Optimal Wafer Illumination for Machine Vision Applications on Silicon Wafers

John R. Goulding

Electro Scientific Industries

SW Test Workshop

June 4, 2001

Turning **Technology** *into Customer* **Value**

Outline

Abstract

Research Statement

Wafer Illumination

- Common Light Sources
- Bright Field Illumination
- Dark Field Illumination

Scribe Marks on Wafers

- Laser-etched Pits
- Small-angle Method
- Scribe Mark Example

Probe Mark Illumination

- Small-angle Experiment
- Small-angle Lab Results

Summary

Future Work

Q&A

References

Contact Information

Abstract

Understanding illumination is the first critical step in developing machine vision applications for silicon wafers. Machine vision algorithms are used for Optical Character Recognition (OCR), locating alignment marks and streets, inspecting the surface of wafers for contamination and defects, identifying and measuring probe mark features on pads, and other "visual" tasks. Digital images of wafers are composed from individual pixels ranging in size from 50µm pixels for OCR, 1µm pixels for probe marks, to 0.1µm pixels for near-metrology optical inspection.

For all magnification levels and all applications, maximizing contrast (signal to noise ratio) is key to robust image processing. Using high-quality optics, low noise electronics and cabling aside, simple structuring of the orientation of the light to the wafer is a highly effective means of improving contrast. Polished wafers are highly reflective, for example, and on-axis or bright field illumination that is normal to the wafer results in a reflection of the illuminator or bright spot. Off-axis or dark field illumination is best for polished wafers. The peaks and valleys of unpolished wafers, for example, cast hard shadows with low-angle dark field illumination. Bright field illumination is best for unpolished wafers.

Abstract, cont.

When designing lighting, the angles between the light source, camera, and wafer must be optimized for maximum contrast. Data from an electron microscope shows that, in general, slight off-axis illumination and viewing is optimal. In addition, different features and different wafer surfaces react differently to certain light compositions. Monochromatic light, such as that from infrared IR-LEDs, maximizes the contrast for "soft" features (50µm wide by 0.5µm deep). While incandescent lighting maximizes the contrast for "hard" features (laser ablated scribes and probe marks). Several illumination examples of die, scribes and probe marks illustrate how light from the infrared through the visible to the ultraviolet is used to improve the contrast of various features on silicon wafers.

Generic lighting systems must accommodate a wider range of wafer surfaces and features. An ideal illuminator should incorporate a combination of bright field, dark field, monochromatic, and full-spectrum illumination. (Note that photo-etch processes can be extremely sensitive to short wavelength light; thus, filters must be used to eliminate blue and shorter wavelengths.) Finally, the illuminator must be considered up-front so that a new machine design does not constrain the illuminator to a particular height and angles of illumination and reflection.

Research Statement

1) Develop an optimal illumination technique for machine vision inspection of probe marks on silicon wafers (mirror-like surfaces).

* * *

2) Utilize the small surface irregularities introduced by the probe mark to reflect light to a camera for machine vision analysis.

* * *

3) Similar illumination methods exist for reading OCR indicia (laser-etched pits) on silicon wafers.

Wafer Illumination

Maximizing contrast (signal to noise ratio) is key to robust machine vision image processing.

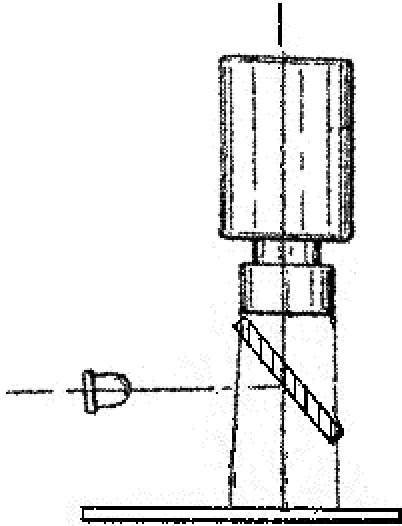
Controllable Parameters:

- **Optical elements** (aberrations, diffraction, focal length, imager size, field of view, aperture, brightness, depth of field, etc.)
- **Electronic elements** (low noise, pixel count, pixel resolution, shielded cables, clean power, etc.)
- **Light property** (IR, ROYGBIV, UV, x-ray)
- **Light source** (diffuse, specular, axial, ring, dome, oblique, bright & dark field, structured, etc.)

Common Light Sources

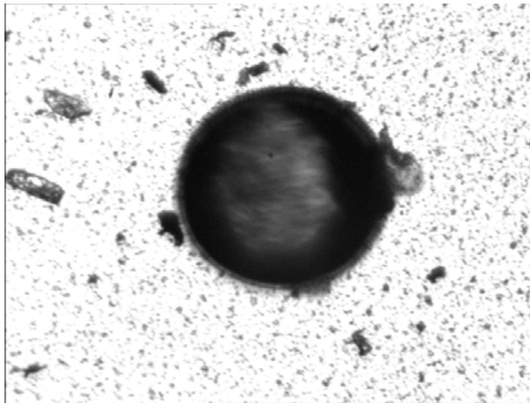
- **LED** -- Monochromatic (IR, red, green, blue, UV) and broad-spectrum (blue biased), bright, linear output, long life, small size
- **Incandescent** -- Broad-spectrum, bright, hot, non-linear output, limited life
- **Xenon gas** -- Broad-spectrum with narrow spectral spikes, bright, high noise, strobe only
- **Fluorescent** -- UV & broad-spectrum, blue biased, cool, diffuse, dim, requires complex controller

Bright Field Illumination



Angle of incident Light is normal to wafer surface (50/50 mirror)

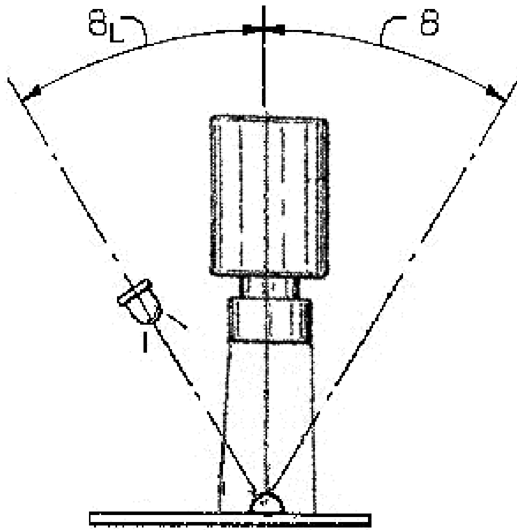
- Specular light source
- Wafer surface is bright
- Objects on surface appear dark



Example

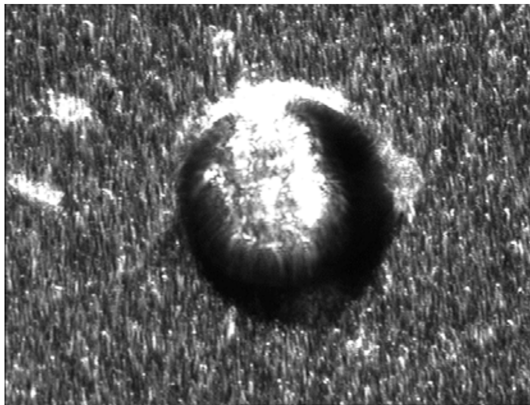
- Axial illumination
- Solder ball on silicon wafer

Dark Field Illumination



Angle of incident Light $\mathbf{8}_L$ equals angle of reflection **8**

- Structured light source
- Objects on surface appear bright
- Wafer surface is dark

