Worksheet for CY 2001 R&D 100 Entry Form

Please provide the following information. It is required for internal processing of your entry.

A. Charge number **3543-00JH**

B. Funding source [e.g., DOE office, other government agency, Work for Others, Laboratory-Directed Research and Development (LDRD)] **100% Funds-In CRADA with nLine Corporation**

C. Point of contact

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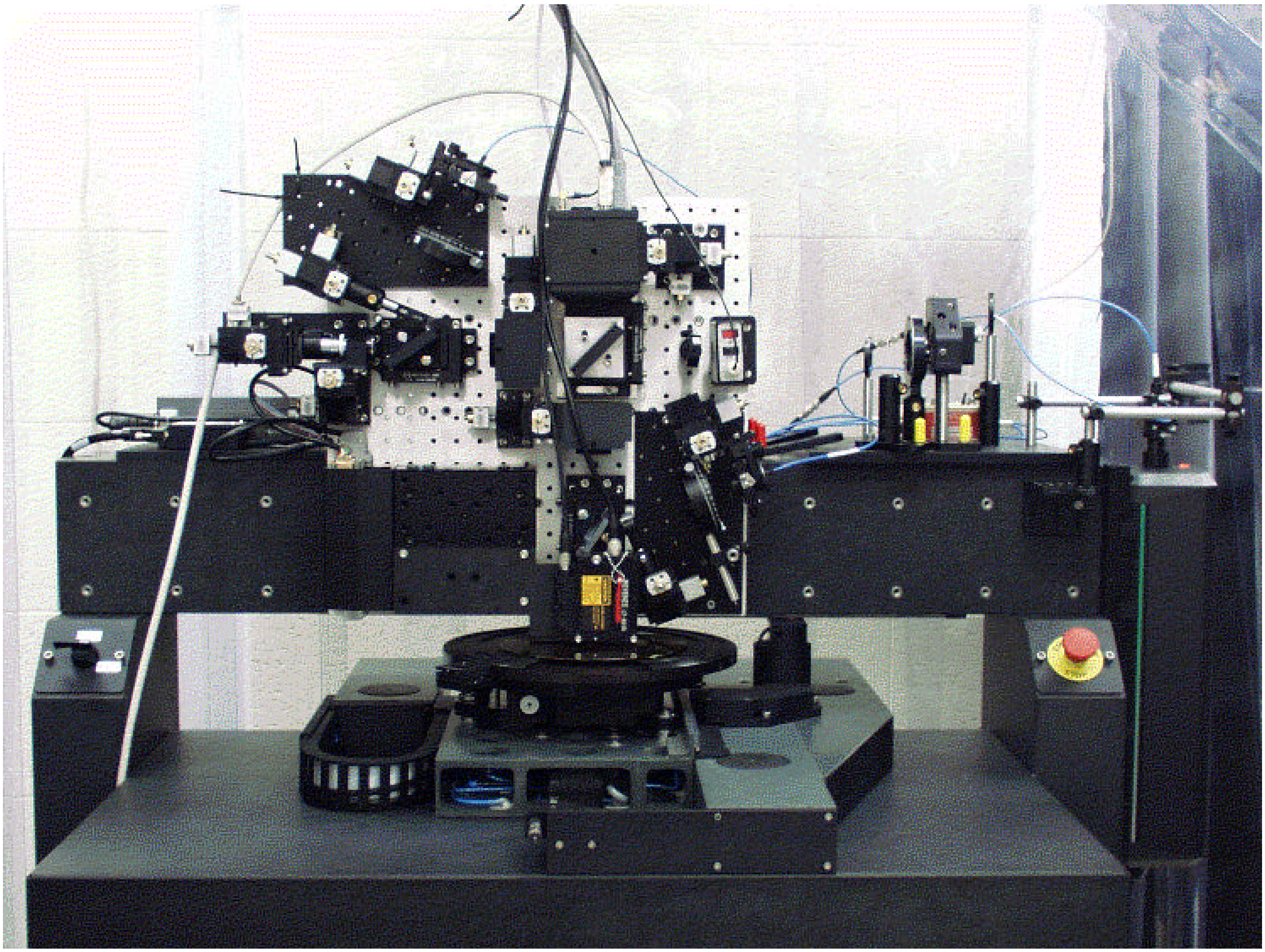
Direct-to-Digital Holography

Defect Detection Tool



2001 R&D 100 Award Entry Form

1. Submitting Organization: Oak Ridge National Laboratory[a]

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- **b. Submitter's name:** William J. Madia, Director
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- **d. FAX:** 865/241-2967
- **e. E-mail:** madia@ornl.gov
- **f. Affirmation:** I affirm that all information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this product.

