Final Report
CRADA No. ORNL02-0655

Benchmarking, Research, Development, and Support for ORNL Automated Image and Signature Retrieval (AIR / ASR) Technologies

Prepared by

Kenneth W. Tobin
Engineering Science and Technology Division
Oak Ridge National Laboratory*

Abstract

This report describes the results of a Cooperative Research and Development Agreement (CRADA) with Applied Materials, Inc. (AMAT) of Santa Clara, California. This project encompassed the continued development and integration of the ORNL Automated Image Retrieval (AIR) technology, and an extension of the technology denoted Automated Signature Retrieval (ASR), and other related technologies with the Defect Source Identification (DSI) software system that was under development by AMAT at the time this work was performed. In the semiconductor manufacturing environment, defect imagery is used to diagnose problems in the manufacturing line, train yield management engineers, and examine historical data for trends. Image management in semiconductor data systems is a growing cause of concern in the industry as fabricators are now collecting up to 20,000 images each week. In response to this concern, researchers at the Oak Ridge National Laboratory (ORNL) developed a semiconductor-specific content-based image retrieval method and system, also known as AIR. The system uses an image-based query-by-example method to locate and retrieve similar imagery from a database of digital imagery using visual image characteristics. The query method is based on a unique architecture that takes advantage of the statistical, morphological, and structural characteristics of image data, generated by inspection equipment in industrial applications. The system improves the manufacturing process by allowing rapid access to historical records of similar events so that errant process equipment can be isolated and corrective actions can be quickly taken to improve yield. The combined ORNL and AMAT technology is referred to hereafter as DSI-AIR and DSI-ASR.

1. Statement of Objectives

The objective of this CRADA with AMAT was to continue with the development, adaptation, and evaluation of ORNL's AIR technology in the AMAT DSI product being developed to provide yield analysis capabilities for knowledge-based queries to discover defect sources. ORNL had worked with AMAT under two separate contracts since the mid-1990s including a Work for others (WFO) contract (ERD-96-XG002) in support of the development of novel Automatic Defect Classification (ADC) technologies for the AMAT Defect Review Scanning Electron Microscope (SEM), and a CRADA (ORNL00-0571) for the technology transfer and integration of the ORNL AIR technology into the DSI software environment. Through this additional CRADA (ORNL02-0655) ORNL supported the continued AIR technology developments required to support and improve the DSI-AIR / ASR products.

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2. Benefit to DOE Office's Mission

The project addresses DOE mission in two major ways. First, the development of new inspection tools and technologies for the semiconductor manufacturing environment has the potential to reduce energy consumption and waste production through improved yield during manufacturing. Second, this project supports the development of new technical business in the United States and moves technology developed at a DOE lab into the commercial sector.

3. Technical Discussion of Work Performed

The use of image retrieval in conjunction with other process and tool parameters used by DSI provides a very powerful, complimentary technique for quickly locating process problems through historical data. Under this CRADA ORNL supported three technical investigations (phases). Phase I addressed the continued software support of the AIR subsystem that was provided to AMAT under the original ORNL/AMAT CRADA. Phase I also included participation of ORNL in an extensive benchmarking activity within AMAT to internally verify the expected performance of the AIR technology prior to full integration in a commercial semiconductor fabrication environment. Phase II addressed the continued support, development, extension, and enhancement of AIR and ASR to provide DSI with advanced capabilities beyond the earlier CRADA contract, i.e., ORNL supported AMAT in its effort to gain the most advantage from the AIR and ASR technologies. Phase III addressed the continued support requirements of the DSI product in consideration of new methods and capabilities provided under Phase I and II activities.

4. Subject Inventions

In support of this CRADA with Applied Materials, the following ORNL-developed intellectual property, including patents and copyrights, were licensed and/or evaluated for potential use by Applied Materials:

Tobin, K.W., Karnowski, T.P., Ferrell, R.K., "Method for Indexing and Retrieving Manufacturing-Specific Digital Imagery Based on Image Content", ERID No. 0668 / Q&B 6321-131, U.S. Patent No. 6,751,343, June 15, 2004.