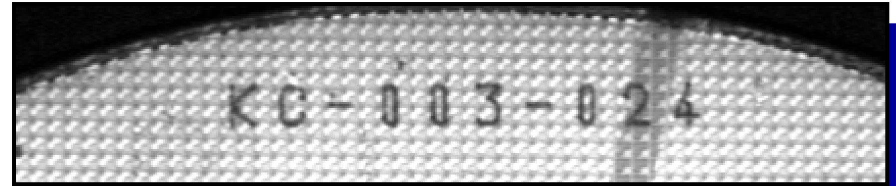


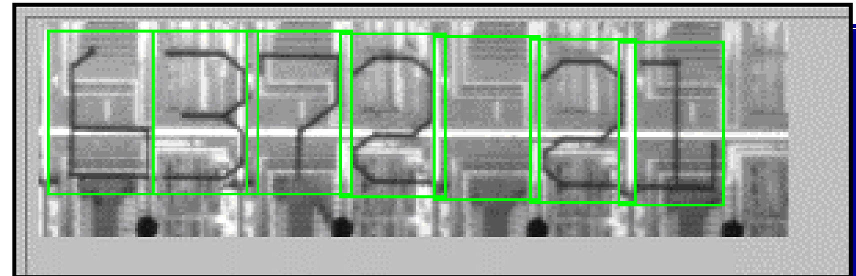
<u>Example</u>

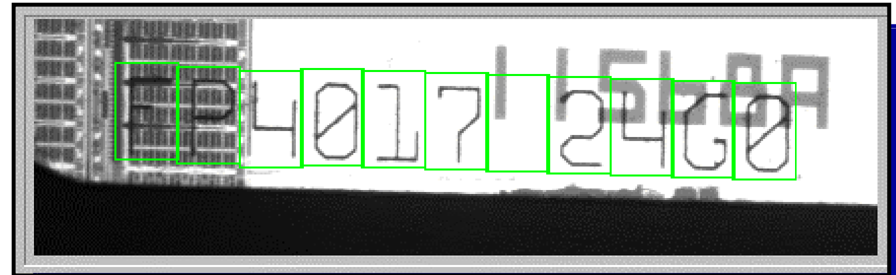
- Single, point light source at 30° from line-of-sight
- Solder ball on silicon wafer

Scribe Marks on Wafers

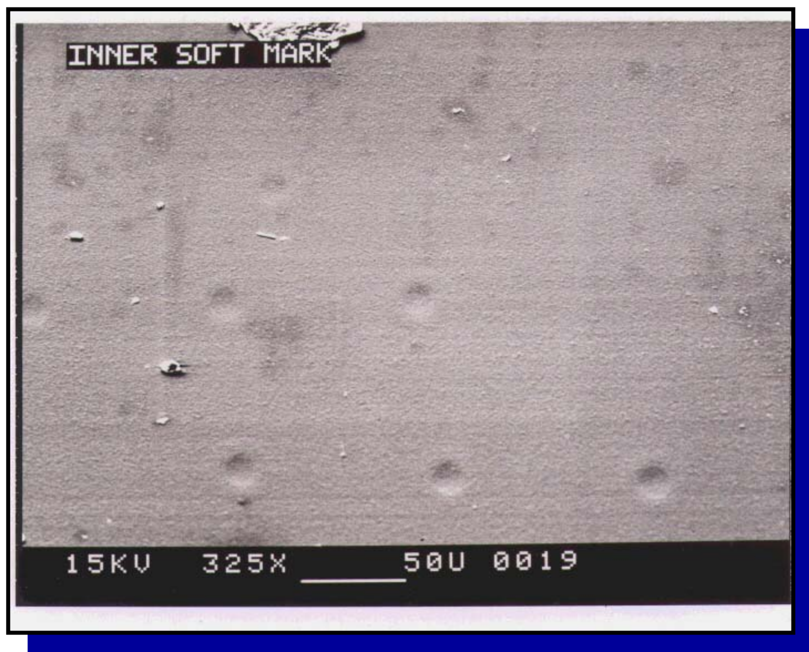
- Typically a matrix of laser-etched pits
- The same color as their wafer substrate with little, if any, relief
- A polished wafer reflects bright field illumination like a mirror
- "Soft" or "Super Soft" Scribe Marks do not reflect Dark Field illumination







Laser-Etched Pits

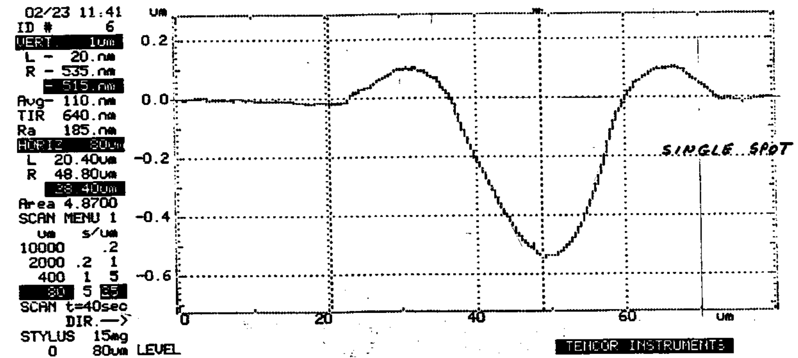


Soft Mark 325 X

Soft Mark 870 X

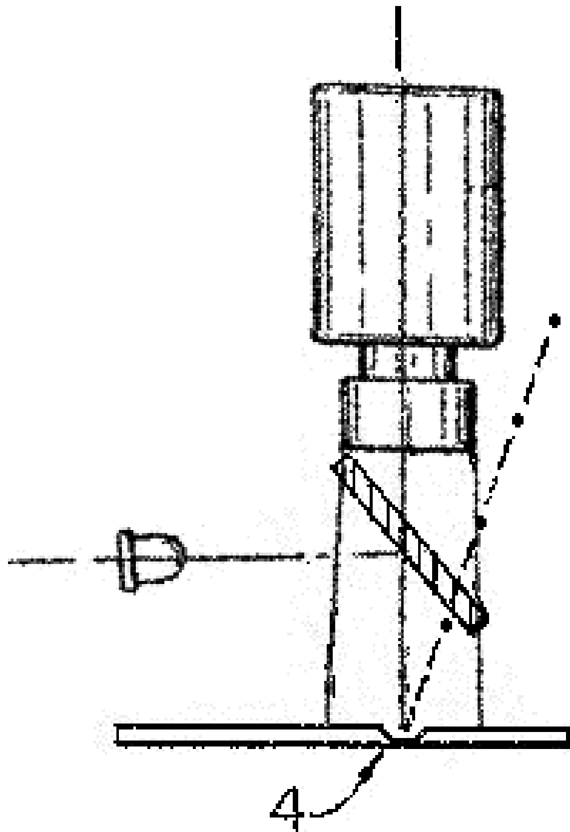
Laser-Etched Pits, cont.