  Submitter's signature ______________________________

2. Joint submitter

- **a. Organization: nLine Corporation**
- **b. Address: 4150 Freidrich Lane, Suite A, Austin TX 78744**
- **c. Submitter's name: Bob Bryant**
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3. Product name

Direct-to-Digital Holography (DDH™) technology from Oak Ridge National Laboratory (ORNL), and the defect inspection tool utilizing DDH by nLine Corporation.

4. Product description

The innovative inspection system detects sub-micron defects hidden within high aspect ratio features on semiconductor wafers by creating and analyzing a digital hologram made using DDH technology. . Defect reduction via detection is one of the five grand challenges to continued yield improvement in the semiconductor industry and its economic viability. **DDH is the only technology** that can detect defects within surface features having aspect ratios > 10:1

5. **Eligibility**

This DDH technology is currently licensed by nLine Corporation (License granted to nLine on September 1, 1999.) A Cooperative Research and Development Agreement (CRADA) ORNL99-0560 " Direct to Digital Holographic Inspection Prototype" was initiated between ORNL and nLine (start date is January 18, 2000) to transfer technology from the invention to a working prototype. In late 2000, the prototype became operational for detecting defects on wafers.

6. **Inventor or principal investigator**

Greg Hanson, Matt Chidley, John Simpson, Jim Hardy, Ken Tobin, Jim Goddard, Philip Bingham, Kathy Hylton, Edgar Voelkl, Jeff Price, Chuck Schaich, John Turner [All of ORNL] Tommy Thomas, Paul Jones, Bob Owen, Martin Hunt, John Price, Ian McMackin , Mike Mayo [All of nLine] and Dave Patek [sub-contractor to nLine].

a. **Name:**

b. **Position:**

c. **Organization:**

d. **Address:**

e. **Phone:**

f. **FAX:**

g. **E-mail:**

7. **Product price**

The commercial system price will be approximately $3.0 million [CONFIDENTIAL].

