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CAD – less Blind Navigation in Focused Ion Beam System

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Introduction

Traditional approaches to navigation in FIB Circuit Edit (CE) include blind CAD navigation based on GDSII data from the manufacturer [1] and navigation assisted by the in-situ Optical Microscope (OM), either coaxial with the ion beam or not [2]. These two approaches are difficult to apply in security audit and reverse engineering fields, where CAD data is unavailable and objects of interest are either too small, or located in an array that is too dense for imaging by in-situ OM. New methodology, developed to address this navigational problem, is based on establishing a chip-specific system of coordinates and determination of precise locations of the objects of interest within the device. The work was performed on a **Vectra 986** FIB system from FEI Company and a proprietary system for optical scanning of semiconductor devices.

Methods and Results

Study of the Device
Initial study of a device with unknown details of internal functionality requires acquisition of the complete device image under a high-magnification optical microscope (OM). While OM images cannot reveal all the details about internal structure of modern ULSI devices, most building blocks of digital devices, such as ROM, RAM, EEPROM, CPU core, and many other units can be identified.

Constructing a high-resolution optical image of the device begins by acquiring, in automated fashion, multiple digital images under the OM. Acquired images are then correlated, to compensate for the inaccuracies of the OM stage, and assembled into the single image file (Fig. 1, as an example) of the entire device. The image is studied by various manual and automated techniques and locations of nodes of interest for contacting are identified. It is often possible to identify locations of the node of interest, even if the node itself is not clearly resolved by the optical microscope. It should be mentioned that sometimes identification of the nodes for contacting requires more advanced techniques, such as full device delayering and automated SEM imaging, however discussion of these techniques are beyond the scope of this publication.

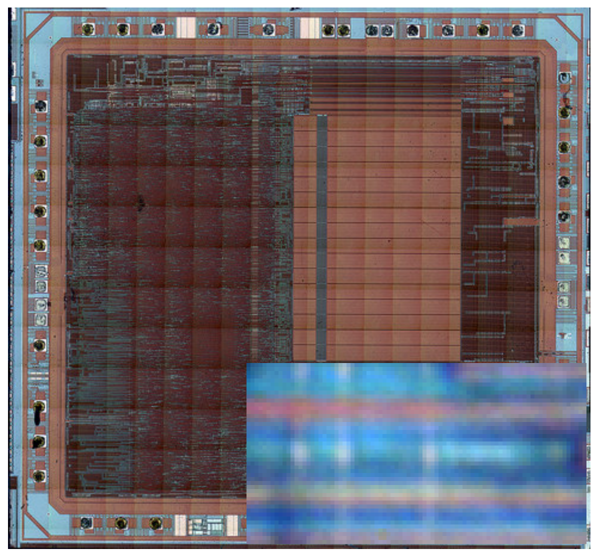

Figure 1: Image file example of an off-the-shelf device. Actual image is larger then 1GB and contains sufficient details to identify functional blocks of the device and (zoom-on in right bottom corner) even locate nodes of interest for contacting.

Identification of Reference Objects
In addition to the nodes of interest for FIB contacting, reference objects for conversion of the coordinate systems, and locations of such objects, must be identified on the device

At least three, but preferably four, reference objects are needed to facilitate conversion of the locations of nodes of interest from the OM image file of the device to chip-specific coordinates in the FIB. Highest possible accuracy coordinate – based navigation will be assured if chosen objects conform to the specific set of requirements. The most critical requirement for reference objects is that they must be clearly visible and well resolved under the optical microscope and in the FIB system. It is also critical for that reference objects surround location(s) of the target nodes.

Most convenient and frequently used reference objects are stepper alignment marks, however any other reference objects conforming to the described criteria would be acceptable.

Bitmap Coordinates

Since the OM image of the device is a rectangular array of pixels (bitmap), the X and Y pixel numbers naturally become the Cartesian coordinates of any location within the image.

Chip Navigation in a FIB system.

After the chip is aligned on the sample holder and loaded into the FIB system with laser interferometer stage, stage coordinates (**X's** and **Y's)** of the reference objects can be determined and correlated with the bitmap coordinates. To conduct this operation in an automated manner, we enter bitmap coordinates of the reference objects as "User" coordinates into the "Lock" dialogue of the FIB software. After at least three reference objects are located on the FIB stage, direct navigation by bitmap coordinates is possible to any location within the area outlined by the reference objects. Typical accuracy of navigation by bitmap coordinates is in the single micrometer range and is limited mainly by the cumulative errors of the OM scanning stage and by coordinate conversion.

Precision Localisation of Node Coordinates

To determine coordinates of the nodes with the accuracy sufficient for blind navigation on modern ULSI devices, the area containing the node of interest is deprocessed by the FIB on a sacrificial device. Once the node of interest is exposed, "User" coordinates of the node are identified by precision measurement with the laser stage of the FIB system. Since "User" coordinates are referenced to the device itself, these coordinates are portable between devices and FIB systems and can be used for making contacts to the node of interest on multiple devices.