Soft Mark (Edge) 5,530 X



Soft Mark Z-Profile

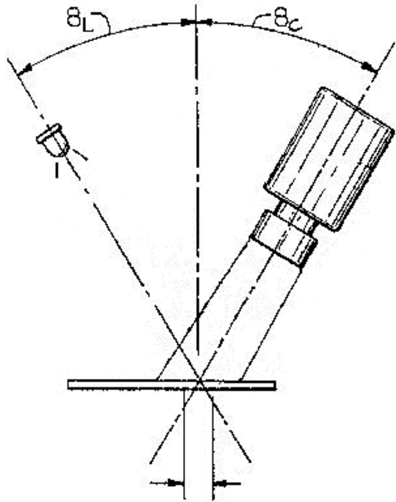
Small-Angle Method



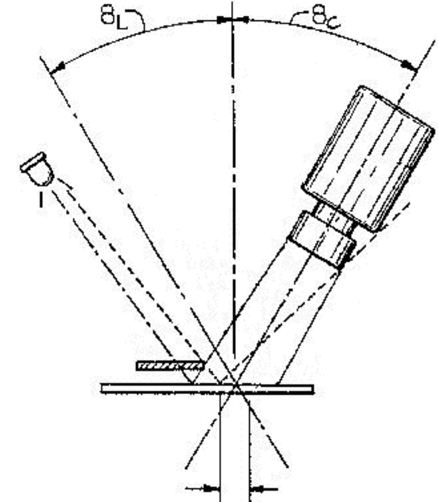
Observation

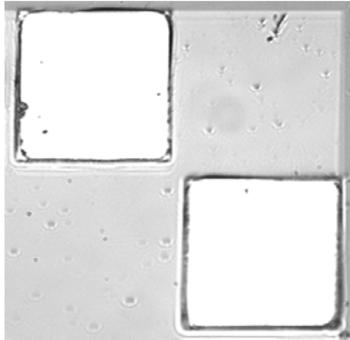
- Scribe Marks **4** disperse light only through a small angle.
- As a result, the light must be at a complementary small angle from the line of sight to illuminate the mark in dark field lighting.
- Traditional axial illumination methods at small angles image the light in the field of view, thus "blinding" the camera.

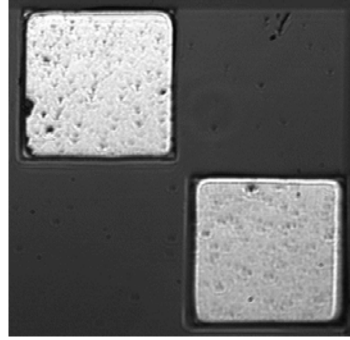
Small-Angle Method, cont.

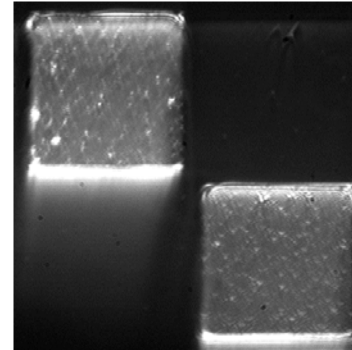


Angle the camera and light **$8_L = 8_C$** to see the probe mark, and move the light outside the camera's field-of-view.









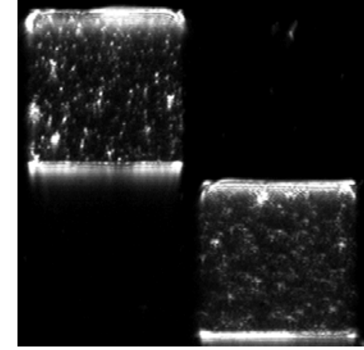
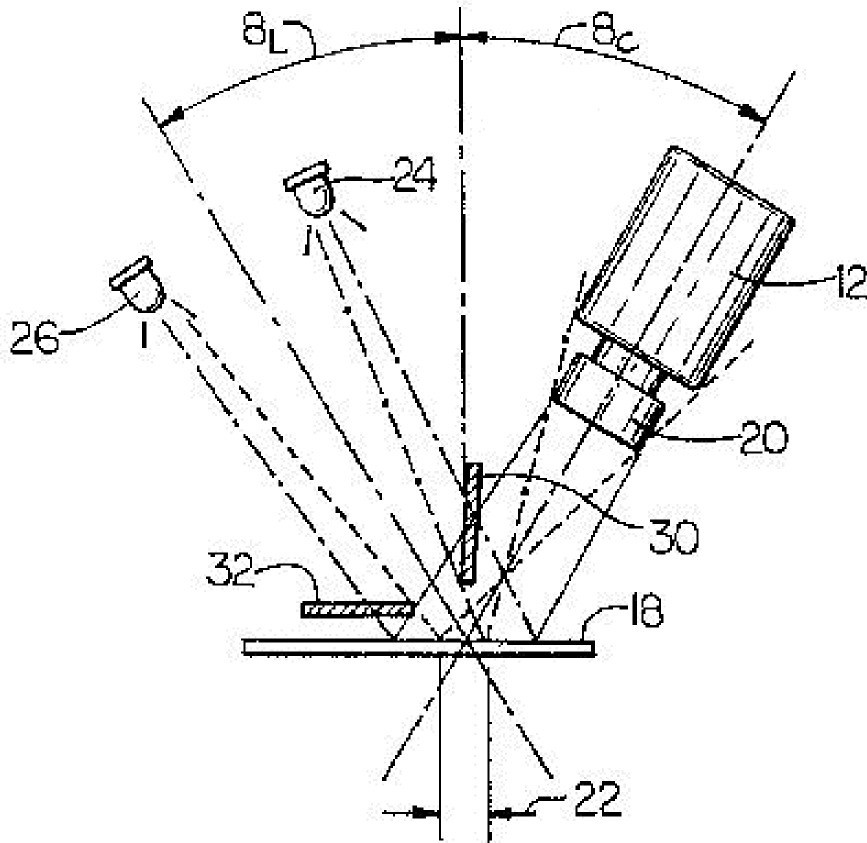


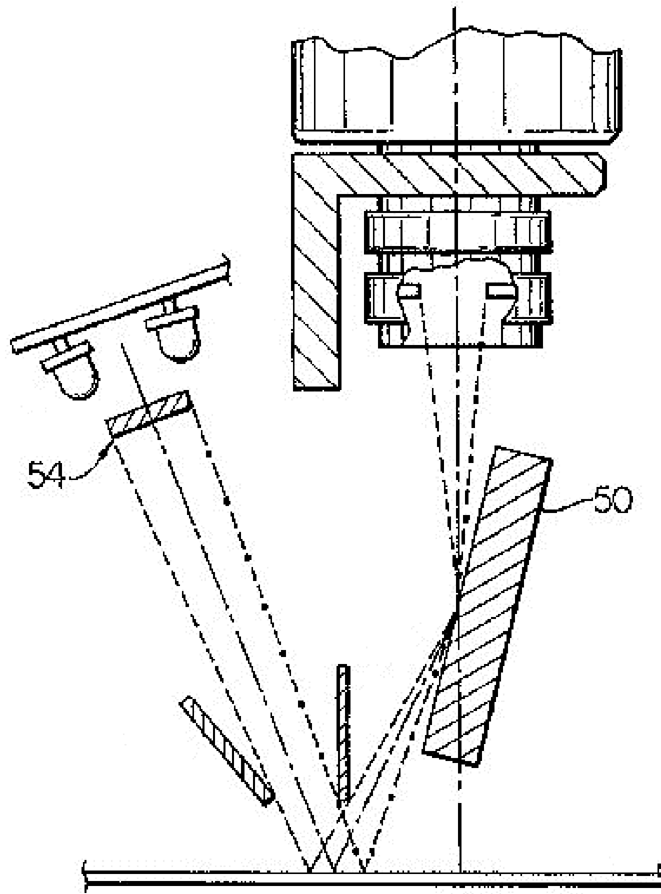
Image of Light (Bright Field) → Image of Pads (Dark Field)

Small-Angle Method, cont.



