TAKING VARIABILITY OUT OF SCRATCH INSPECTION

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- **Sources of variability**
- **The light box tradition makes good sense**
- **A simple vision system that mimics the traditional light box (SCR-1)**
- **The Sira approach (polarized light comparator)**
- **AFM pictures of #10 and #80 (contact measurement)**
- **What's a good scratch measurement device?**

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The inspection of scratch standards for this specific manufacturing process has helped us gain insight into the a more general problem of scratch inspection. We have a better grasp of some of the factors that cause variability in scratch inspection. Also having succeeded in solving this limited problem we will discuss briefly the instrument and why we think it works. It is not a a result of a new discovery, just a product of paying attention to the common sense reasons why some inspection traditions have evolved. But in the process we will coincidentally run into some interesting science.

SOURCE OF VARIABILITY: HUMAN

- The experienced eye is quite repeatable in comparison measurements. The untrained eye has difficulty judging "perfect" from "in spec".

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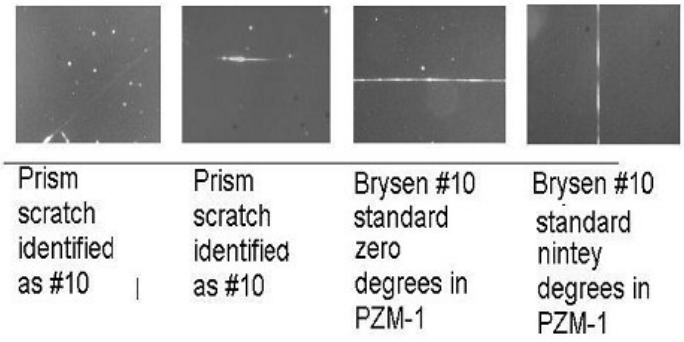
The trained human eye is quite good (repeatable) in making accurate side by side comparisons. We automated the system to avoid the long training involved and also to reduce the inspection time from minutes to seconds. In this picture a freshly made scratch standard is being compared to a master. In many cases however it is not possible to compare the defective component to the scratch standard using the same illumination technique. For example a prism cannot be held up against this inspection light and compared with the scratch standard in the manner shown. This is the likely reason scratch defects are often measured in reflection and not in transmission.

SOURCE OF VARIABILITY:INSTRUMENT



Prism scratch identified as #10 | Prism scratch identified as #10 | Brysen #10 standard zero degrees in PZM-1 | Brysen #10 standard nintey degrees in PZM-1

- Incorrect illumination causes angular dependence of scratch visibility

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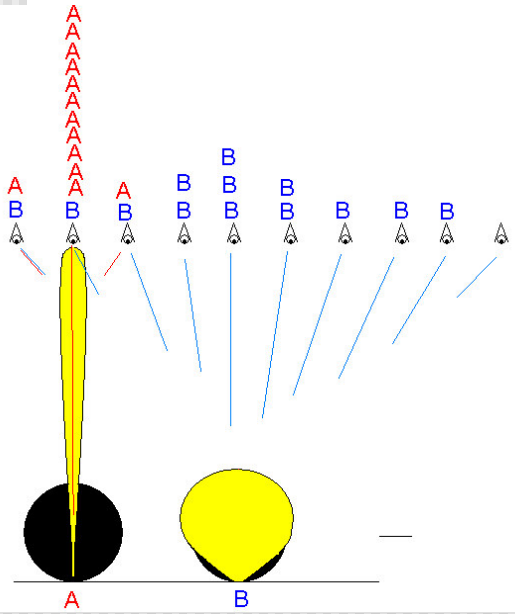
Sometimes the problem is the instrument. First and second picture both showed up as a #10 in a microscope with asymmetric illumination. In symmetric lighting conditions the first scratch appears much fainter than the second. 3rd and 4th pictures demonstrate that symmetric lighting reduces variability. In the asymmetrically illuminated microscope the #10 scratch standard disappears in the 90 degree orientation. Illumination by “goose neck” lights are asymmetric and therefore an unreliable measure of scratch severity.

SOURCE OF VARIABILITY: SCRATCH "VISIBILITY" HAS MORE THAN ONE PARAMETER



- A single number that quantifies scratch visibility is elusive. Sample "A" flashes brightly in a small range of angles but is *invisible* outside this range. Sample "B" remains visible, albeit faintly, at all angles.

