Software for the design of optical control systems for the manufacture of precision microelectronics equipment

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***Abstract*—This paper describes the main functions and architecture of software control system for inspection equipment of integrated circuit on basis of computer vision. Advantages of the developed architecture are described, as well as its application for image processing of integrated circuit layouts. The system allows identifying effectively defects what it is especially important for Very large-scale integration manufacturing based on submicron technology.**

***Keywords*—image processing, VLSI, automatic layout inspection, control and measurement equipment**

I. Introduction

Contemporary means for designing electronic circuits are aimed at shortening the time required for developing and launching new products into production and reducing the cost of the mass production of digital equipment. This is possible due to computer vision systems, which are a constituent part of the modern technology of the designing and producing integrated circuits (ICs). The transition to submicron design standards and the complication of the actual circuits necessitate the development of novel approaches, methods, and algorithms for the digital processing of IC images taking into account the design and technological limitations (DTLs) in IC manufacturing.

Currently, research in the field of IC manufacturing automation is carried out in the following main directions: developing optoelectronic conversion methods, improving the pattern recognition quality [1] – [7], and designing special inspection methods [1], [8]. The principal problems for increasing the efficiency of designing and manufacturing ICs using the planar technology are as follows [9]:

- development of a unified approach to digital transformations of images of layouts;
- application of the theory of artificial neural networks (NNs) in IC data processing during the development and manufacturing of ICs [10];
- combination of technologies that in a single production cycle make it possible to design, analyze, and redesign ICs, employing both digital processing methods and NNs;
- development of parallel algorithms and means for mapping the corresponding algorithms onto multiprocessor computing structures, including supercomputers.

The equipment of ICs layout inspection is characterized by a large diversity and essentially differs in degree of complexity: from simple visual inspection tools for mass production to the most complex automatic inspection and measurement systems which are used both in R&D of new technologies and devices, as well as in the large-scale production. Automatic inspection and measurement system for defects in semiconductor wafers is already used in microelectronics [11]. Special systems for realization of critical technologies in microelectronics and precise engineering are foundation for development and further growth of modern technology.

Modern means of developing ICs are aimed at reducing time for mastering and launching new products into production, as well as reducing cost of digital equipment during its mass production. Such an opportunity is provided by technological base, including machine (computer) vision systems, which are an integral part of modern technology for the design and production of ICs.

In connection with updating new submicron design standards and increasing complexity of the ICs themselves, it becomes necessary to solve problems of processing, storing, receiving and transmitting large amounts of data obtained during lithographic process of ICs design. Original approaches for image processing allow to fully complying with conditions of submicron manufacture of Very large-scale integration (VLSI) and to reduce cost of production. The object of the study is process of critical dimensions inspection on the photomasks and VLSI layouts. The processing consists of image analysis, generating reports based on the previous analysis results, controlling the focusing system, coordinate table and other external devices, as well as synthesis of routines for the automatic operation of control equipment for monitoring of layout critical sizes.

The developed Software Control System (SCS) for equipment of ICs layout inspection is based on machine vision and provides the following functions: image preprocessing taking into account design and technological constraints; image processing and analysis with support for third-party video camera equipment; image analysis to control design and technological constraints; storage and access to data with the ability to import and export data in various formats; program synthesis for automatic operation; management of third-party mechanisms; data visualization. The main analogs of the SCS are the Olympus MicroSuite FIVE software systems from Olympus Corporation (Japan) and NIS-Elements Microscope Imaging Software from Nikon Instruments Inc. (USA). Analogs of installations for monitoring critical dimensions and their approximate cost: LEICA LWM 250 UV – 4.8 million dollars, KLA Tencor IPRO4 – 5 million dollars.

II. SCS Architecture

The developed architecture of the SCS is shown on Fig. 1. The work of the SCS is carried out as follows:

1) Initialization of user work by issuing control actions to the control system (by the user interface or loading the configuration for automatic operation).
2) Transformation of control commands, if necessary.
3) Receiving data from video camera using the appropriate SDK, convert data for processing.
4) Processing and analysis of data by appropriate subsystems.
5) Transmission of video stream and analysis results in the control system, if necessary, format conversion.
6) Development of control actions by the decision-making subsystem (decision based on the received commands, video stream and analysis results).
7) Transferring of data at the control process to the virtual data model.
8) Signal transmission when changes the state of the model from the virtual data model to the graphical user interface.
9) Request the required data graphical user interface from the virtual data model and retrieving them.
10) Transmission commands of control to equipment by the decision-making subsystem through the appropriate next path (interface, the mechanism control system and the corresponding Software Development Kit (SDK)).
11) Save the results of control in the DB.