- Silicon wafer **18** (mirror-like surface) having area of interest **22**
- Camera **12** and lens **20** having optical center lines $\mathbf{8_L}$ and $\mathbf{8_C}$
- Lights **24** and **26** occluded from field-of-view behind opaque baffles **30** and **32**

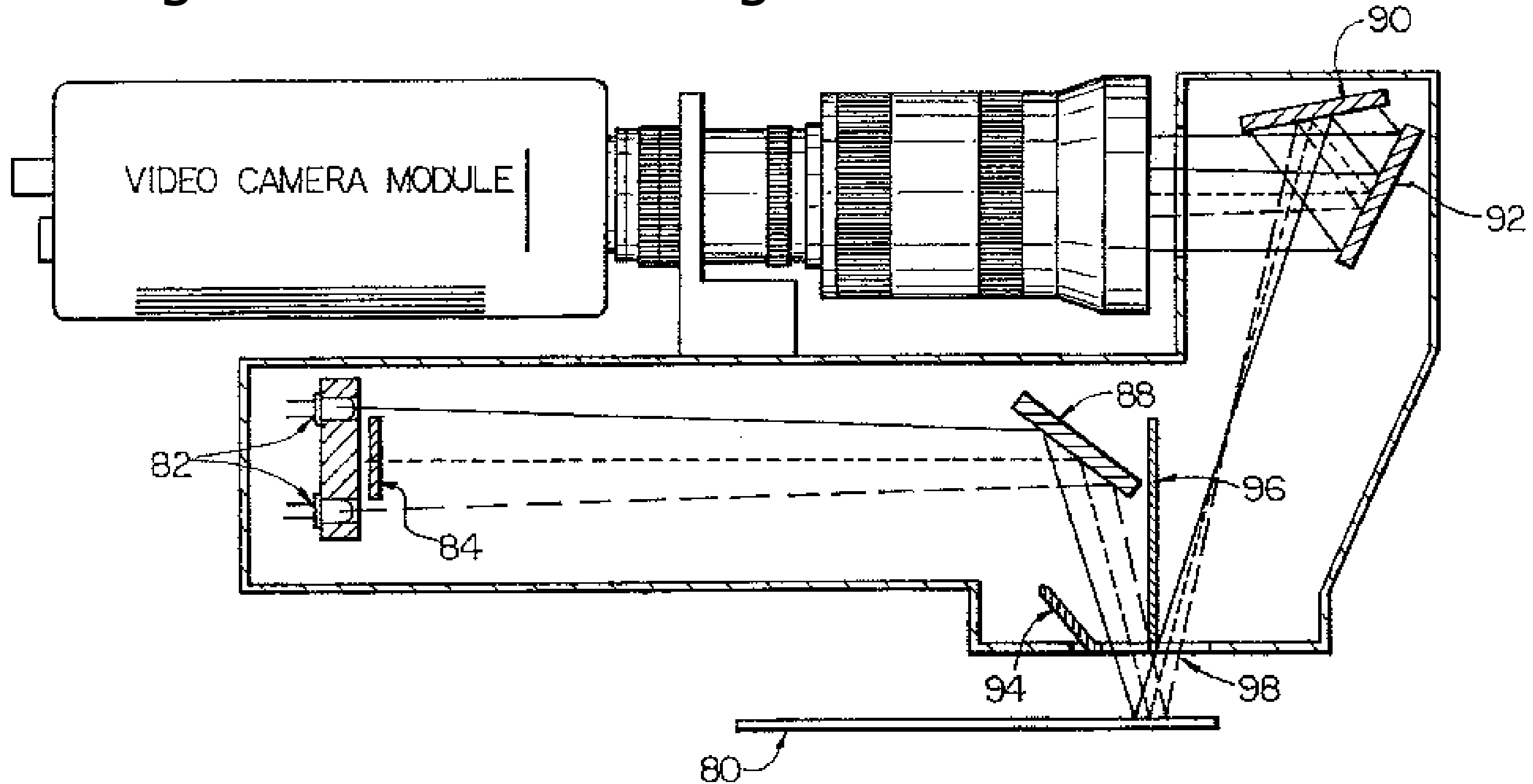
Small-Angle Method, cont.



- Opaque baffle **54** allows closer placement of lamps.
- Front of baffle **54** may be used for diffuse bright field illumination. (And provides more light than 50/50 beamsplitter.)
- Mirror **50** allows standard vertical camera or microscope configuration.

Small-Angle Method, cont.

Configuration of Small-Angle Dark Field Illuminator

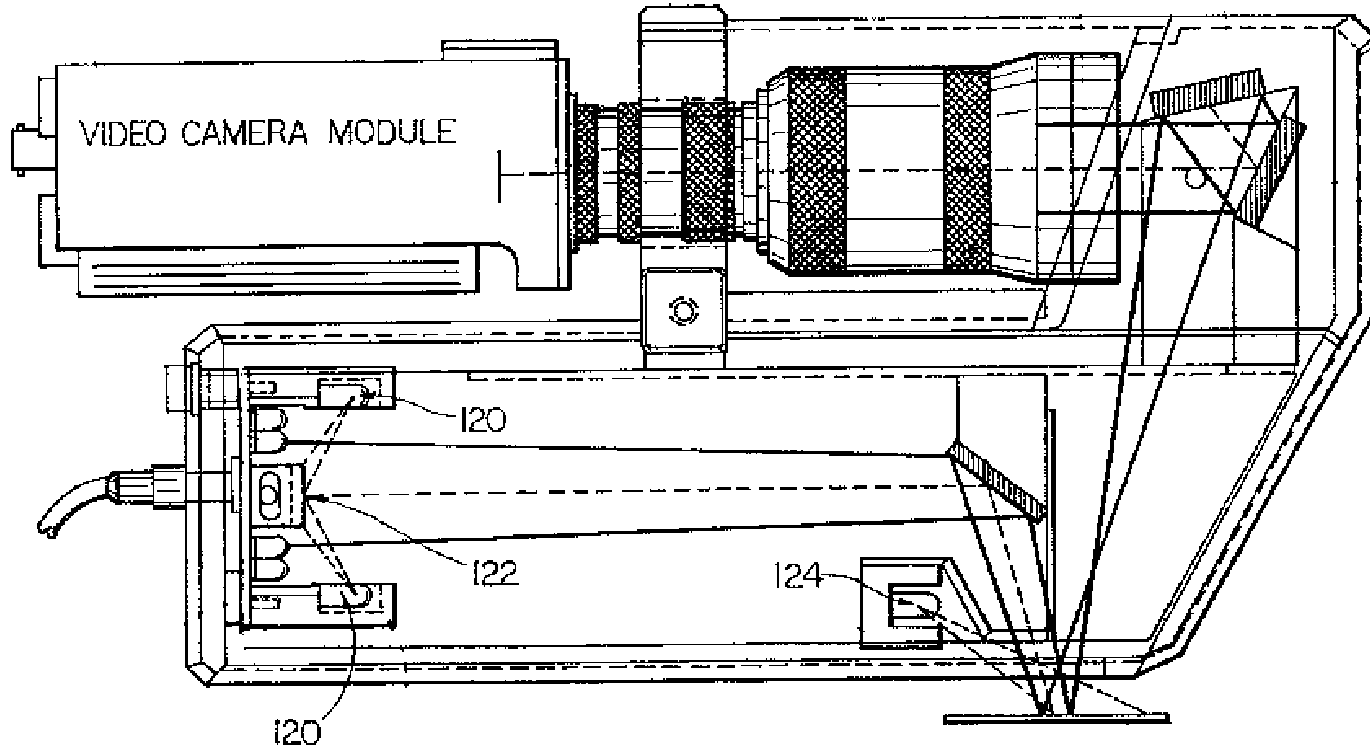


80. Silicon Wafer
82. IR LEDs

84, 94, 96. Opaque Baffles
88, 90, 92. Optical Mirrors

Small-Angle Method, cont.