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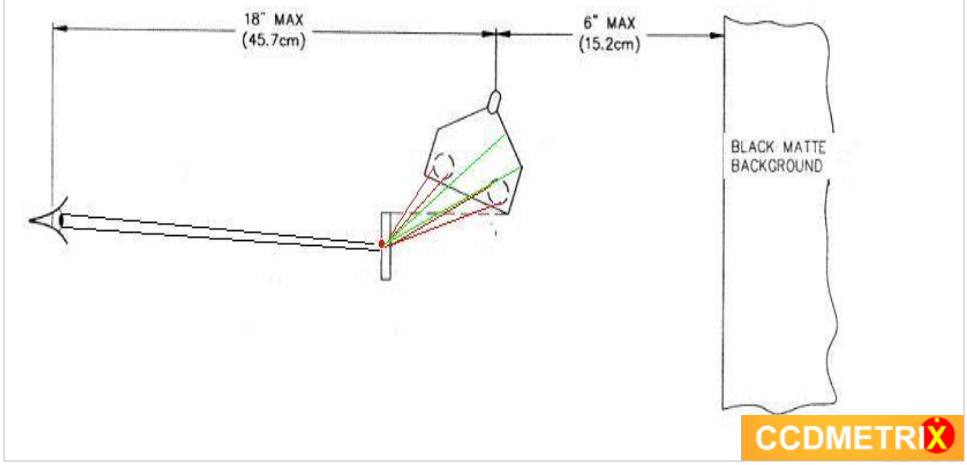
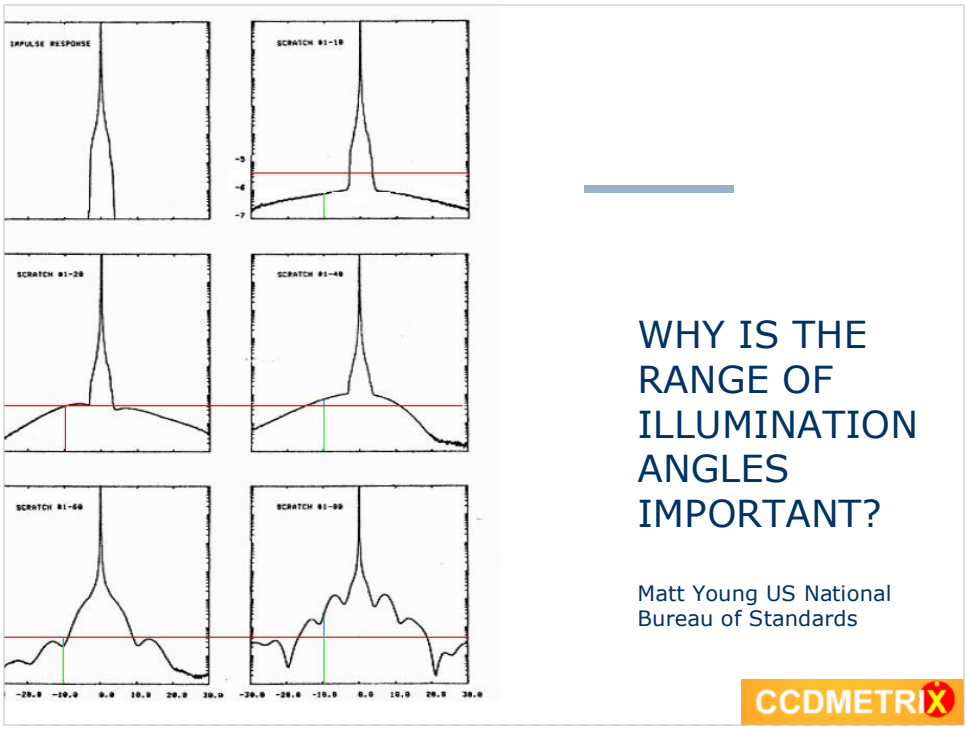
What we informally call "flash visibility" factor and "dull visibility" factor. These factors are weighed by the human operator who tend to assign higher numbers to "dull visible" scratches, as they are easier to find.

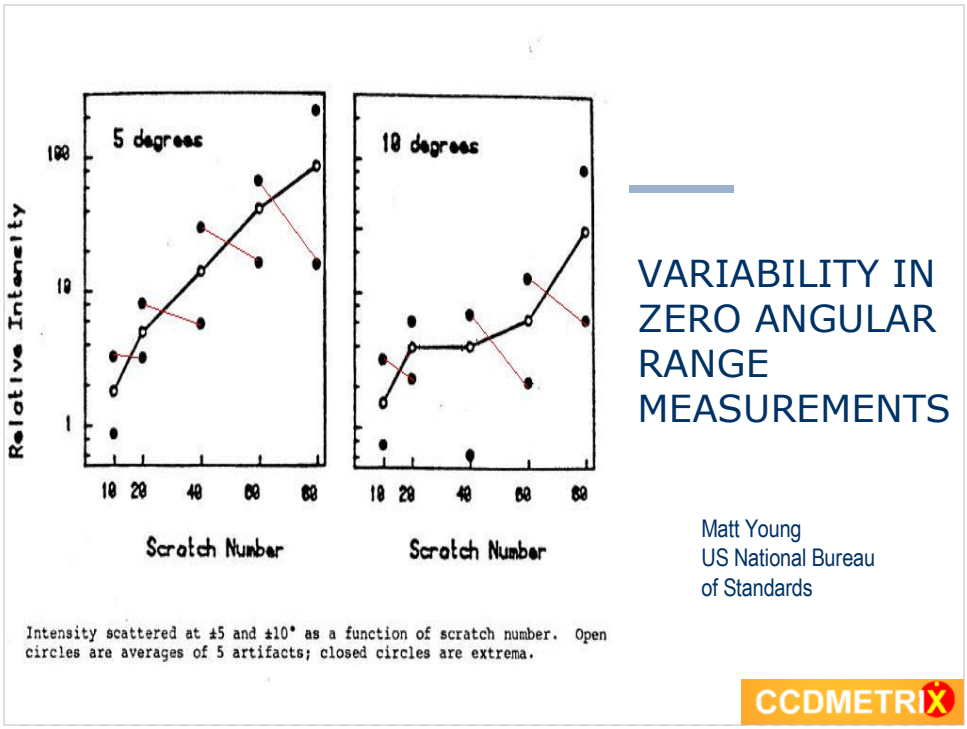
THE TRADITIONAL LIGHT BOX



Schematic arrangement of a light box used in scratch inspection. The cone inside the red lines illuminates the sample brightly. The cone inside the green lines illuminate somewhat less brightly. Overall the scratch is simultaneously illuminated by a cone no smaller than +30. The fact that the operator is able to move the sample up and down increases the range of illumination angles , but adds to the variability.