Enhancements of Navigational Accuracy

FIB software establishes a relationship between the "User" system of coordinates and the physical device, and accuracy of this relation is inherently dependent on the accuracy of locating reference objects within the device. While utilizing edges and corners of the reference objects seems natural for the operator, it is common that edges of the features printed on integrated circuit are most strongly affected by the manufacturing process variations. In case of the planarized devices, reference objects should be deprocessed to become visible in a FIB, and edges of the objects are frequently damaged during the deprocessing.

Centers of the objects and groups of objects are, however, much less susceptible to the position variations. Automated location of centers of the reference objects by use of computer-based pattern recognition has been proposed [3] in the past, but it is not commercially available to the most of FIB users. We utilized a manual technique, which was found effective in improving accuracy of locating reference objects (Fig. 2).

In this technique [4] a group of repair boxes is arranged on the screen to outline the reference object. Two additional repair boxes with zero width are placed in the center of the reference object and the whole group of boxes is saved as a repair file for future use. During the location process the whole group of repair boxes is aligned to overlay reference object symmetrically, thus automatically indicating a precise position of the center of the pattern.

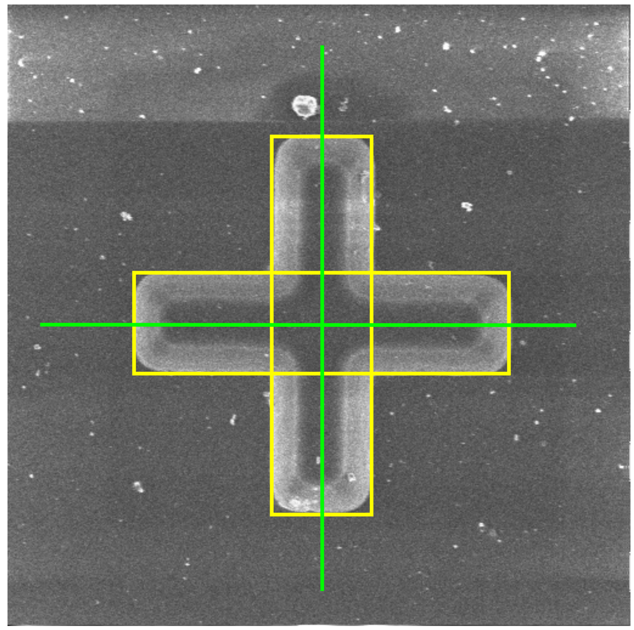

Figure 2: Box pattern overlay, aligned symmetrically with the reference object. Interception point of two boxes with zero width indicates location of the center of the reference, allowing repeatable lock even on damaged reference objects.

Residual errors are inherent to any positioning system, and practically achievable accuracy of blind navigation with the laser stage of Vectra system did not exceed ± 150 nm in our experience.

To overcome residual positioning error problem and successfully contact nodes in devices with linewidth below 350 nm by blind coordinate navigation, we utilized rectangular repair boxes instead of traditional squares. In the arrangement illustrated by Fig. 3 there are horizontal metal lines located above the vertical line targeted for contacting. Relatively small navigational errors in Y direction could cause a short between the nodes, while even significant X direction errors would not affect results of the contacting. With the available window between the horizontal lines of 0.5 µm, the error budget of ± 150 nm of stage positioning leaves only 200 nm of space available for via height, if successful contacting is to be guaranteed. With addition of the safety margin, a repair box with dimensions of 150 nm X 600 nm provides assurance that the contact will be successful.

Figure 3: Contacting deeper buried vertical node by rectangular repair box. Safety margin above and below the box accommodates residual positioning errors in Y direction to avoid accidental short with the above-the-node horizontal lines.

Conclusions

We developed and practically utilized methodology for reliable coordinate-based navigation on integrated semiconductor devices without CAD data from the manufacturers. This method utilizes a proprietary system for scanning integrated circuits under the optical microscope and standard FIB equipment. Auxiliary techniques allowing enhancement of navigational accuracy, developed for this application, are equally applicable to the general navigation procedures during generic FIB circuit modification (Circuit Edit).

References

[1] FEI Company: “Vectra 986+ Focused Ion Beam System User’s Guide”, pp 244-260

[2] J.P.Wolpert and R.Lee, "In-situ use of an Optical Microscope for FIB Microsurgery of Planarized Devices *Proc 25th International Symposium for Testing and Failure Analysis,* Santa Clara, CA, November 1999, pp. 127-133.

[3] Ray, V. *et al*, “Small Via High Aspect Ratio Circuit Edit,” *Proc 29th International Symposium for Testing and Failure Analysis,* Santa Clara, CA, November 2003, pp. 355-361.

[4] **Private communication**. Mr. Alex Krechmer, from FEI Company, Peabody, MA, is credited for the idea of box pattern overlay.