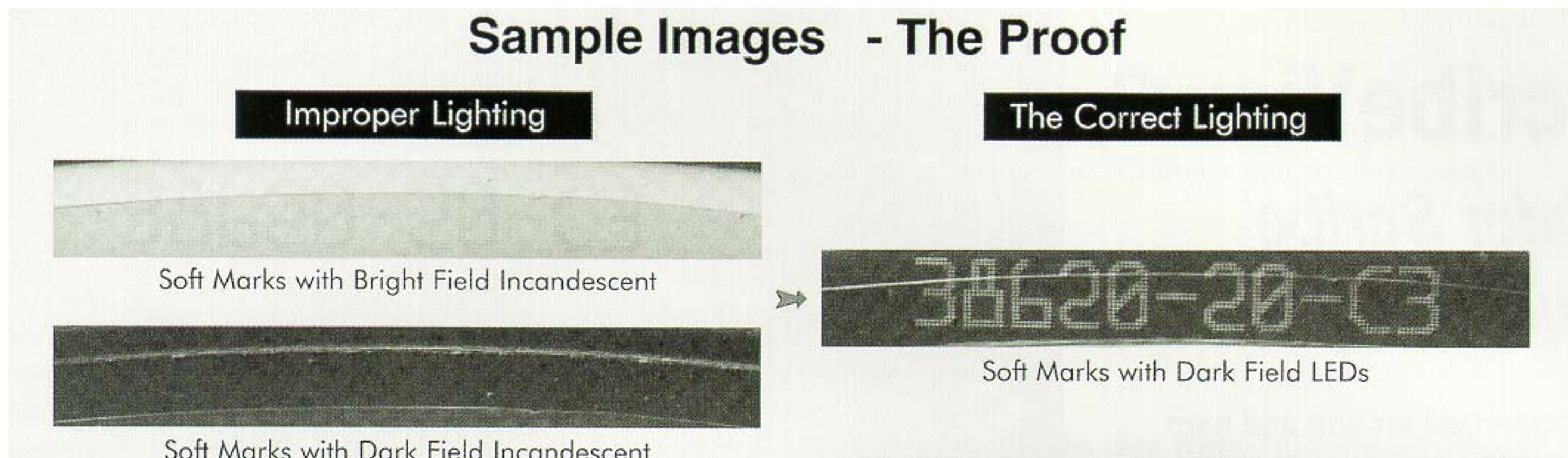
Addition of Bright Field & Dark Field Lamps



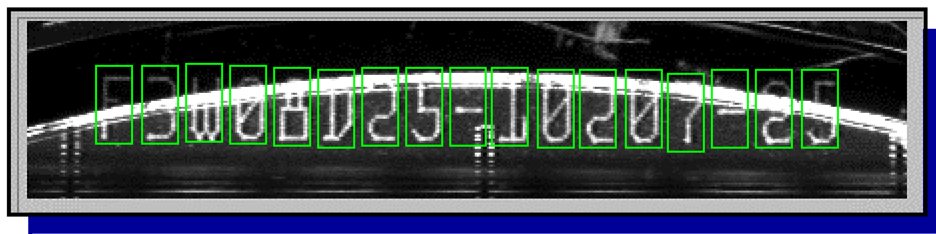
120. Bright Field Lamps
122. Frost-White Plate

124. Dark Field Lamp

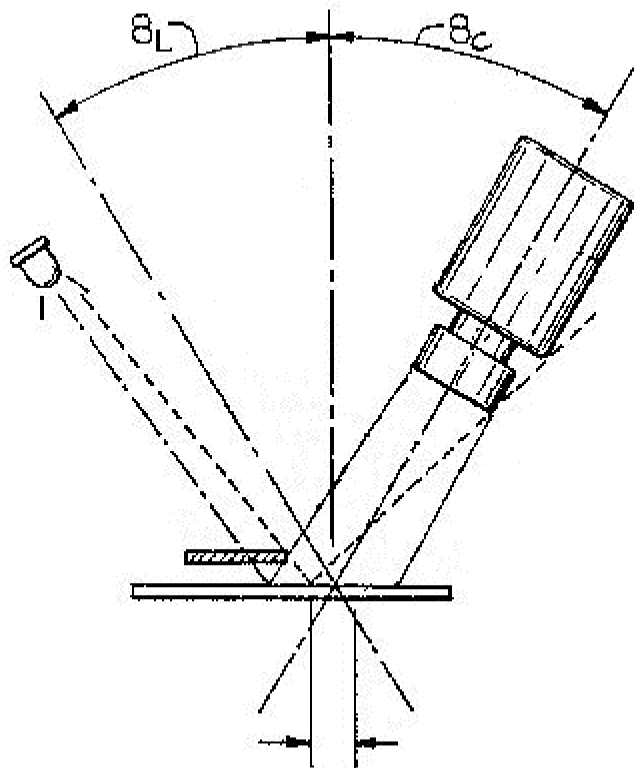
Scribe Mark Example



Soft Marks with Small-Angle Dark Field IR LEDs



Probe Mark Illumination



Null Hypothesis

- Probe Marks are similar to Scribe Marks and will respond similarly to small-angle dark field illumination.
- <u>Proof-of-concept</u>: One lamp, positioned at a small angle with an opaque baffle to occlude lamp and thereby prevent lamp from being imaged within the field of view of the camera.

Small-Angle Experiment

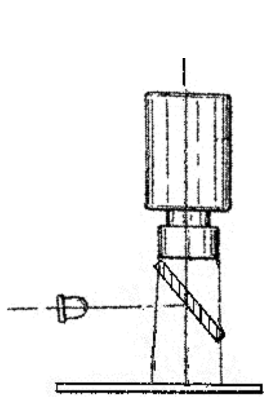
Laboratory Equipment

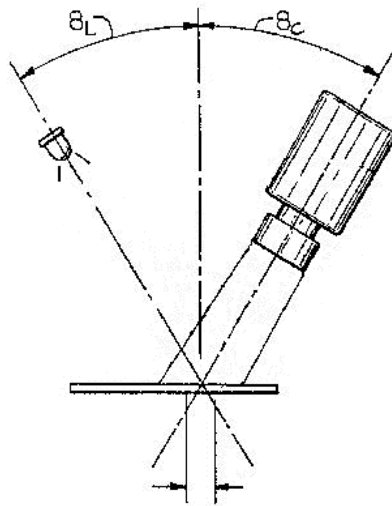
- Optics Bench
- X-Y-Z Stage
- Microscope Optics in Small-Angle Stage
- Fiber Illumination
- Opaque Baffle
- 640x480 B&W Camera, Sony XC-75

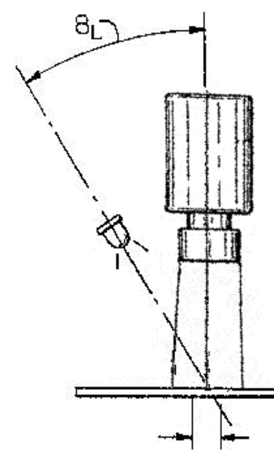
Small-Angle Experiment, cont.