Tobin, K.W., Karnowski, T.P., Ferrell, R.K., "Method for Localizing and Isolating an Errant Process Step", U.S. Patent No. 6,535,776, March 18, 2003.

Karnowski, T.P., Tobin, K.W., "Content-based Pattern Retrieval", UT-Battelle, LLC, Invention Disclosure No. 1227C, DOE S-101,813, January 2003.

UT-BATTELLE Copyright Docket Number 40000031, "Automated Image Retrieval (AIR) Version 1.0," Creators: T. P. Karnowski, R. K. Ferrell, K. W. Tobin

UT-BATTELLE Copyright Docket Number 40000032, "Automated Image Retrieval (AIR) Version 2.0," Creators: T. P. Karnowski, R. K. Ferrell, K. W. Tobin

UT-BATTELLE Copyright Docket Number 40000053, "Intelligent Data Management (IDM) for a Content Based Image Retrieval," Creators: T. P. Karnowski, K. W. Tobin

UT-BATTELLE Copyright Docket Number 40000054, "Defect Mask Encoder (DME) for a Content-Based Image Retrieval System," Creators: J. R. Price, K. W. Tobin

5. Commercialization Possibilities

The ORNL AIR technology was initially developed through an ORNL LDRD project. The technology was then proved through a CRADA with International SEMATECH, Austin, Texas (ISMT). It was through field testing and reporting that AMAT first contacted ORNL to discuss the original licensing of the AIR technology. Due to the nature of the close relationship between ORNL, ISMT, and AMAT, it was agreed that AMAT could license the AIR technology for a limited exclusivity period to gain a time-to-market advantage. Therefore, ORNL still maintains non-exclusive licensing rights for the AIR technology within the semiconductor industry and exclusive rights for the technology outside of the field of use of semiconductor manufacturing.

As examples of continued commercialization activity, the AIR technology has been successfully licensed and integrated into back-end wafer inspection products produced by Rudolph Technologies, Inc., Inspection Business Unit, Bloomington, Minnesota. The technology has also been adapted to the medical imaging industry where two new patents have been filed:

> Tobin, K.W., Karnowski, T.P., Chaum, E., "A Method for the Diagnosis of Blinding Eye Disease using Image Content and an Archive of Diagnosed Human Patient Data," UT-Battelle, LLC, Invention Disclosure No. 1596, DOE No. S-105,198, July 2005.
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> Tobin, K.W., Karnowski, T.P., Lakhani, F., "A Method for the Reduction of Image Content Redundancy in Large Image Libraries", UT-Battelle, LLC, Invention Disclosure No. 1485, US DOE S-105,086, December 2005.

These technologies are being further developed under an NIH National Eye Institute grant and will potentially be licensed in the medical imaging marketplace for the automated diagnosis of blinding eye diseases resulting from diabetic retinopathy and age-related macular degeneration.

6. Plans for Future Collaboration

Future collaboration with AMAT regarding this technology is not likely at this juncture. In 2002, after a significant semiconductor industry downturn, AMAT disbanded the DSI product development group through relocations and layoffs and changed marketing strategies; moving away from the concept of "total fab solutions" to a tool-centric new product development strategy that no longer required the datamining concepts and capabilities of AIR and DSI.

7. Conclusions

The DSI-AIR concept was proved to be particularly effective in managing the large volumes of fab data collected by a wide variety of inspection tools in the semiconductor manufacturing environment. Beta-testing of the DSI-AIR product was underway in Europe when financial difficulties in the industry resulted in a change in commercial strategy for the company (in concert with worldwide layoffs of approximately 3,000 AMAT employees). Subsequent licensing of AIR to Rudolph Technologies in 2006 demonstrates the usefulness of the technology even today. AIR is currently being evaluated for potential use by another semiconductor industry inspection tool manufacturer through a WFO contract with ORNL and work is ongoing to adapt the technology to other fields such as biomedicine. The following publications and awards have resulted from the CRADAs with AMAT and ISMT.

