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LithoWorks PEB^{tm}

Software Requirements Specification

1. Introduction

Last Modified:	Initial SRS: T. Zavecz 3/19/03
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Version No.	1.0
Description:	A stand-alone analysis tool for Post-Exposure Bake optimization with respect to Critical Dimension (CD) uniformity.

1.1 Product Scope

Dimensional spreads across the wafer during each lithographic imaging step are most strongly controlled by the speed and uniformity of the post-exposure bake (PEB). During the PEB a thermal dose is delivered to latent acid image of the exposure to drive the deblocking reaction that changes the solubility of the resist in the develop step.

Device critical geometries are rapidly approaching 70 nanometer (nm) node with tolerances of about 2 nm, 3 sigma variation about the feature size. Since the sensitivity of deep ultraviolet (DUV) resists to temperature variation during the PEB range around 3 nm/^{o}C, it is critically important that uniformity of the bake cycle be closely characterized, controlled and monitored during production.

LithoWorks PEB™ provides tools to characterize, model and control the uniformity of critical feature dimensional variation arising from the PEB process step. LithoWorks PEB is capable of gathering data from several thermal mapping products such as the OnWafer and SensArray temperature monitors. Critical dimension (CD) data are also gathered from measurements taken by many commercial sources including CD-SEM' s, Scatterometry, Ellipsometric and Electrical Linewidth Measurement (ELM) tools. Thermal and CD data are then convolved using models and SLS proprietary analyses to characterize the PEB cycle and set it' s control variables to minimize variations across the wafer.

1.2 Perspective

The LithoWorks© product suite provides tools for the analysis, control and design of the semiconductor lithographic process. Each module can be used separately or in conjunction with others; sharing a common interface, design and feel for the user. LithoWorks PEB© is one offering of this suite of simple to implement data analysis, modeling and visualization tools.

LithoWorks provides an open system of access and versatility for the user. Any form of metrology data can be easily imported into LithoWorks. Data is stored in Microsoft Excel© worksheets for easy access and customization. Analysis is conducted using the unique object-oriented lot models of SLS Inc.

LithoWorks PW provides process centering within the exposure-dose and focus process windows. LithoWorks PEB is used to minimize process variation of critical dimensions within the window.

1.3 The Customer

LithoWorks PEB provides valuable information, process optimization and equipment characterization and setup tools for the lithography, track, photoresist process, and exposure tool engineer.

2. Description of the product

2.1 Objectives

LithoWorks PEB uniquely provides tools to setup and control process variation and therefore maximize the number of highly functional

?? Provide a tool-set for the characterization and

2.2 Supporting Functions

?? Data import from any industry standard vendor format
?? Data conversion into a LithoWorks standard format for storage.
?? Tools for specifying exposure and focus layout of the raw data focus-exposure matrix.
?? Tools for manual specification of critical feature target and threshold size.

2.3 Background

Process "centering", as addressed by the LithoWorks PW product, focuses semiconductor manufacturing at a point that guarantees that the distribution of critical feature dimensions is properly centered within the specification window of the device design as shown in the top half of Figure 1. Use of LithoWorks PW guarantees the maximum possible number of devices will yield functional integrated circuits for any process state.

Critical feature dimensions of each integrated circuit device must be both tightly centered about the optimum device size and uniformly distributed within the circuit and across the entire silicon wafer. Uniformity not only guarantees high functional