Scattering of [red] light as a function of illumination angle. Looking for a signature of a 10 scratch is easy. But in this experiment the 40 and the 60 scratch show the same amount of scatter at 10 degrees. The integrated scatter from 5 to 30 degrees appears to be a decent indicator of scratch severity.



VARIABILITY IN ZERO ANGULAR RANGE MEASUREMENTS

Matt Young
US National Bureau
of Standards

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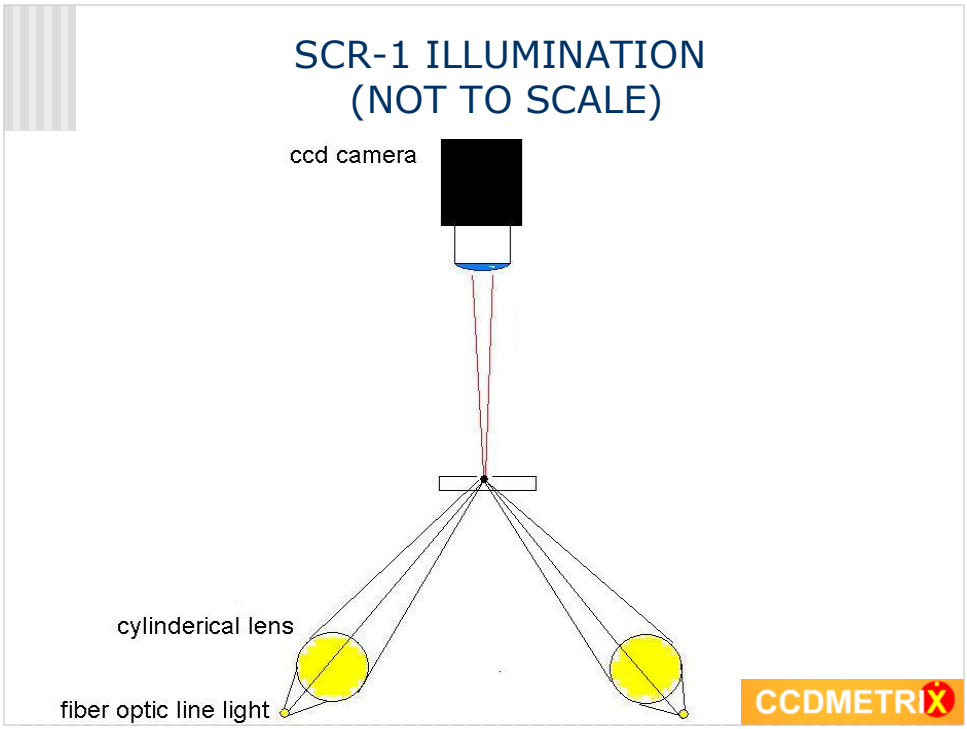
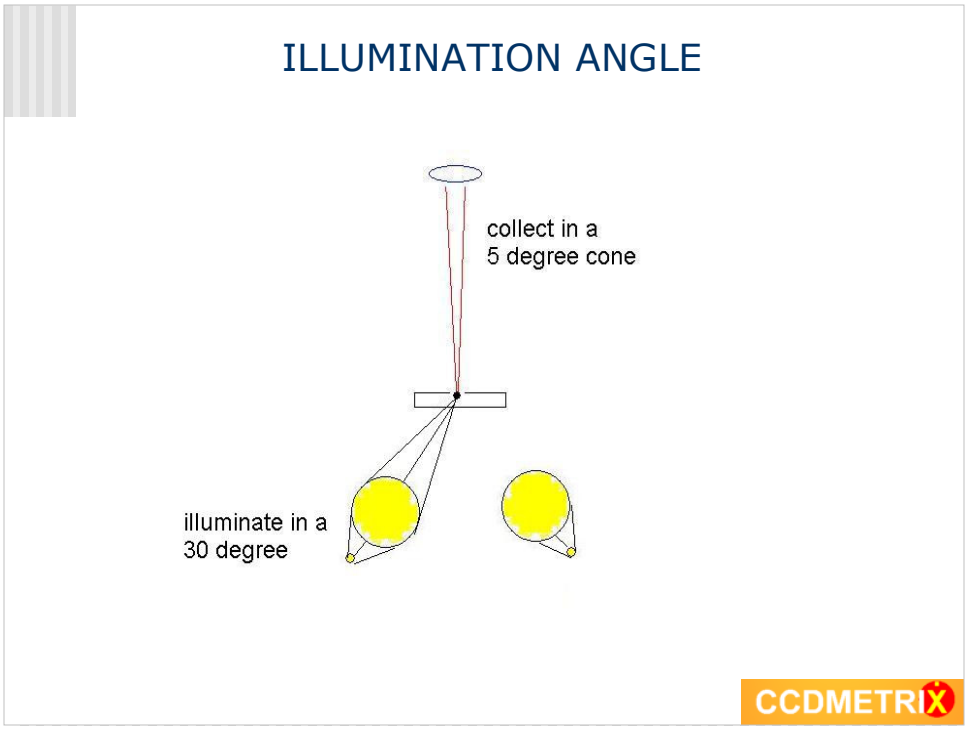
Very difficult to get consistent numbers by single angle measurements. Red lines show samples where a lower numbered scratch standard scatters more light than a higher numbered one.