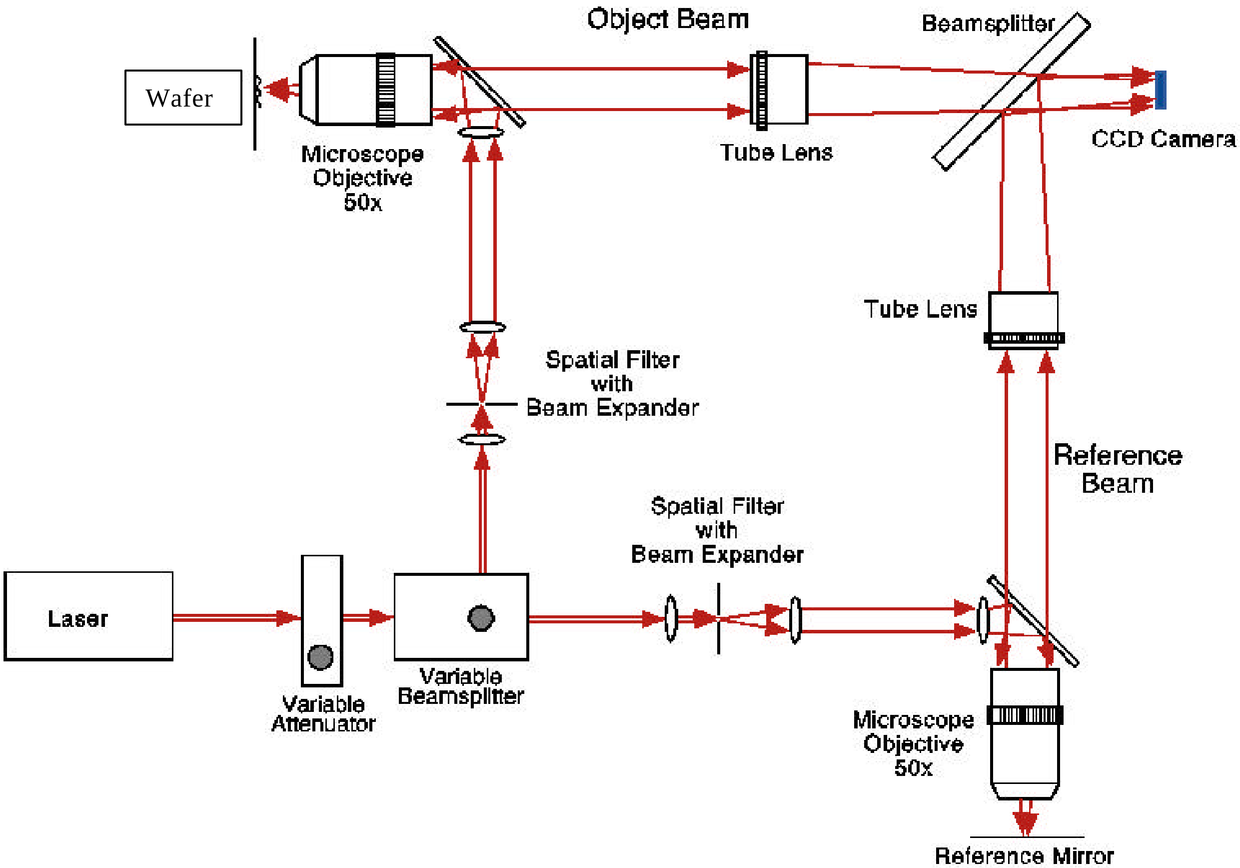
8. **Patent information**

a. **Patents held**	Yes __X__	No _____
b. **Patents pending**	Yes __X__	No _____
c. **Patents held by others**	Yes _____	No __X__

9. **Function**

The DDH technology allows recording optical holograms directly from a CCD (charge coupled device) camera (or any other suitable video camera with a digital computer interface) to any digital storage medium (RAM, hard drive, tape, recordable CD, etc.) No film, no plates, no developer, no darkroom and no waiting are required. The inspection system finds tiny defects on the surface of patterned semiconductor wafers by using light-phase measurement enabled by Direct-to-Digital Holography (DDH) technology. Light from a laser is split into reference and object legs and then recombined as shown in Figure 1. In the object leg, light passes through imaging optics and is projected at normal incidence onto the wafer

Figure 1. Optics Layout Diagram



surface from which it reflects and retraces the incoming beam path. In the reference leg, light passes through identical optics but is instead projected onto a reference mirror, reflects, and in like manner retraces its incoming beam path. The two reflected light beams are recombined by optics and focused at the detector of a Charge Coupled Device (CCD) camera. A photograph of the optics in shown in Figure 2.