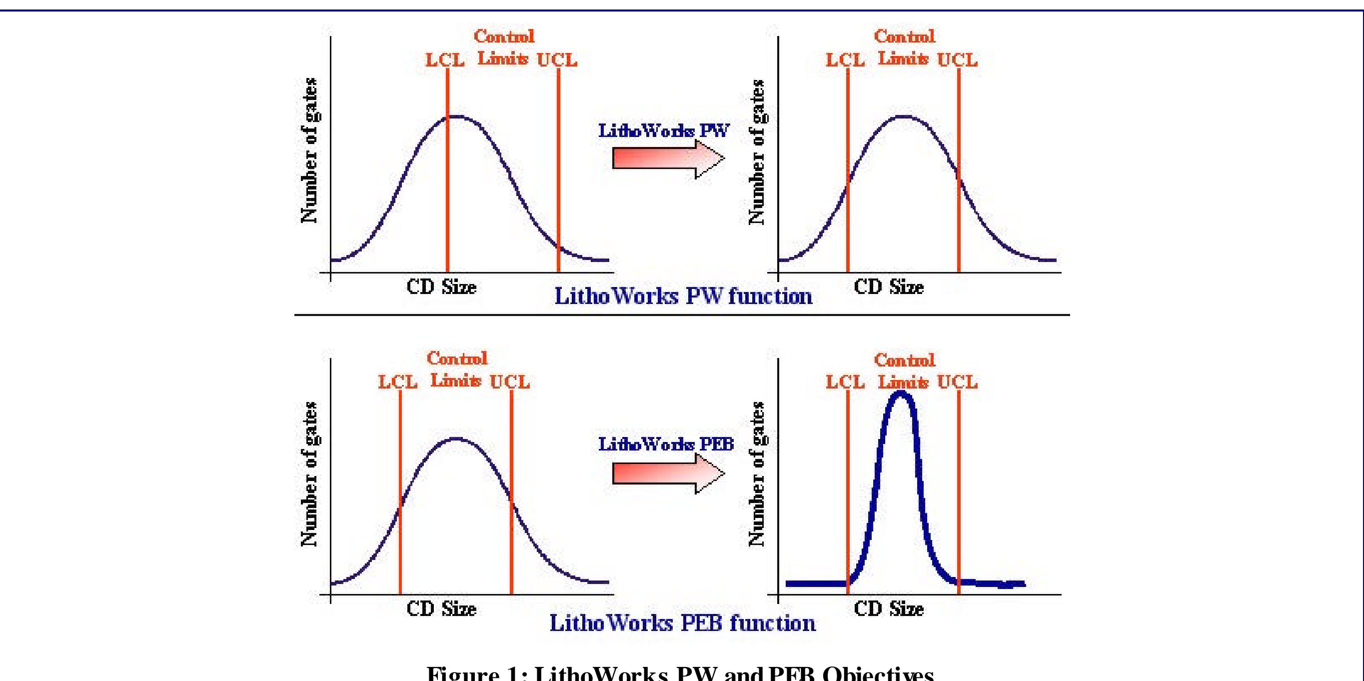

Figure 1: LithoWorks PW and PEB Objectives

Top: LithoWorks PW is used to center the production process within the design control-limits of the process
Bottom: LithoWorks PEB improves the distribution of high-performance devices within the process.

yield but also tightens the process spread about the design point of the integrated circuit. Devices nearest the design point exhibit improved performance, such as faster access and internal clock speeds, garnish higher sale prices and provide improved profit margins for the manufacturer. As shown in the lower half of Figure 1, LithoWorks PEB is used to tighten the process spread and therefore increase both the yield and the number of devices functional at optimum design performance levels.

Dimensional uniformity across each exposure field is directly related to the stability and setup of the exposure tool. Variation of the one hundred or more aerial images repetitively exposed across the wafer is regulated by the uniformity of each focus point and actual dose imparted to the photoresist to define each latent photo-acid image. Exposure uniformity is therefore

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limited by the exposure tool vendor' s skill in tool design and service in the field. This level of uniformity will be the optimum that the process can hope to achieve. Process variation can only degrade dimensional uniformity from this ideal artifact.

Process variation across the wafer is the greatest contributor to feature size variation. Variation enters the image during the injection of the thermal dose required to drive the latent acid image to the deblocking reaction that increases the solubility of the photoresist in the final conformal-mask develop step. This thermal dose is imparted during the post-exposure bake (PEB) step and perturbs the latent image size by approximately 3 nm for each degree centigrade of variation from uniformity.

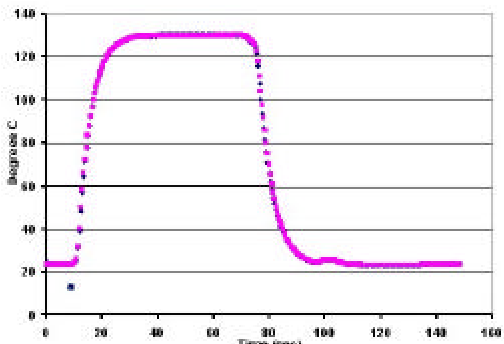

Figure 2: PEB thermal cycle

The PEB cycle incorporates a rapid ramping of the wafer from room temperature to approximately 130C for 60 to 120 seconds as shown in Figure 2. In some applications the wafer may undergo a double-bake cycle, raising the initial temperature to ten or more degrees above the target temperature for about 1/10 of the cycle and then reducing it to the final bake value. This initial high-bake is an attempt to reduce the effects of the rounding and asymptotic approach of the wafer to its target temperature. The extent of the deblocking reaction is a function of the total time and temperature experienced by the wafer. That is, it is sensitive to the area under the curve shown in Figure 2 as well as the value of the final bake temperature set-point.