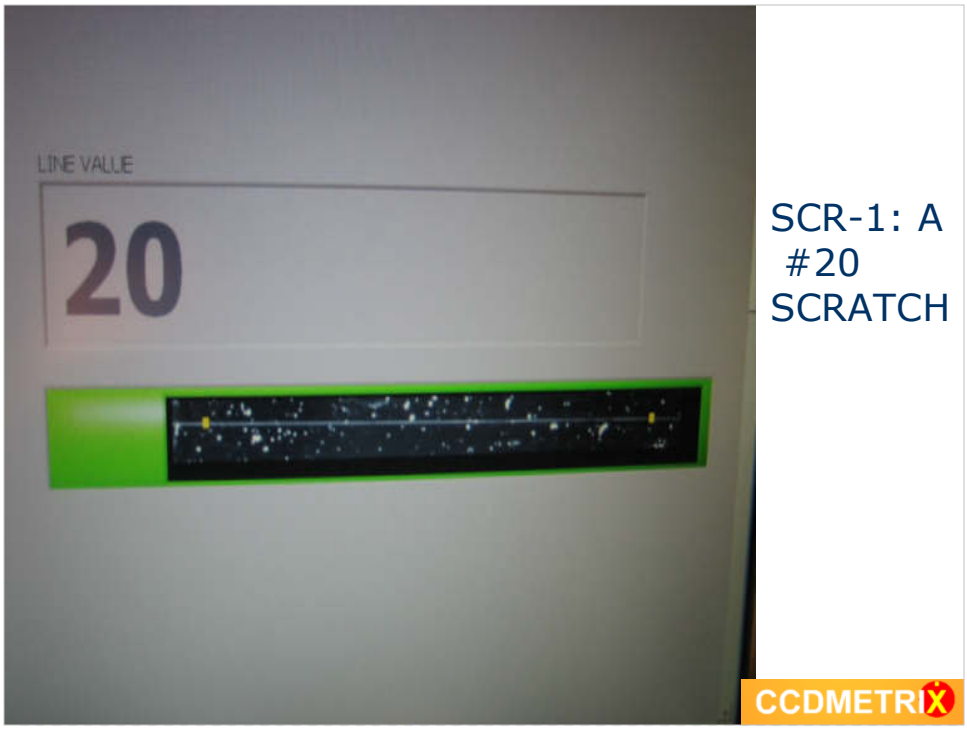
Schematic of SCR-1 shows simultaneous multiple angle illumination.



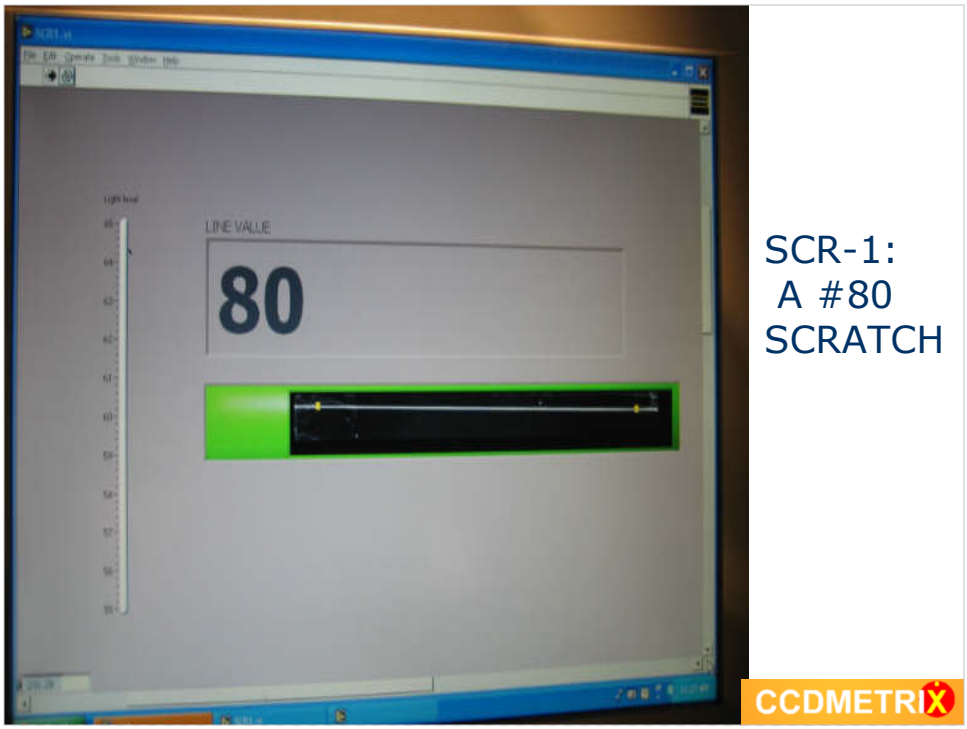
Illumination and collection angles in SCR-1

The SCR-1 is designed to see the entire 50 mm span of the scratch standard. Load/unload is a one-motion operation. There is no “part present” detector. The vision system decides when a part is present. The operator interface has one number on it and also a red/green pass/fail light. The simple operator interface is to reduce variability due to the operator.

The cylindrical lens illuminating a scratch standard.

