long after the picture has been taken. It is an art, the desired end result requiring skill and many tries in establishing the right combination of sweeping speed, fully uncovered time, print film type, and exposure brightness.

With the advent of digital photography, dodging becomes a science, or at least a more trustworthy tool of science. Since the digital image is composed of numbers, the dodging mask becomes a numerical function of position. Once applied, the function can be recorded with the image, thus documenting exactly the method by which a particular result was obtained. In addition, the flexibility of mathematics provides an endless choice of techniques for bringing out the desired image features.

The script described here realizes one very simple approach. The idea is to subtract a linear ramp from the log of the image and then take the exponential of the result. This mimics the multiplicative effect of varying the exposure time with the dodging mask under an enlarger. A multiplicative approach is appropriate for compensating electron micrographs of specimens of varying thickness since both contrast variations and average intensity tend to be proportional to the inverse of the thickness.

This script is divided into two parts. The first (s.plane dodge setup) places four annotations onto the image to be dodged and then stops with a message to position the boxes over areas in the image which, to the judgement of the dodger, should be of similar image intensity. The boxes can also be reshaped and resized to fit into odd-shaped areas. After the boxes have been adjusted, the dodging script (s.plane dodge) can be run. This script finds the centers



In the example image, note the profile (b) of the original image (a). The contrast becomes smaller as the image value becomes smaller. Dodging with a linear ramp gives a washed out appearance to the darker areas in the image (c). The logarithmic dodge (d) gives a much better result, allowing detail to be rendered equally well throughout the image.

and average values of the three areas and does the logarithmic subtraction. It queries the user whether the result should overwrite the original or be placed in a new image.

s. plane dodge setup

```
image frontImage := GetFrontImage()
number xsize, ysize
number top,left,bottom,right
GetSize( frontImage, xsize, ysize)

top=ysize/10; left=xsize/10; bottom=2*ysize/10; right=2*xsize/10
number id1 = CreateBoxAnnotation(frontimage,top,left,bottom,right)
SetNumberNote(frontimage,"id1",id1)
top=4*ysize/10; left=8*xsize/10; bottom=5*ysize/10; right=9*xsize/10
number id2 = CreateBoxAnnotation(frontimage,top,left,bottom,right)
SetNumberNote(frontimage,"id2",id2)
top=8*ysize/10; left=xsize/10; bottom=9*ysize/10; right=2*xsize/10
number id3 = CreateBoxAnnotation(frontimage,top,left,bottom,right)
SetNumberNote(frontimage,"id3",id3)

UpdateImage(frontimage)
OKDialog("Position and resize the three boxes to cover three areas which are
desired to be of equal intensity.")
```

s. plane dodge

```
image frontImage := GetFrontImage()
number xsize, ysize
number top,left,bottom,right
GetSize( frontImage, xsize, ysize)

//get the average values and centers of the three rectangular areas

number id1, x1, y1, i1
If(!GetNumberNote(frontimage,"id1",id1))
{
        OKDialog("No box annotation found.\n        Run dodge setup.")
        break
}
GetAnnotationRect(frontimage,id1,top,left,bottom,right)
i1=log(average(frontimage[top,left,bottom,right]))
x1=(left+right)/2
y1=(top+bottom)/2

number id2, x2, y2, i2
GetNumberNote(frontimage,"id2",id2)
GetAnnotationRect(frontimage,id2,top,left,bottom,right)
i2=log(average(frontimage[top,left,bottom,right]))
x2=(left+right)/2
y2=(top+bottom)/2

number id3, x3, y3, i3
GetNumberNote(frontimage,"id3",id3)
GetAnnotationRect(frontimage,id3,top,left,bottom,right)
i3=log(average(frontimage[top,left,bottom,right]))
x3=(left+right)/2
y3=(top+bottom)/2

//generate 2 in-plane vectors

x1=x1-x3
y1=y1-y3
i1=i1-i3
x2=x2-x3
y2=y2-y3
i2=i2-i3

//generate plane to be subtracted from the log of the image

image dodgeimg = RealImage("dodgeimg", 4,xsize,ysize)
dodgeimg=((y1*i2-i1*y2)*icol+(i1*x2-x1*i2)*irow)/(y1*x2-x1*y2)
dodgeimg=dodgeimg-average(dodgeimg)

//generate the dodged image

If(OKCancelDialog("Create New Image?"))
{
dodgeimg=exp(log(frontimage)-dodgeimg)
SetZoom(dodgeimg,GetZoom(frontimage))
ShowImage(dodgeimg)
}
Else
{
frontimage=exp(log(frontimage)-dodgeimg)
}
```

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