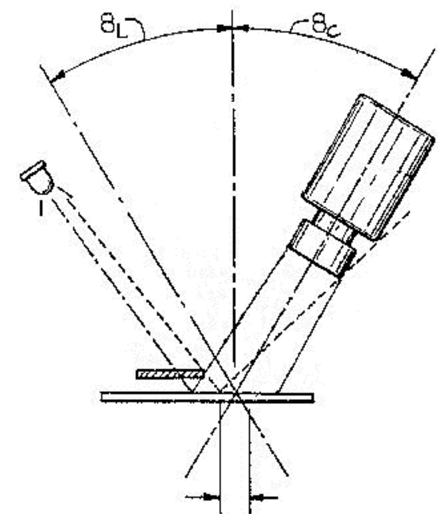
Procedure

- Take images of probe marks using four methods:





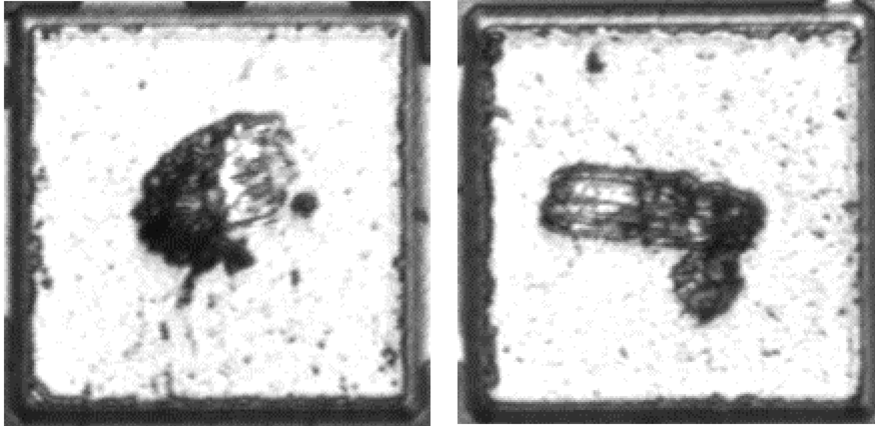


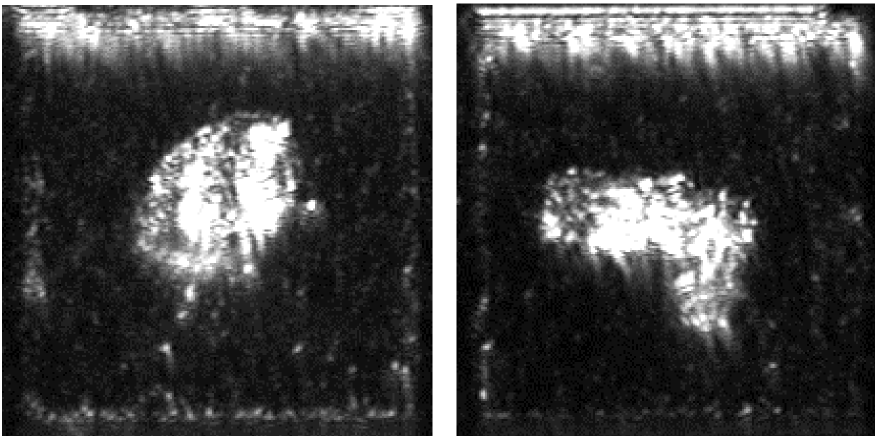


Axial **Oblique**
Bright-Field Illumination

Axial **SA Oblique**
Dark-Field Illumination

Small-Angle Lab Results





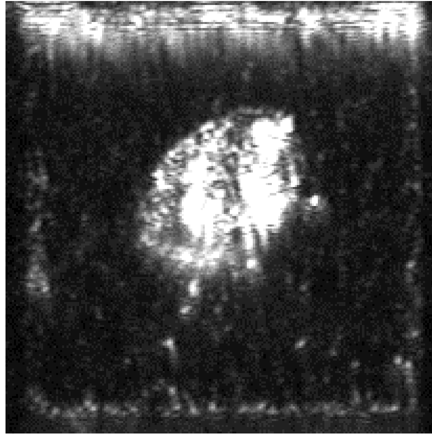
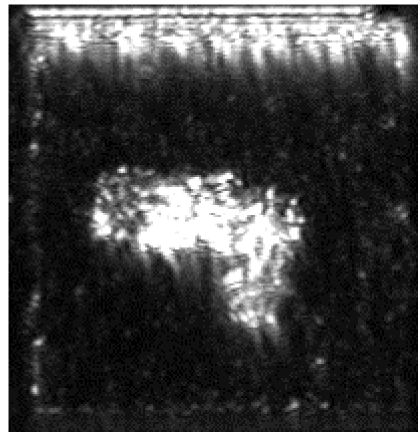
Bright Field Image

- Bright Pad
- Mostly Dark Probe Mark but Internal Reflections

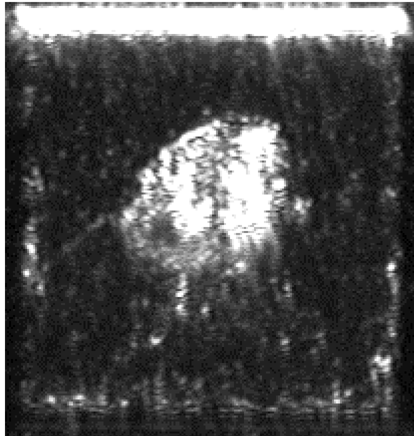
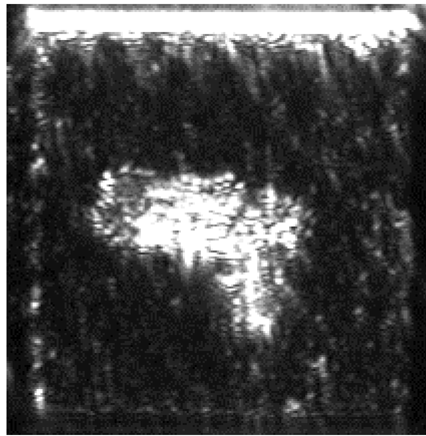
Small-Angle Dark Field Image

- Bright Probe Mark
- Dark Pad

Small-Angle Lab Results, cont.