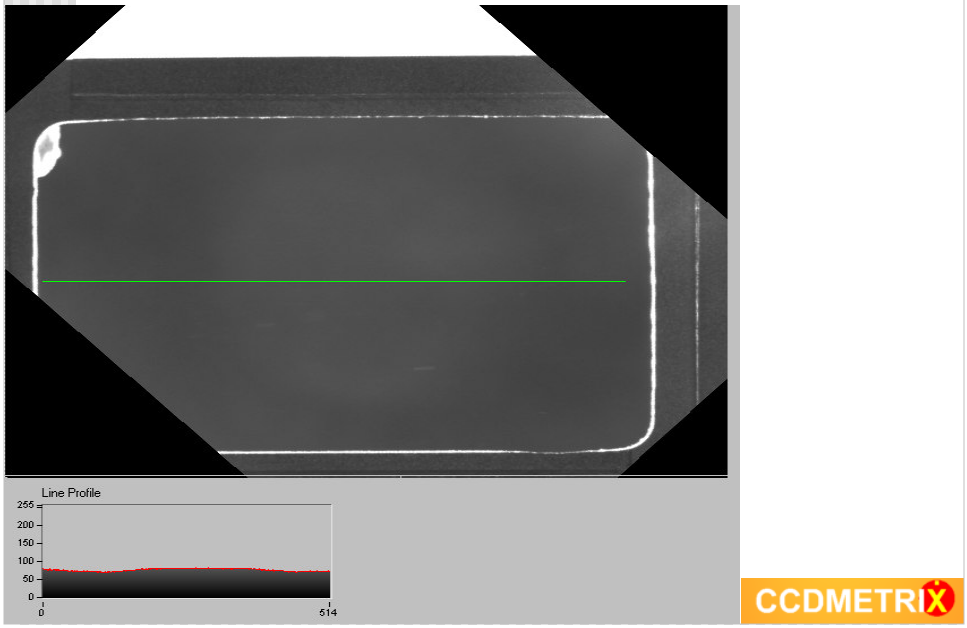


A “20” scratch is identified. Notice the area around the image has gone from red to green. The yellow bars indicate limits of inspection along the length of the scratch. The dimming towards the edge may be an artifact of the photograph or it may be real. SCR-1 allows the operator to clearly see broken lines or uneven scribing. This is an improvement over the manual inspection process where scribing unevenness is difficult to detect.

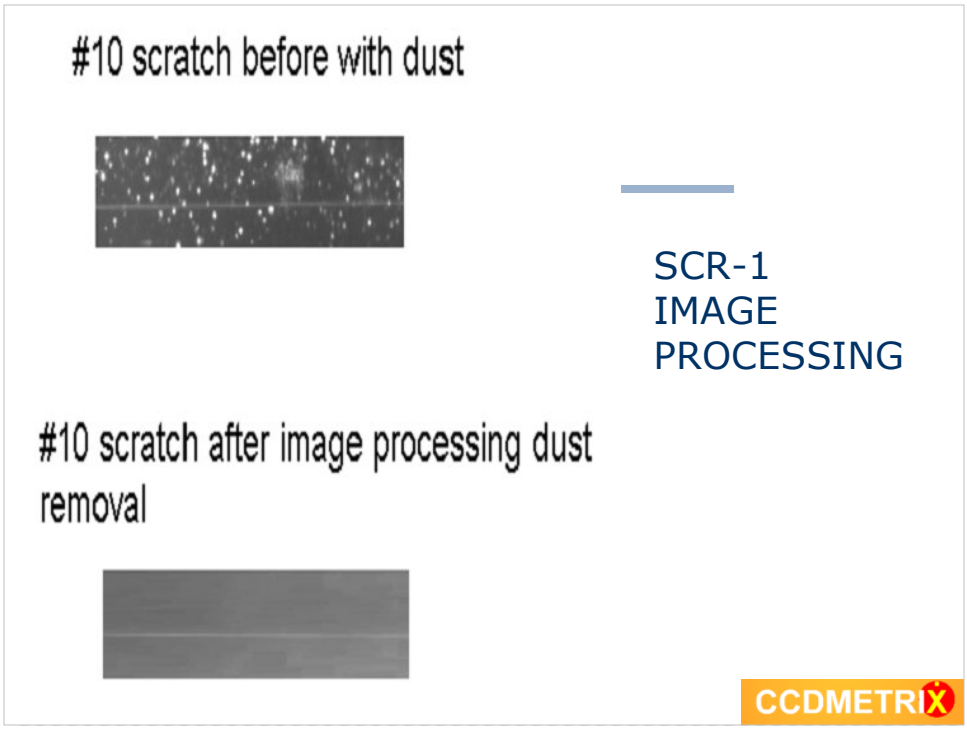


Notice that the line is not centered in the image. This affects scratch illumination angle and is part of the reason SCR-1 has two light sources.