III. Image processing

The SCS includes implementation of main function by special systems and subsystems: an image processing and analysis system, including a video camera subsystem for preparing data for use; a control system for functional linking of other systems and subsystems; the mechanism control system for generating unit control commands; graphic user interface for the user to control the functioning; subsystem of interaction with the DB for storing the results of inspection; a subsystem for control program generation (description preparation of the configurations of operation used in the automatic mode of operation). In addition, each of the systems must be implemented with a sufficiently high level of abstraction to ensure uniform operation when using different video equipment and control equipment. So when choosing an design pattern for software package, the following criteria were used: modularity; openness; configurability; separation of graphical user interface and functionality. The most convenient design pattern based on the listed before criteria is MVC (Model-View-Controller). MVC pattern with some modifications allows to take into account mentioned above criteria and requirements to the architecture of the SCS: the control system must be able to receive commands from several sources – an interface for receiving control commands is added for converting general view commands (meta-commands) into specific commands for such equipment; the control system must be able to receive a video stream from several sources – an interface for receiving video data is added, which converts various data formats to a single format an interface for receiving control commands is added for converting general view commands (meta-commands) into specific commands for such equipment, the virtual data model that stores a description of the state of the parameter control process is implemented. The main part of SCS is the image processing subsystem that implements both basic and special image processing algorithms The basic ones are : Contrast Correction; Gamma Correction; Invertion; Laplace Filtration; Mean Filtration; Median Filtration; Morphological Closing; Morphological Dilatation; Morphological Erosion; Morphological Opening; Threshold Binarization [2] – [4], [12] – [14]. The special ones include preprocessing, autofocus and analysis algorithms. The preprocessing algorithms are:

- algorithms of preliminary processing of images of layers of VLSI taking into account DTLs;
- algorithms for increasing the informativeness of images of layers of semiconductor chips, taking

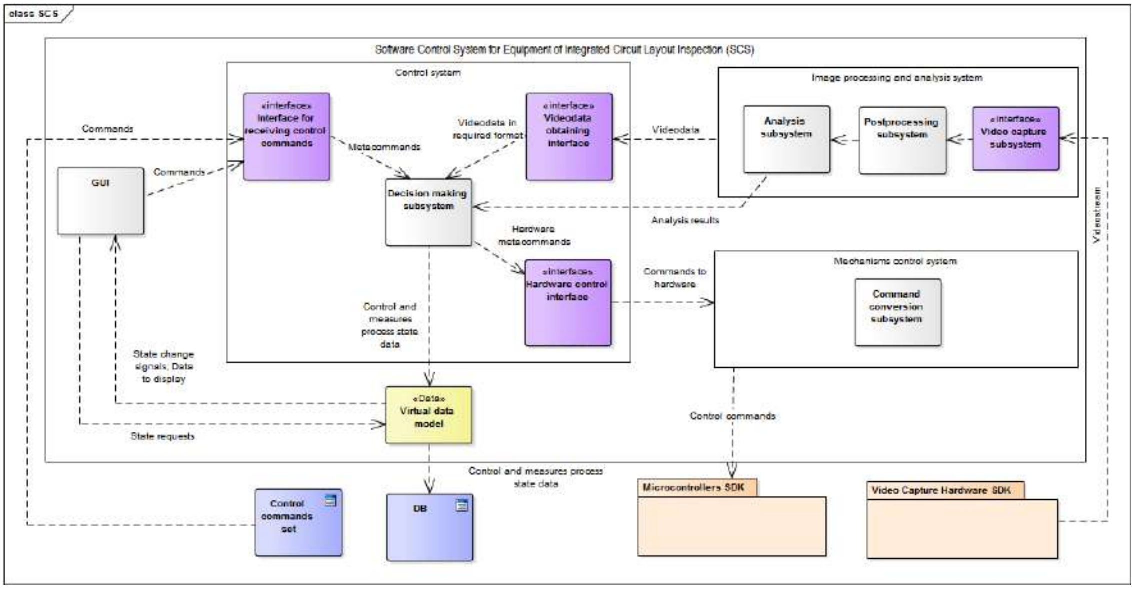

Figure 1. Architecture of the SCS

into account DTLs, based on combining objects of interest from several copies of the chip;

- algorithms of semantic filtering of images taking into account DTLs, based on the use of descriptors of the shape of the image segments: the total area of the segment, the geometric center of the segment, the length of the main diagonal of the segment, the dimensions of the approximant rectangle for the segment;
- an algorithm for preprocessing images taking into account DTLs based on soft morphology, conditional erosion and dilatation;
- algorithms of stitching images taking into account DTLs;
- algorithm for improving images taking into account DTLs, which allows you to align the heterogeneity of lighting of individual frames and brightness differences at their border.