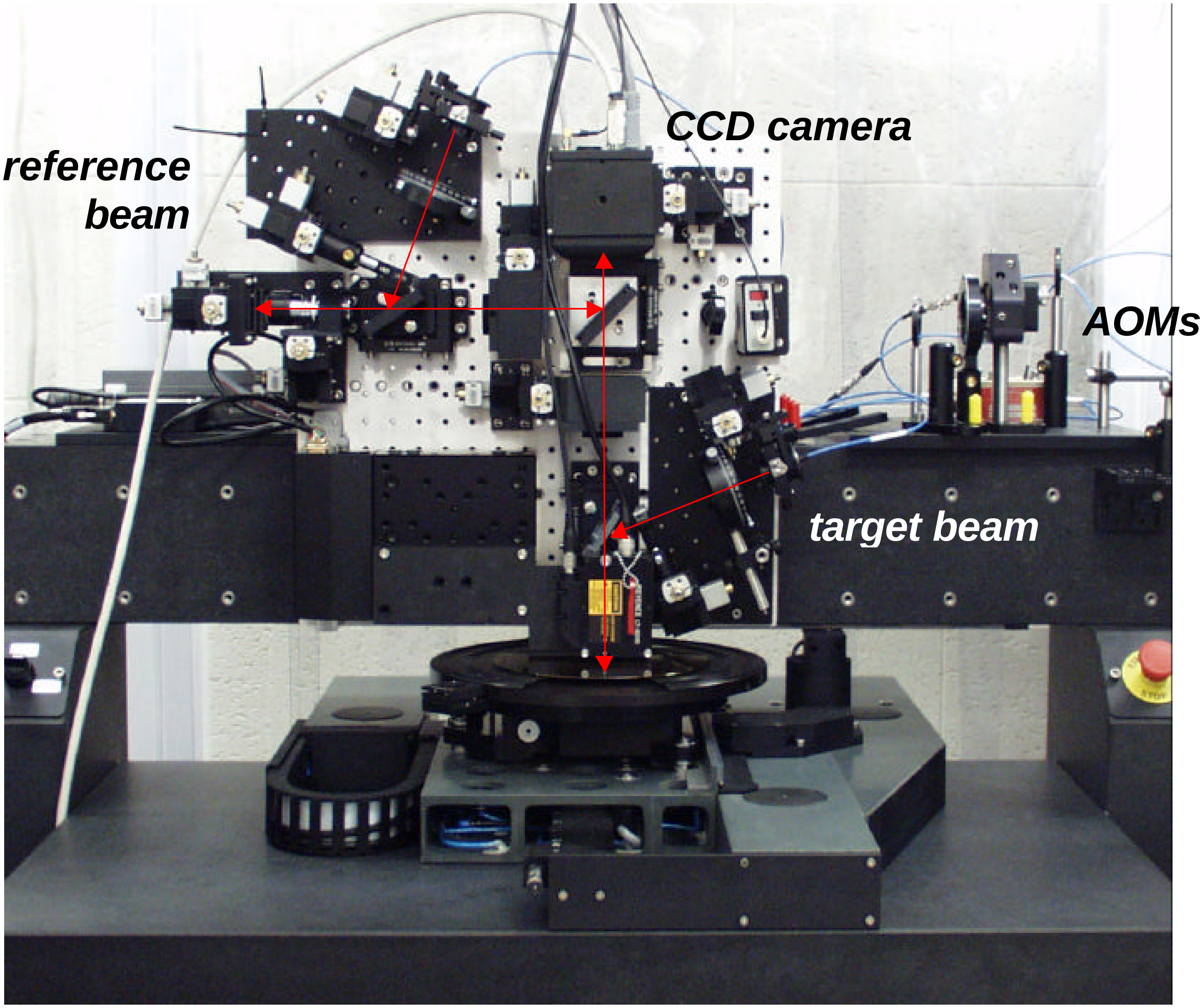
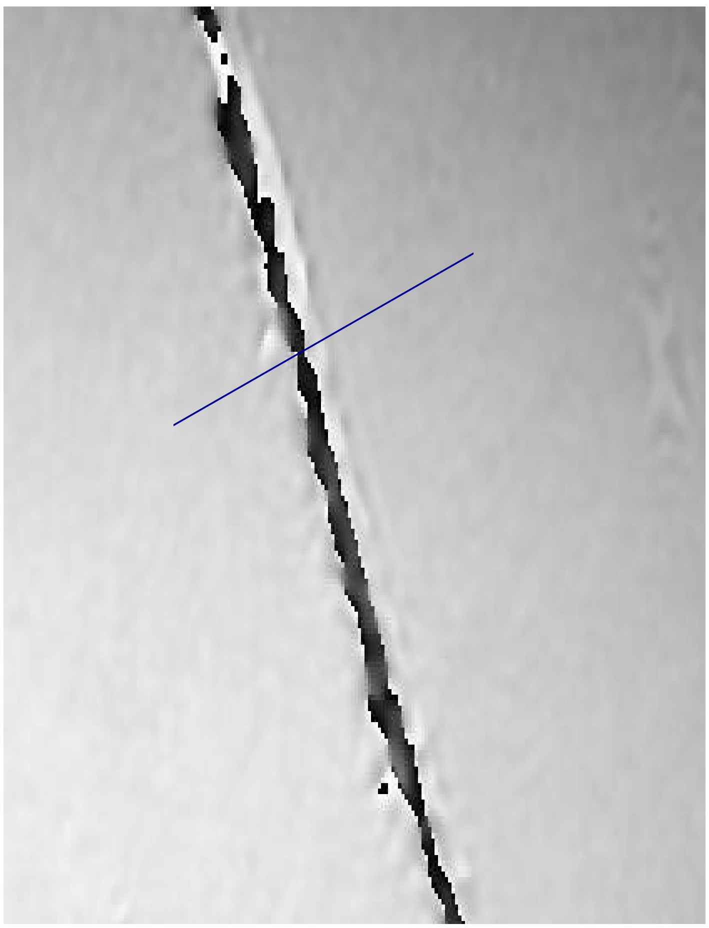