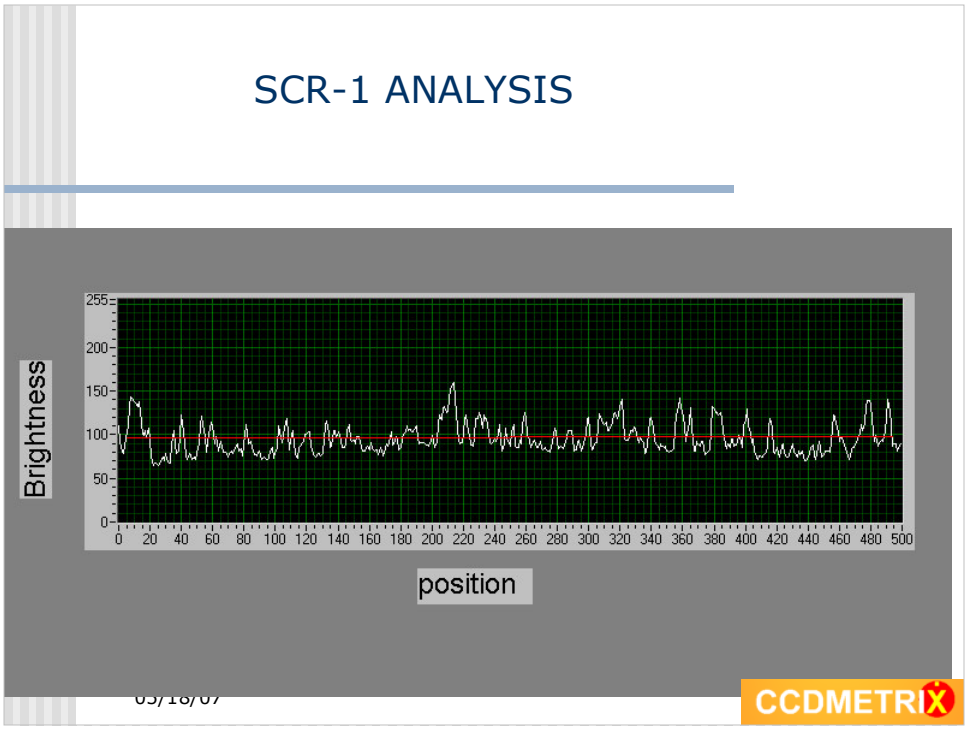
SCR-1 BACKGROUND IMAGE



The SCR-1 part holder without a part present. There is background correction in SCR-1 vision system. SCR-2 will have additional safeguards such a field stop to eliminate saturated area above the image.

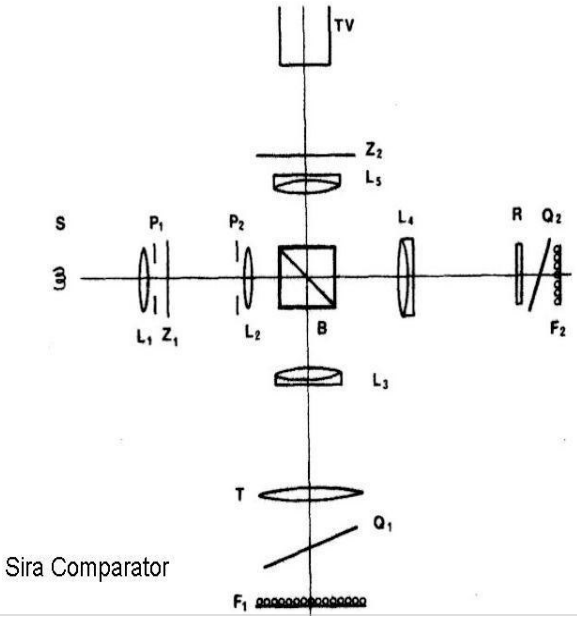


SCR-1 uses this image processing algorithm to find the scratch. The analysis however is done on the raw image, “almost.”



Best fit line determines scratch severity.

THE SIRA APPROACH



Sira Comparator

USES
POLARIZED
LIGHT

L.R Baker
OPTICA ACTA
1984

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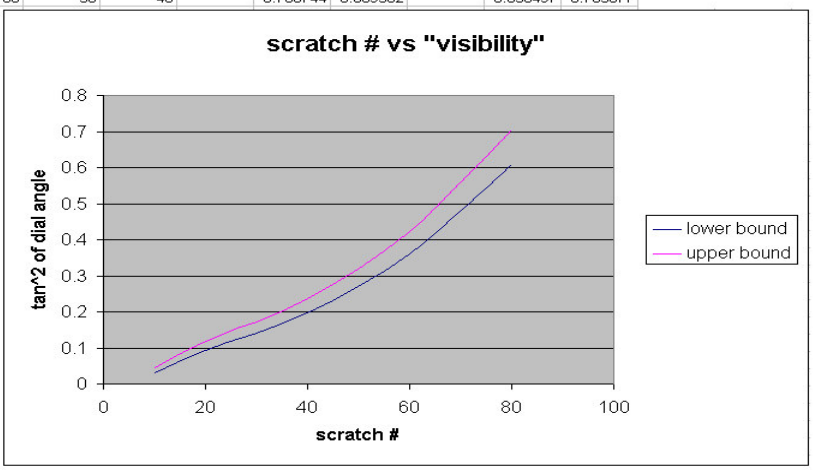
The Sira microscope comparator superimposes the images of the test scratch and a standard reference scratch. The polarizer Z2 is rotated until the image from the reference and the test scratch appear at the same brightness on the camera monitor. A polarizing beam splitter (B) setup illuminates reference and sample with complementary polarization channels. The Sira comparator appears to be a device for measuring light depolarization by the test scratch relative to that of the reference scratch. The quarter wave plates and the retroreflectors(Q and F) serve to create the superimposed image of the two channels.

ANGLES ON THE SIRA MICROSCOPE DIAL

scratch #	low angle	high angle		tan^2 low		tan^2 high
10	10	12	0.176236	0.031059	0.212446	0.045133
20	17	19	0.305566	0.093371	0.34414	0.118432
40	24	26	0.444974	0.198002	0.487448	0.237605
60	31	33	0.600487	0.360585	0.648993	0.421191
80	38	40	0.780744	0.609562	0.838497	0.703077