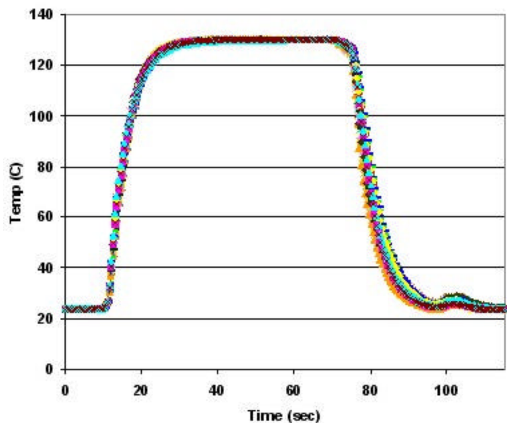

Figure 3: PEB cycle for multiple points across a wafer.

Process variations occur when, as can be seen in Figure 3, the area under this curve varies from location-to- location on the wafer. Variations in the ability of the bake-plate to uniformly transfer heat to the wafer occur from heating-element control response and physical thermal-mass constraints of the bake-plate that differ from wafer center to its edges. The greater the rapidity of thermal diffusion, the less pronounced will be the rounding and settling of the leading edge of the thermal curve. The closer to the center of the wafer, the faster the temperature can stabilize.

This implies that the variations of a 300 mm wafer will be even greater than those experienced by the older, 200 mm wafer fabs. Critical dimensional variation across the new 300 mm wafers will therefore be even more sensitive to bake cycle uniformity because of the larger thermal mass constraints and the enhanced sensitivity of the newest photoresists to these fluctuations in temperature.

LithoWorks PEB™ is designed to provide the process engineer with the needed tools for characterizing and controlling the uniformity of this reaction.

2.4 User Characteristics

User	Characteristics
Process Engineer	Engineers responsible for daily control and stability of the production process benefit greatly from the LithoWorks PEB ability to clearly identify problem process steps and out-of-control equipment. PEB stability is a production function that requires periodic monitoring of the process. The process engineer will use the software to adjust production settings when new chemical batches are introduced. Changes of hot-plate response can be easily measured and recognized. Spatial models and dimensional covariance to temperature mapping can be used for individual tool setup and response matching across the facility.
Design or Device	LithoWorks PEB will be used as part of the design cycle of the device. Photoresist process response to bake cycle rise, fall and steady state can be clearly defined with the modeling and graphic visualization of the

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User	Characteristics
Engineer	toolset. Calculations that tie modeled response elements to each of these control functions are automatically performed by the software.

2.5 Operating Environment

LithoWorks PEB will initially be designed as a stand-alone executable functional under Microsoft Windows NT, 2000 and XP. Data is acquired from any text, binary or Microsoft Excel format file. Metrology is imported from many sources of critical dimension and film thickness measurement tools. Thermal metrology during the bake cycle can be input from commercial wafer-sensors manufactured by SensArray and OnWafer.

Data will enter the system from local disk storage, floppy, CD-rom or from remote nodes located across the Intranet.

2.5.1 License Control

LithoWorks PEB employs software-only license control that keys to the disk and CPU of the system of installation. Transfer of the license from one computer to a second would require the user to return a license-removal code to SLS confirming removal of the software. Updates for demonstration or permanent licenses are delivered using telephone, email or any other textual means.

LithoWorks PEB supports only single-user licenses.

2.6 Operational Modes

LithoWorks PEB is a user-interactive application. The user is required to tune and guide analysis decisions that will influence the size of the process window.

The product image can be initiated as a stand-alone application from the user' s "Start" menu or by sequence calling from a program external to the computer using windows-standard function calling conversions.

Data is stored in Microsoft Excel© workbooks. Output can be printed or cut/pasted into other windows applications.

2.7 Data Import Types

?? CD-sem
?? Electrical Linewidth Measurement
?? KLA Tencor ProData and ProLith formats.
?? Optical metrology tools
?? Ellipsometric and scatter based metrology tools.
?? Thermal sensors.

3. User Interface

The interface is a windows compatible point-and-click graphic interface. Data is stored in a hierarchical object model that allows both thermal modeled constants and spatial sensitivity of the critical feature sizes to be analyzed.

