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UCN-13672 (26 8-85)

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Y/AMT-423

Project Accomplishment Summary
for
Project Number 93-Y12P-075-C1

SEMICONDUCTOR YIELD IMPROVEMENTS THROUGH AUTOMATIC DEFECT CLASSIFICATION

Shaun Gleason
Lockheed Martin Energy Systems, Inc.
Ashok Kulkarni
KLA Instruments Corporation

September 30, 1995

MASTER

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Prepared by the
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LOCKHEED MARTIN ENERGY SYSTEMS, INC.
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U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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PROJECT ACCOMPLISHMENT SUMMARY

Title: Semiconductor Yield Improvements Through Automatic Defect Classification
DOE TTI Number: 93-Y12P-075-C1
CRADA Number: ORNL92-0140
Partner: KLA Instruments Corporation

BACKGROUND

Automatic detection of defects during the fabrication of semiconductor wafers is largely automated, but the classification of those defects is still performed manually by technicians. Projections by semiconductor manufacturers predict that with larger wafer sizes and smaller line width technology the number of defects to be manually classified will increase exponentially. This cooperative research and development agreement (CRADA) between Martin Marietta Energy Systems (MMES) and KLA Instruments developed concepts, algorithms and systems to automate the classification of wafer defects to decrease inspection time, improve the reliability of defect classification, and hence increase process throughput and yield. Image analysis, feature extraction, pattern recognition and classification schemes were developed that are now being used as research tools for future products and are being integrated into the KLA line of wafer inspection hardware. An automatic defect classification software research tool was developed and delivered to the CRADA partner to facilitate continuation of this research beyond the end of the partnership.

DESCRIPTION

KLA Instruments was to generate sets of characterized image pairs with available database information using the KLA 2100 Series Wafer Defect Inspector. These image pairs contained a reasonable distribution of circuit cell backgrounds, normal process variations, flaw types and categories for use by the MMES Staff in developing and testing inspection approaches. KLA and MMES would interact with the major manufacturers of semiconductor products and key players in the DOE DO microelectronic R&D program to identify relevant image descriptors and a classification "language" for use with the automated classifier. MMES would develop novel techniques for image segmentation and feature extraction in the presence of semi-regular background texture, and develop feature extraction in the presence of semi-regular background texture, and develop feature vectors that best differentiate between flaw types and classes. MMES would develop high-speed adaptable classifiers based on image feature vectors. Merge classification language, description data-base, and image features into a coherent adaptive classification technique. KLA would identify the hardware, software, and operating procedure modifications required of KLA Instruments' three primary product lines in wafer inspection to accommodate automated defect classification. Perform technical trade-off studies, market assessments, and cost-benefit analysis on the implementations which hold the most promise for benefiting the semiconductor wafer manufacturing industry. MMES would assimilate a developed approach (optimum feature vectors, classification scheme, and classification language) into a demonstration prototype. Complete system testing, verification, performance characterization, system demonstration, and final report.

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BENEFITS TO DOE

The DOE relies heavily on the availability of high quality, thoroughly tested integrated circuits for practically all Defense Programs ranging from nuclear weapons production, testing, and detonation, to safeguards and security, and advanced manufacturing feedback and control systems. Most of these circuits are purchased commercially and thus the benefit of providing high speed silicon wafer inspection systems to the manufacturers of semiconductor products is inherent.

DOE also develops and produces custom integrated circuits for its program. The Microelectronics Development Laboratory (MDL) at Sandia National Laboratory is responsible for semiconductor manufacturing process development and specific integrated circuit design for many DOE defense and intelligence needs. They have primary responsibility for the Development of high temperature tolerant circuits and radiation hardened circuits and processes. Although the state of the art for these technology areas lag those of the commercial sector in wafer area and line widths, they have already exceeded circuit complexity for which human inspection is viable.

While MDL could benefit directly from the use of an enhanced wafer inspection system, they are basically a low volume, prototype development and demonstration facility. The main economic advantage to DOE-DP with respect to custom integrated circuits lies in receiving high yield manufacturing runs from commercial vendors who mass produce MDL perfected circuits (such as the United Technologies Inc. Microelectronics Center, Colorado Springs, Colorado). Another DP program which could benefit directly from this projects is the joint SEMATECH/DOE Center for Contamination Free Manufacturing also at Sandia National Laboratory. In each of these cases control of the fabrication line to minimize defects and maintain acceptable yields of high quality product is not possible without on-line wafer inspection and defect classification. This project will allow Wafer Inspection Systems to meet current and future demand for yield optimization by providing rapid analysis of the semiconductor manufacturing process.

ECONOMIC BENEFIT

Defect detection and classification plays an important part in maintaining and improving production yield in semiconductor fabrication lines. A wafer must be processed to 80 or 90% completion before it can be tested electrically. Optical methods and Scanning Electron Microscopes (SEMs) are the only methods available for inspection during most of the processing.

Because "killer" defects are detected on sample wafers after a lot (usually 25) of wafers has been processed, prompt detection and classification of any defects is essential to correcting process problems and maintaining the yield of the fabrication line. With smaller and smaller design rules (feature size, line width, etc.) The allowable particle and defect sizes are correspondingly reduced. In other words, the range of particle and defect sizes is increased leading to a drastic increase in the number to detect and classify. To this is added the larger wafer size, so the area to be inspected is almost 80% greater with the new 200-mm diameter wafers than with the older 150-mm wafers. The trend towards a 300-mm diameter wafer standard will again more than double the area to be inspected, hence double the number of defects to detect and classify.

To put this into a national perspective, the cost of Motorola's newest 200-mm fabrication line in Austin was approximately \$500M. The value of product wafers in a typical process line at any one time is in the range of \$50M to \$100M. (It normally takes about 6 weeks to completely process a lot of wafers). It should be clear that increasing inspection and analysis time to accommodate the larger wafers and increased number of defect classes cannot be easily tolerated.

Both the increased speed of wafer scanning and automation of defect classification is essential for the industry to maintain the volume of production with adequate yield to pay for the rapidly escalating cost of the production facilities and equipment. Improved defect inspection is essential for the long term profitability of U.S. semiconductor industry. A 0.1% yield improvement in wafer production is worth \$100M annually to the U.S. semiconductor industry.

PROJECT STATUS

This project is complete.

DOE FACILITY POINT OF CONTACT

Shaun Gleason
Martin Marietta Energy Systems
P.O. Box 2009
Oak Ridge, TN 37831-6011
423-574-8259

PARTNER POINT OF CONTACT

Ashok Kulkarni
KLA Instruments Corporation
P.O. Box 49055
San Jose, CA 95161-9055

PROJECT EXAMPLES

No project examples are available due time lapse between the end of the project and the writing of this report.

TECHNOLOGY COMMERCIALIZATIONS

The path to commercialization of the ADC technology has already been established by KLA. For example, work that MMES performed with regard to the radial basis function network classifier led to the integration of this classification scheme into KLA's existing ADC prototype located at a customer site. The ADC tool provided by MMES will be a valuable research test bed that KLA can use to evaluate the applicability of various combinations of features and classifiers.

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Ashok Kulkarni, KLA Instruments Corporation, P.O. Box 49055, San Jose, CA 95161-9055 (5 copies)