"visibility"= constant* tan^2 Sira angle

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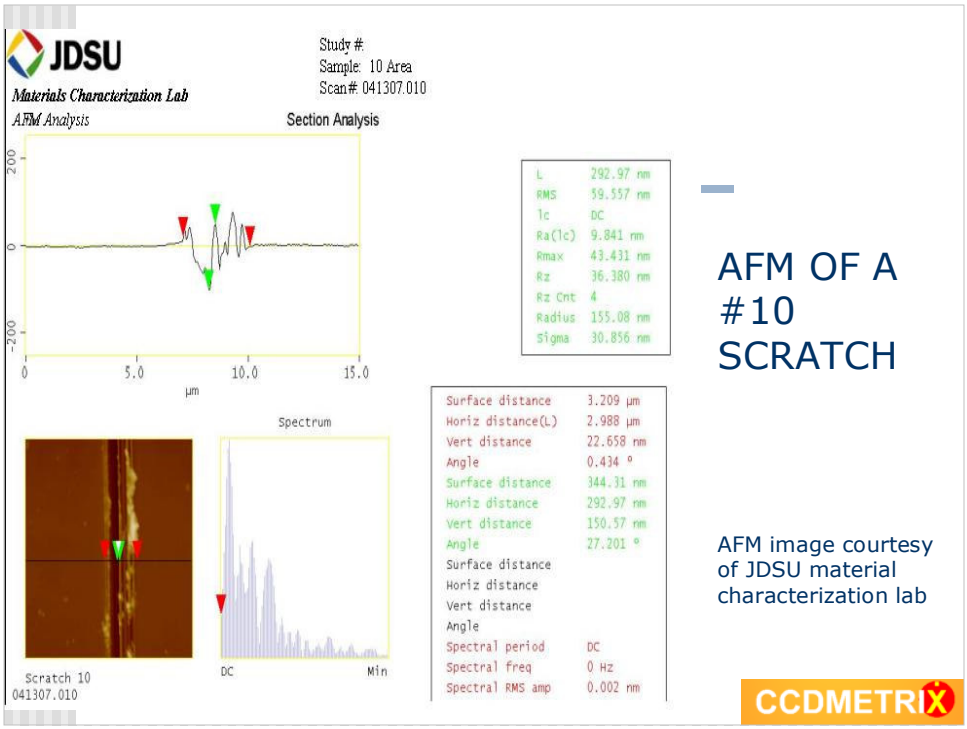
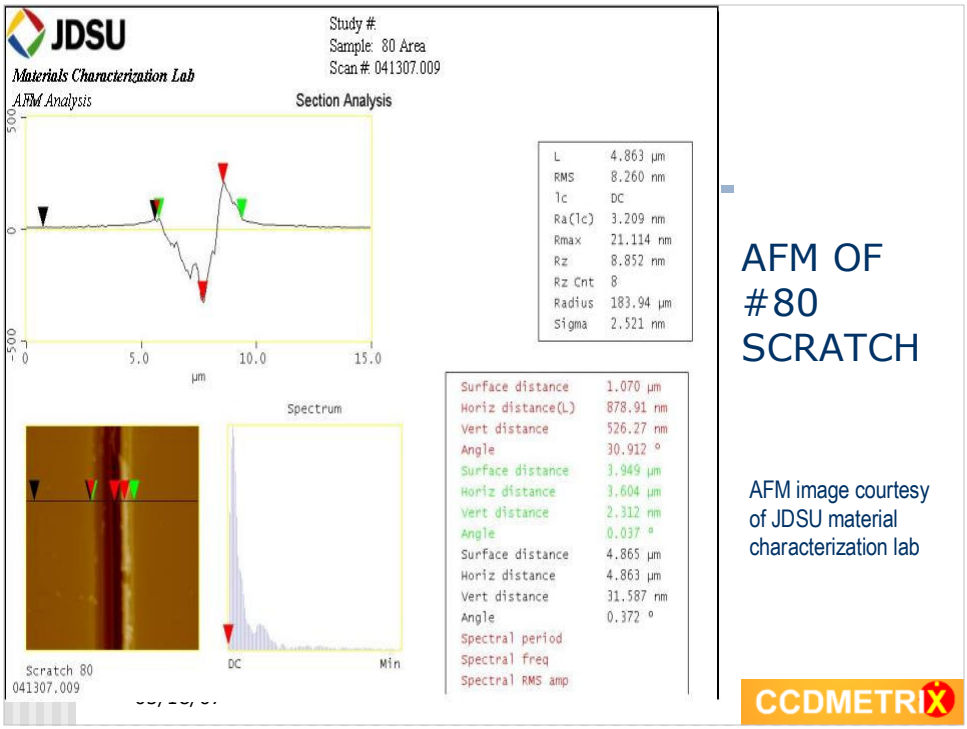
Each standard scratch has a 2 degree band on the Sira dial. There is a 5 degree Sira dial separation between the scratch numbers. This clean, integral Sira dial separation between the scratch standard numbers suggests that perhaps the mil-spec standard scratches were redefined after the Sira microscope became available. However, there is evidence in this graph that the original standard scratches (now lost) were kept in mind: The mil-spec numerical assignments are 20 apart except between the #10 and the #20 where the assignment is only 10 apart. This is the reason for the "kink" in the graph at #20. Unfortunately this curvature anomaly allows for different ways to define lower numbered scratch standards (#5 and below) that are today being demanded by laser, telecom, etc applications. A polynomial extrapolation to this graph may be a consistent way to define such faint scratches. Incidentally, contradicting what this theoretical graph suggests,the visibility distinction between real life #60 and #80 standards is less than that between the #10 and #20 standards.



Notice the regularly spaced features. Also the “gob” of material next to the scratch. These features have different scattering characteristics. This profile was taken across a “gobless” region of the scratch. Perhaps not a good idea as the gobs are significantly taller (note false color topography) and may play an important role in the overall scattering character of the scratch.