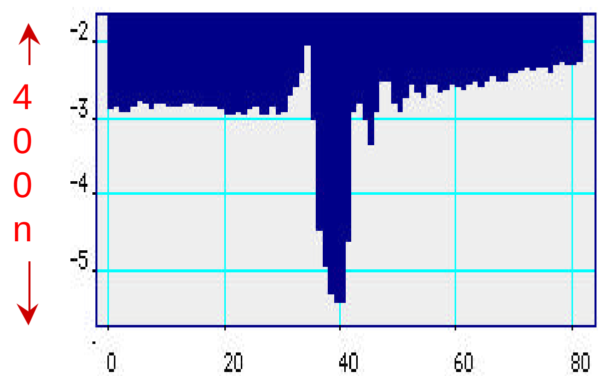
Figure 2. Photograph of Optical Layout for the DDH

The image formed is a hologram that contains information about the phase and intensity of light reflected from the wafer surface. The phase information is encoded in interference fringes in the hologram.

Before the phase data can be used for defect detection it must first be extracted from the interference pattern. This is done by application of Fast Fourier Transform (FFT) mathematics to transpose the image to a frequency domain representation, digital filtration of the image is done to remove extraneous information, then an inverse FFT is run to produce an areal "phase" image (Figure 3). The phase image records the phase of light at each pixel of the CCD camera. The technology to perform Direct Digital Holography was awarded a United States Patent on June 20, 2000.

Since phase is linearly proportional to path length, the phase image contains the information for a three-dimensional map of the wafer surface. Because adjacent die on a semiconductor wafer should be identical, this phase image can be compared to adjacent images using conventional image comparison techniques and any differences are necessarily defects.





Dimensional Profile showing a depth of less than 300 nanometers.

Grey-scale phase map of a scratch in a mirror made from Fourier analysis of interferogram.

Figure 3. Phase Image and Dimensional Profile of a Scratch

The high resolution of a phase-based technique allows identification of height differences of less than 1/100th of the wavelength, or 2.6 nanometers for a 266 nanometer beam, 50 times higher sensitivity than conventional diffraction-limited optical imaging techniques. Unlike other imaging techniques, DDH uses a heterodyne signal amplification technique that allows very weak signals to be used for measurement, hence sufficient light can be gathered from within deep, narrow surface features to enable defect detection. DDH can detect defects within contact holes and between metal lines having openings of 65 nm and aspect ratios (depth:height) greater than 12:1. Ability to do such High Aspect Ratio Inspection (HARI) is required by today's semiconductor industry. DDH is the only technology that offers such HARI capability.

10A. The competition

Competing defect inspection technologies fall into three classes: Optical Imaging, Optical Scattering, and SEM Imaging. All of these technologies rely on the *intensity* of scattered or reflected light, i.e. the number of photons at the camera pixel, to detect defects. DDH, in contrast, relies on *phase*. Therein lies the key difference. The major suppliers of tools using these competing technologies include:

- KLA Tencor Inc., San Jose CA
- Applied Materials Inc., Santa Clara CA
- Schlumberger Inc., New York NY
- Hitachi America Limited
- TSK, Tokyo Japan

These three technology classes are relatively mature so tools within a given technology class, such as optical imaging, have substantially the same capabilities with relatively small differences between the offerings of competing manufacturers. None of these competing technologies can detect tiny defects within High Aspect Ratio (HAR) structures as required by the semiconductor industry. The intensity-based systems have extreme difficulty in transmitting a sufficient quantity of light into and then back out of deep, narrow features. The International Technology Roadmap for Semiconductors (1999 Edition), sponsored by the Semiconductor Industry Association (of America) in collaboration with European, Korean, Japanese, and Taiwanese national semiconductor industry associations, defined the requirements for future HAR inspections. Those requirements are detailed in the competitive matrix below. The inspection tool using DDH technology is the only defect inspection system capable of meeting the ITRS HARI requirements.