Feature target and size limits are specified in the Data Setup window. This window is accessed from a button-menu item.

A user-options interface will be provided for custom setting of:

?? The default data import format
?? Data directory location
?? Graph colors

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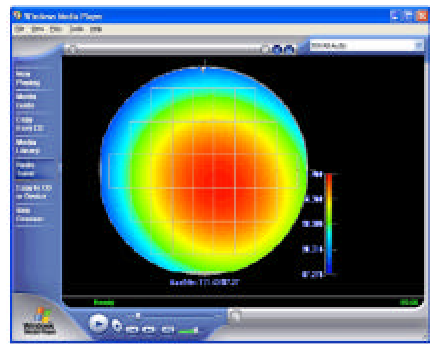
4. Features

4.1 Graphics and Analyses

Thermal Graphics or Analysis	Function
Spatial thermal analysis	An XY graph of temperature vs time is used for time-slice selection. Contour plots of temperature distribution as a function of wafer position and resulting statistics can be displayed. This analysis visualizes thermal uniformity of across the wafer for any time slice. Problems in control circuitry, heat transfer and roll-off can be seen and quantified.
Thermal response curve.	Model thermal transfer variables such as slope, roll-off and arrhenius area for all segments of the heating curve using: $T=(T_{initial} - T^*) \exp(-time/?) + T^*$ Where Tinitial is the start temperature and T8 is high equilibrium. ??is the rise/fall heat constant.
Contour Gallery	N x M array of contours from each selected slice in time.
Contour Movie	Movie version of the contour gallery. Select any time-segment and run wafer maps to generate a video of move functions. 

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Thermal Graphics or Analysis	Function
Modeled element spatial contours.	Plot area contours of thermal variables such as the arrhenius area, rise/fall constants, time at temperature etc. against position on the wafer. These constants can then be correlated against CD variations to examine dependencies and tuning elements. Modeled element variations for both thermal and dimensional data sets provide the opportunity to characterize feature variation and the influence that each PEB element has in its generation.

4.2 Coefficients and Variables

The following coefficients and variables will be calculated and derived from the non-linear thermal and dimensional uniformity models of the wafer. Studies of the behavior of each variable will provide critical information on the most critical control elements for comparison characterization and process tuning.

Coefficients and Variables	
Rise time constant	Computed for each sensor location provides information on heat transfer rates during heating for every critical spatial point
Fall time constant	Provides information on heat removal across the wafer
Time at bake temperature	Study how time varies at each point when at critical temperature.
Time-temp area	Arrheneous values for the thermal PEB dose calculation.
To= start-time for each curve	The start time for each curve is in fact not constant for every point on the wafer. A study of the spatial distribution of these items against critical dimensions and profiles yields information on cooling and heating resistance.

Feature dimensions and profiles can be derived for each wafer using ellipsometer and scatterometer tools. These full-feature profiles define the imaging quality of the process.

A final set of tools embodied by XY variables plots and a response covariance matrix complete the analysis set needed for process optimization.

4.3 Feature Summary

The ability of LithoWorks PEB to gather in both thermal and dimensional data provides the engineer with an efficient tool set for tuning the imaging process. Many of the variables involved in PEB are not understood in the semiconductor process of today. Thermal drive times are known contributors to the variations of the process. However, what about the fine structure of these drives. Roll off, uniformity, heating stability and cooling uniformity all contribute to the chemical reaction but the relative importance of each element is not well understood.

Comparisons of raw-data distributions to thermal signatures are not sufficient since they are frequently masked by the variations seen from across photomask and field-exposure variations. LithoWorks PEB provides the tool set to remove these predictable, systematic feature size errors and clearly display the wafer-scale contributions of each.

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Solution of the non-linear equations involved in the heat transfer and chemical reactions allow LithoWorks PEB to derive the coefficients encountered using production data in the facility. The selection of values for these coefficients is critical since commercial process simulation programs such as Prolith and Solid C can then utilize them in tuning extrapolations.

Simulators excel when used in an initial process setup. However they concentrate on one single, theoretical spatial location in the process and do not model variations across the wafer due to exposure or bake. LithoWorks PEB can employ empirical models to characterize thermal uniformity by temperature and any of the control variables that characterize the bake cycle.

The cross interaction of LithoWorks PEB and the commercial process simulators provide a complete tool set for process setup, tool characterization and stability maintenance during daily production.

5. User Documentation

Documentation is provided as an adobe acrobat “pdf” file on CD-rom.

A hard-copy user manual is provided with every license.

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