7.1. Awards

National Federal Laboratory Consortium Award for "Automated Image Retrieval System for Semiconductor Yield Improvement", recognition for Excellence in Technology Transfer, May 2003.

Southeast Region Federal Laboratory Consortium Award for "Automated Image Retrieval Technology", recognition for Excellence in Technology Transfer, January 2003.

R&D Magazine's R&D 100 Award for applied research in the development of the Defect Source Identifier – Automated Image Retrieval (DSI-AIR) System for Semiconductor Image Data Management, 2002.

UT-Battelle, LLC, Awards Night Director's Award for Outstanding Team Accomplishment in Science and Technology, for Successful Development of a Content-based Image Retrieval System for Semiconductor Yield Improvement October 2002.

UT-Battelle, LLC, Awards Night Recognition for Outstanding Engineering Development Team Accomplishment, for Successful Development of a Content-based Image Retrieval System for Semiconductor Yield Improvement October 2002.

7.2. Publications

Weber, C., Sankaran, V., Tobin, K.W., "Quantifying the Value of Ownership of Yield Analysis Technologies", IEEE Transactions on Semiconductor Manufacturing, Vol. 15, No. 4, November 2002.

Tobin, K. W., Karnowski, T.P., Arrowood, L.F., Ferrell, R.K., Goddard, J.S., Lakhani, F., "Content-based Image Retrieval for Semiconductor Process Characterization", EURASIP Journal on Applied Signal Processing, Special Issue on Applied Visual Inspection, Vol. 2002, No. 7, 2002.

Tobin, K.W., Karnowski, T.P., "Revolutionizing Defect Image Management", SPIE's OE Magazine, Vol 1, No. 7, July 2001.

Tobin, K.W., Bingham, P.R., Price, J.R., and Bennett, M.H., "An Application of Image Retrieval Technology to Sidewall Structure Estimation from Top-down SEM Imagery", SCANNING, The Journal of Scanning Microscopies, Vol. 23, No. 2, March / April 2001.

Tobin, K.W., Karnowski, T.P., Lakhani, F., "Technology Considerations for Future Semiconductor Data Management Systems", Semiconductor Fabtech, Vol. 12, ICG Publishing, Ltd., London, England, Spring 2000.

Tobin, K.W., Karnowski, T.P., and Lakhani, F. "Managing Defect Image Databases for Semiconductor Yield Monitoring and Control", Global Semiconductor, Sterling Publications, London, England, February 2000.

Price, J.R., Bingham, P.R., Tobin, K.W., and Karnowski, T.P., "Semiconductor Sidewall Shape Estimation using Top-down CD-SEM Image Retrieval", IEEE/SME/SPIE 6th International Conference on Quality Control by Artificial Vision, Proceedings of the SPIE Vol. 5132, May 2003.
Karnowski, T.P., Tobin, K.W., Ferrell, R.K., Lakhani, F., "Using an Image Retrieval System for Image Data Management", Design, Process Integration, and Diagnostics in IC Manufacturing, Proceedings of the SPIE Vol. 4692, March 2002.

Gleason, S.S., Ferrell, R.K., Karnowski, T.P., Tobin, K.W., "Detection of Semiconductor Defects Using A Novel Fractal Encoding Algorithm", Design, Process Integration, and Diagnostics in IC Manufacturing, Proceedings of the SPIE Vol. 4692, March 2002.

Tobin, K.W., Karnowski, T.P., Arrowood, L.F., and Lakhani, F., "Field Test Results of an Automated Image Retrieval System", 12th Annual IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop, Munich, Germany, April 23-24, 2001.

Tobin, K.W., Karnowski, T.P., Lakhani, F., "Integrated Applications of Inspection Data in the Semiconductor Manufacturing Environment", Metrology-based Control for Micro-manufacturing, Proceedings of the SPIE Vol. 4275, 2001, pp. 31-40.

Tobin, K.W., Karnowski, T.P., Lakhani, F., "The Use of Historical Defect Imagery for Yield Learning", The 11th Annual IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop, Fairmont Copley Plaza Hotel, Boston, MA, September 12-14, 2000.