10B. Comparative matrix

High Aspect Ratio Feature Inspection	2000 Requirement (1999 ITRS)	Competing Defect Inspection Technologies				
		DDH	Optical Imaging	Optical Scattering	SEM Imaging	Comment
Minimum defect size detected (nm)	40	40	100(1)	100(1)	100(2)	Must detect defects ≤1/3 the feature size, or 60 nm for the current 180 nm semiconductor device generation.
Max Aspect Ratio (height:width)	>11:1	>12:1	~4:1	~1:1	~7:1	Must detect defects within > 11:1 AR features. Only DDH can.
Camera Pixel size required for 130 nm defect detection (nm)	NA	>500	<150	NA	NA	Larger pixel, all else equal, gives higher throughput
Energy to detect 130 nm defect (mj/m^2)	NA	100	10,000	8,000	NA	High energies damage low K films. (3)
Compatible with Low K films?	Yes	Yes	No	No	No	Organic low K films required for future devices. (3)
Throughput @ 100 nm detection limit (8”-wafers/hour)	NA	1-3	2-3	30	0.2	Higher throughput provides better capital utilization. (4)
System price ($ million/unit)	NA	~3.0	~3.0	~0.3	~7.5	Lower cost provides better capital utilization. (4)

(1) Imaging techniques other than DDH phase imaging are diffraction limited and can not detect defects smaller than about one half the wavelength

(2) Smaller details can be seen by SEM, but searching for defects (defect detection) at such high resolutions would be too slow to be useful

(3) Organosilicate low dielectric constant (“low k”) films that are used on current and future devices are thermally sensitive and can be degraded by high levels of irradiation. Such films also outgas in the vacuum of a SEM system making SEM a problematic technique to use on these films.

(4) DDH has equal or better throughput and cost than competing HARI technologies. Optical scattering has higher throughput and lower cost but is not able to do HARI so does not compete in the HARI application

10C. Improvements upon competitive products or technologies

DDH is a revolutionary improvement on existing intensity-based optical and SEM defect detection methods. The inspection tool with DDH technology measures the phase of light at each camera pixel. Conventional methods measure only the intensity, or quantity, of photons incident on the pixel. For that reason DDH has revolutionary improved detection capabilities over conventional systems. Improvements include:

- High Aspect Ratio Inspection capability required by industry but not offered by any other technology.
- Higher sensitivity that conventional diffraction limited, intensity-based techniques using the same wavelength.
- Inspection at low incident energies makes it compatible with low k films. (Current technologies (imaging and scattering) can inspect low k films in low AR applications, but not in the demanding and necessary HARI application without high, film-damaging levels of illumination.)
- Volumetric detection (i.e. DDH measures height as well as surface area) rather than merely surface area. This provides another parameter semiconductor manufacturers can use to trouble-shoot and correct sources of process defects.
- Potentially higher throughput than conventional optical imaging techniques due to the use of a larger camera pixel.
- About the same cost as conventional optical imaging systems (~$3 million) but with much higher HARI capability. For comparison, scattering tools cost ~ $0.3 million without any HARI capability, and SEM tools cost ~ $7.0 million and have limited HARI capability and very low throughput. [Price information is confidential.]

11A. Principal applications

The principle application for the inspection tool with DDH technology is detection of sub micron defects on patterned wafers during the semiconductor manufacturing process. Potential customers for the tool will be semiconductor manufacturers such as Intel, Motorola, Micron, Texas Instruments, NEC, Samsung, and many others around the globe. Application of this tool will enable such manufacturers to detect yield-killing defects in HAR structures and with that information trouble-shoot and solve defect causing problems in their manufacturing processes. This new yield improvement capability will help lower product cost and enable lower prices to industry and consumers for semiconductor devices.

11B. Other applications

DDH can also be applied to a myriad of other applications that require fast, precise measurement of surface topography on manufactured products. Such applications include:

- Inspection of Photolithographic reticles
- Inspection of computer hard drive storage media
- Fast cheap three-dimensional imaging of microscopic structures such as on Micro Electro Mechanical (MEM) devices.

12. Summary

The nLine inspection tool using Oak Ridge National Laboratory's DDH technology is a needed breakthrough in defect detection technology for the semiconductor industry. Without such HARI capable technology the semiconductor industry's ability to design and pattern smaller and smaller features would outstrip its ability to inspect those feature during the production process. The result would be a slowing of the technical advancement that has been crucial to the building of ever faster, cheaper circuits. DDH technology also offers a new volumetric way to characterize defects, a capability never before available, that will provide greater insight to engineers in wafer fabs working to increase yields. And many other applications are available for development that will exploit the fast, cheap, high-resolution surface mapping capability of DDH. The inspection tool using DDH technology represents a revolutionary improvement in defect detection and surface imaging technology.

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