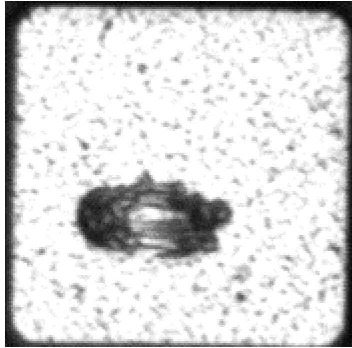
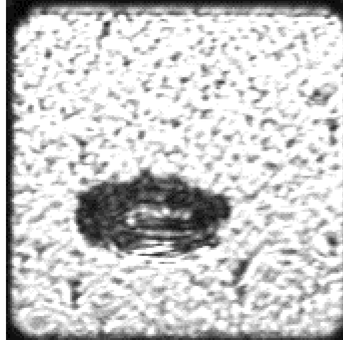
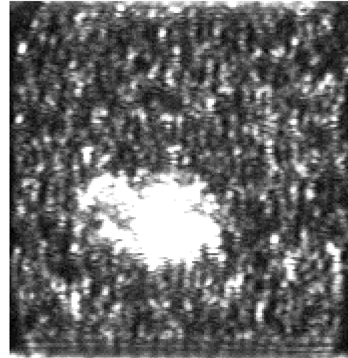
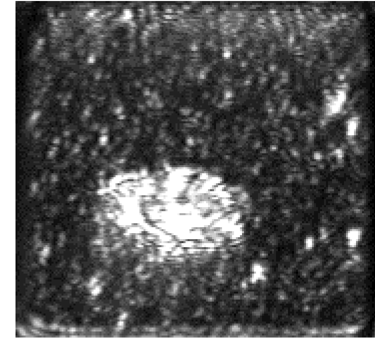
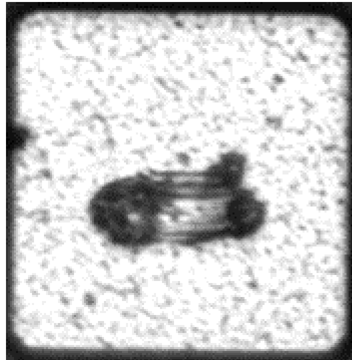
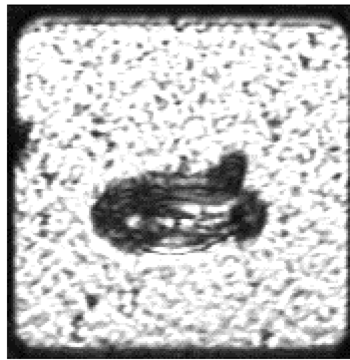
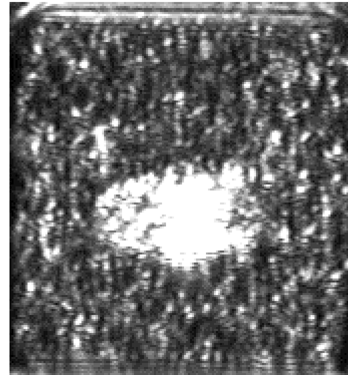
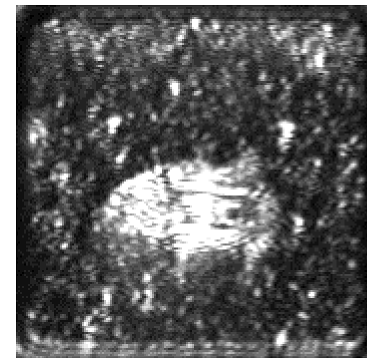



Small-Angle Oblique Dark Field illumination exhibits greater contrast than

Traditional Axial Dark Field illumination

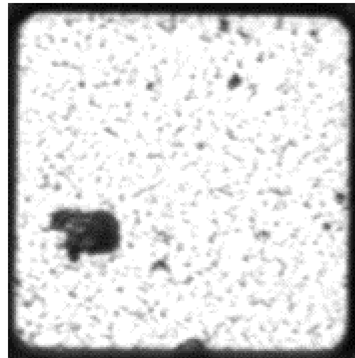
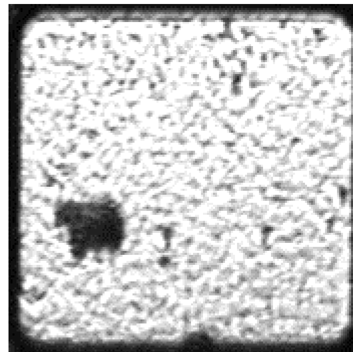
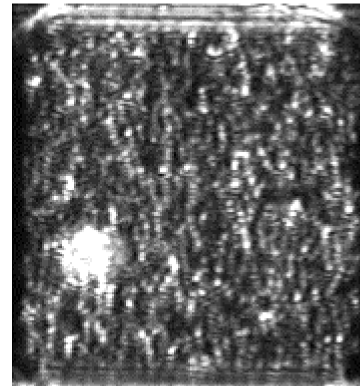
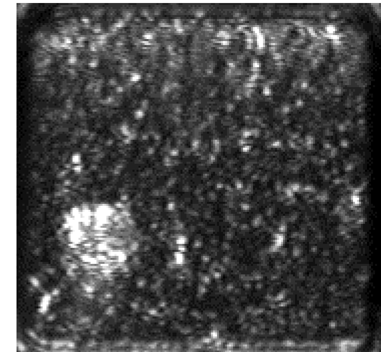
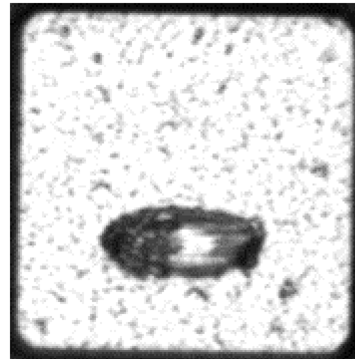
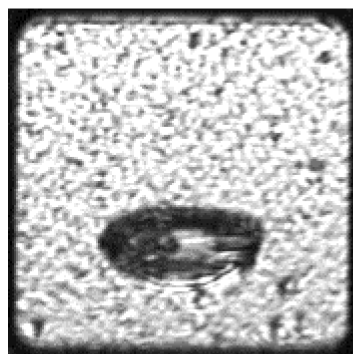
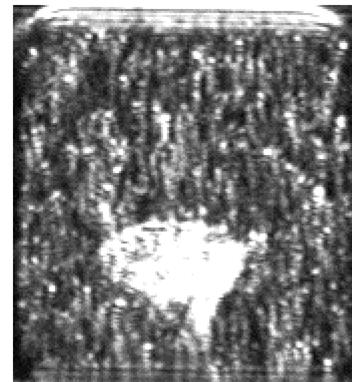
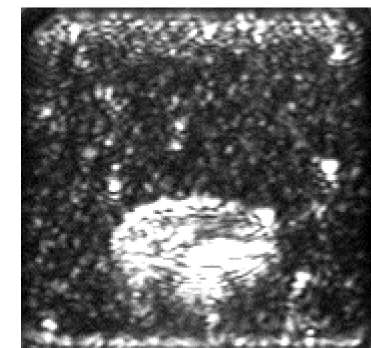
Small-Angle Lab Results, cont.

Axial Oblique
Bright-Field Illumination

Axial SA Oblique
Dark-Field Illumination

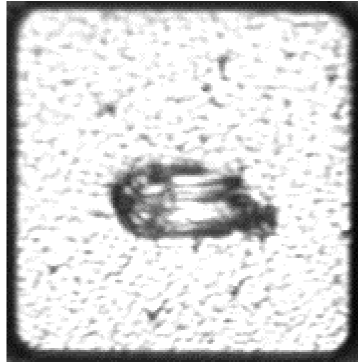
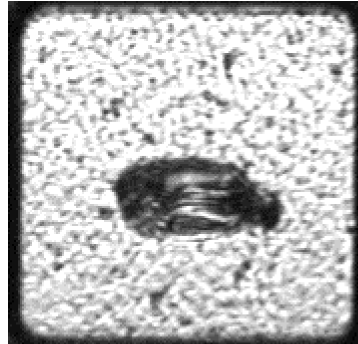
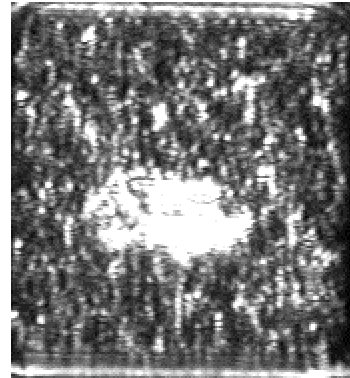
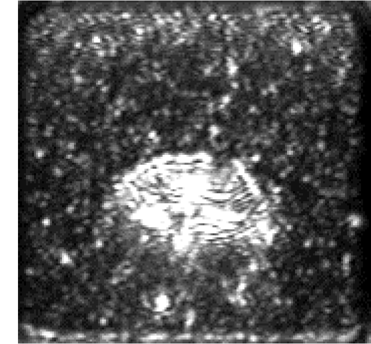
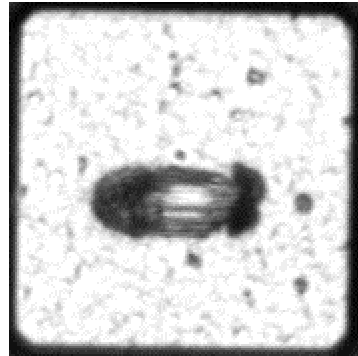
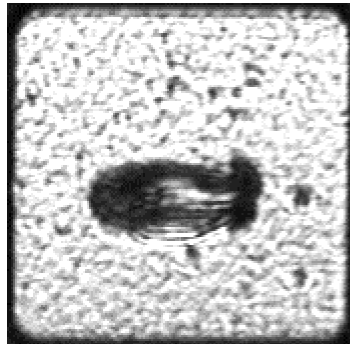
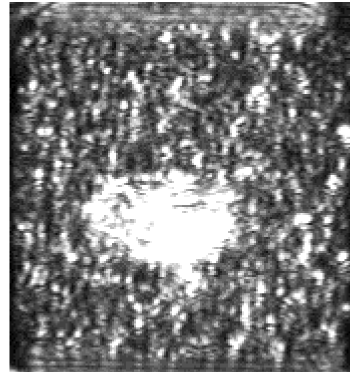
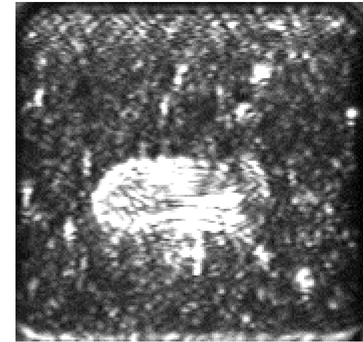
Small-Angle Lab Results, cont.