The autofocus algorithms are:

- the algorithm for estimating the sharpness function in which several different criteria are quantied on specific series of images;
- the algorithm of continuous automatic determination of focal length for continuous determination of the correct focal length for the survey system from images of the VLSI topology;
- the lgorithm for determining the unevenness of illumination based on the analysis of the edge of the topology. According to this algorithm, it is supposed to set the direction of the scanning line on the image, along which the edge analysis is performed.

The analysis algorithms do:

- alignment and orientation – binding of the reference system and the coordinate system of the object to the coordinate system of the installation;
- control and measurement of dimensions – launch of algorithms for control and measurement of dimensions;
- automatic measurement – launch of algorithms for automatic measurement of dimensions;
- determination of the size of elements - the launch of algorithms for determining the size of the image;
- creation of a control and measurement program for automatic mode - the formation of a list of control effects with the appropriate parameters and their saving as a file or record in the database.

The functioning of the system is carried out according to the generalized algorithm, the steps of which are given below [15] - [19].

Step 1. Loading operation parameters from the command source ICommandSource.

Step 2. Loading dynamic libraries.

Step 3. Preparation of the algorithms' implementations required for processing.

Step 4 If the images in the IFrameSource are still available, then go to step 5, otherwise go to step 10.

Step 5. Loading image from source.

Step 6. Image processing with the selected algorithm / algorithms.

Step 7. Analysis of the processed image.

Step 8. Saving the analysis result to the IProcessingResult Storage result storage.

Step 9. Go to step 4.

Step 10. Completion of work. As noted earlier, the software module for image processing and analysis, almost all elements of the SCS should be a set of dynamically loaded libraries containing supported functions.

Conclusion

The general architecture of program complex for control of equipment for monitoring of critical size based on machine vision systems has been developed, which allows working with big input data and easily adapted to specific equipment. In this paper, the requirements and the structure of the SCS are described. technology allows identifying effectively defects that is especially important for software engineering for equipment of critical sizes inspection of VLSI manufacturing based on submicron technology. The developed software provides the following functions:

- image preprocessing taking into account design and technological restrictions;
- image processing and analysis with support of different video equipment;
- image analysis for inspections of manufacturing operations;
- storage and access to data with the ability to import and export data in various formats;
- synthesis of the program for automatic operation mode;
- control of different mechanisms;
- data visualization.

The architecture of the software system was developed, providing possibility of flexible adjustment of general algorithm of image processing and analysis. The user can independently compose chains of simple algorithms to obtain more complex ones. It is also possible to connect external routines. The operation parameters and automatic processing programs are stored in the database. The software is used in production of competitive precision equipment for VLSI manufacturing what determines its practical importance: for automatic photometry with precision laser focusing system; for automated microsize inspection system; for mask pattern coordinates measurement system, equipment for mask pattern generation and inspection. A significant advantage of equipment of the controlled of SCS and developed by JSC Planar for the production of VLSI over foreign counterparts is that it is designed on a single design and technological base, realizing full hardware, software and metrological compatibility of the entire set of installations operating in a single technological cycle for Embodiments in silicon of critical technologies of the microelectronic industry.

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Программная платформа для проектирования систем оптического контроля изготовления прецизионного оборудования микроэлектроники

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При реализации программного комплекса была разработана архитектура, обеспечивающая возможность гибкой настройки общего алгоритма обработки и анализа изображений.

Отличительной особенностью архитектуры программной платформы и используемых алгоритмов является обеспечение измерения с автофокусировкой для повышения повторяемости и точности контроля и возможности гибкой настройки общего алгоритма обработки и анализа изображений, включая распараллеливание.

Программная платформа применяется при производстве конкурентоспособного прецизионного оборудования для изготовления высокоточных оригиналов топологий изделий электронной техники и обеспечивает определение неровности края на всем участке измерений и контроль критических размеров полупроводниковых пластин СБИС с поддержкой минимальных элементов размером 350 нм и повторяемостью не хуже 2 нм.

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