AFM OF #80 SCRATCH

AFM image courtesy of JDSU material characterization lab

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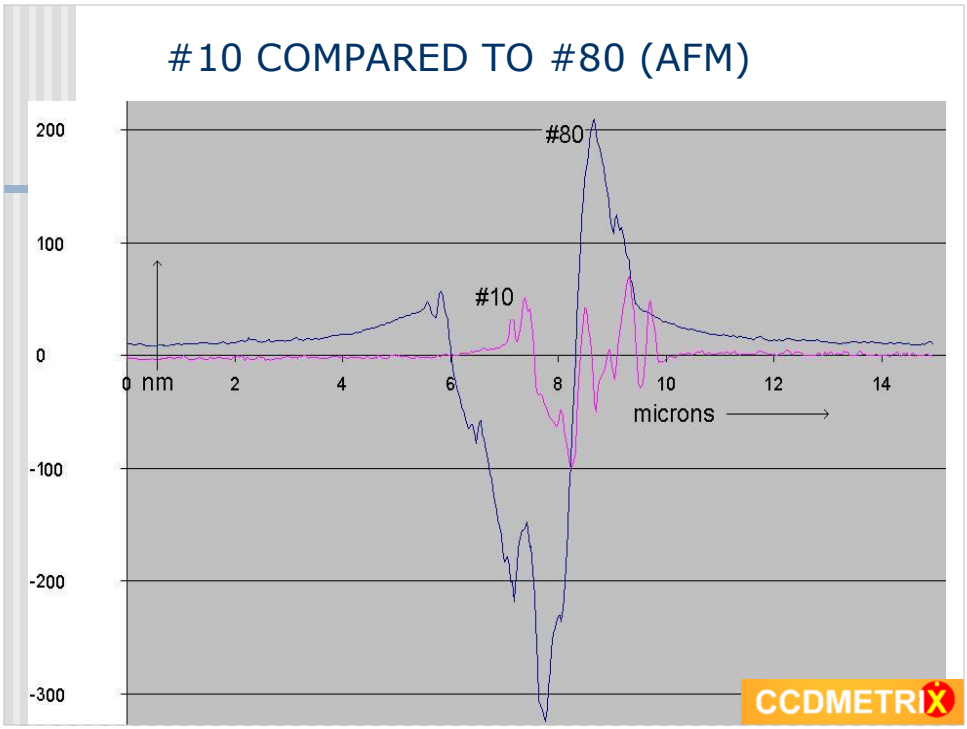
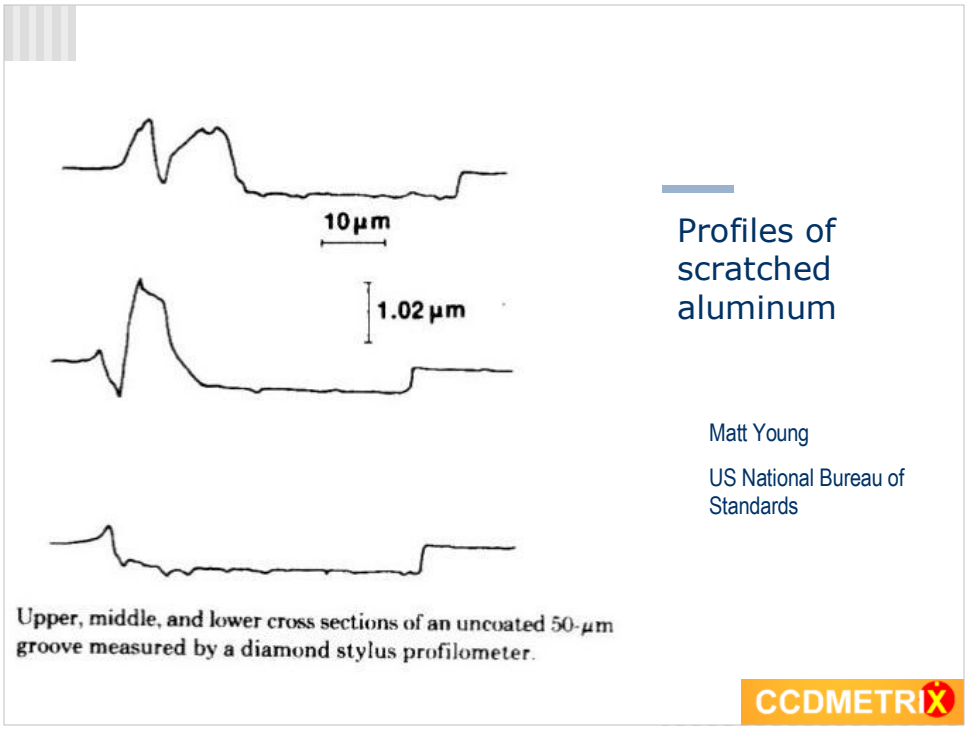
The curvature around the edge bends (does not scatter) some light, but probably less than 5 degrees (we think).



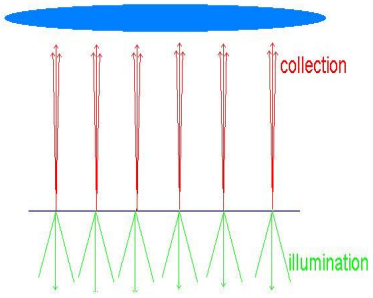
Superimposed 80 and 10. Roughly the same width (#10 would appear somewhat wider with “gob” included). The width and height are not to scale in this graph. The scratch is actually a thousand times shorter than shown, making it practically rectangular, not wedge shaped.



Aluminum scratch. Note the asymmetric pile up effect. Another reason to have symmetric illumination on the SCR-1.

WHAT MAKES A GOOD GENERAL PURPOSE SCRATCH MEASUREMENT DEVICE?

- Omni-directional illumination. Range +/- 30 degrees
- “Telecentric” light collection
- Broadband (“white”) Light.



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Good illumination and light collection are the key to repeatability. The parameters of the illumination should be “open source” and specified like scratch/dig. For instance a 30/5 3400 illumination means illuminated at a 30 degree cone angle, collected at a 5 degree cone angle using 3400 color temperature bulb. This way vendor and customer have an easier time comparing results.