Axial Oblique
Bright-Field Illumination

Axial SA Oblique
Dark-Field Illumination

Small-Angle Lab Results, cont.

Axial Oblique
Bright-Field Illumination

Axial SA Oblique
Dark-Field Illumination

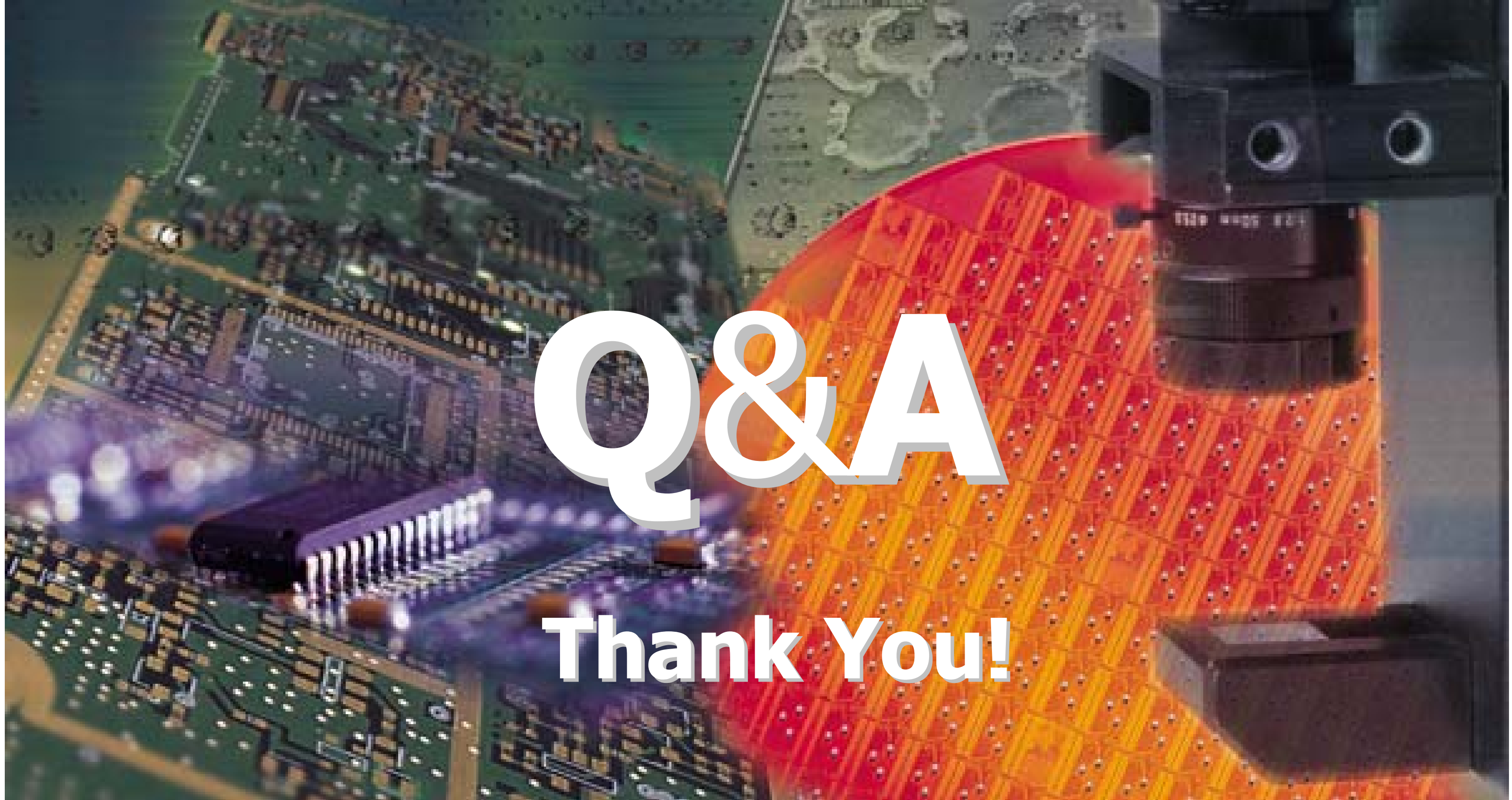
Summary

Evaluation of the geometry and apparent results:
(tests performed on only small sample of wafers)

- Oblique viewing ($8_L/8_C$) at 10-25 degrees maximizes contrast between the Probe Mark and the Pad.
- Maximum Probe Mark illumination is observed when the source of light is at a small angle from the line of sight.
- Opaque baffles occlude the light source and prevent it from being imaged within the field of view. Thus allowing the light source to be relatively intense.
- (Patent pending method…)

Future Work

- **Improve Dark Field Light**
  - Small-Diameter Fiber Ring, Broad-Spectrum Light
  - Small-Diameter Ring of IR LEDs, Single Wavelength
  - Increase Depth of Field of Optics (Scheimpflug)
  - Elliptical Baffles
- **Study More Probe Marks**
  - Sample a Variety of Wafers
  - Vertical Pins with Single Round Indentation
  - Cerprobe P4 with Very Fine Scratch Marks
- **Write Journal Paper**


Q&A
Thank You!

References

US Patent No. **5,231,536**

- Robust, LED illumination system for OCR of indicia on a substrate. Donald Wilt and Richard Sidell. July 27, 1993.

US Patent No. **5,469,294**

- Illumination system for OCR of indicia on a substrate. Donald Wilt and Richard Sidell. November 21, 1995.

US Patent No. **5,737,122**

- Illumination system for OCR of indicia on a substrate. Donald Wilt and Richard Sidell. April 7, 1998.

Contact Information

John R. Goulding
Wafer Technology Specialist
Electro Scientific Industries, Inc.
13900 NW Science Park Dr.
Portland, OR 97229 USA

(503) 672-5821
gouldingj@esi.com