

Multiple Column High-Throughput E-Beam Inspection (EBI)

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ABSTRACT

Single-column e-beam systems are used in production for the detection of electrical defects, but are too slow to be used for the detection of small physical defects, and can't meet future inspection requirements. This paper presents a multiple-column e-beam technology for high throughput wafer inspection.

Multibeam has developed all-electrostatic columns for high-resolution imaging. The elimination of magnetic coils enables the columns to be small; e-beam deflection is faster in the absence of magnetic hysteresis. Multiple miniature-columns are assembled in an array. An array of 100 columns covers the entire surface of a 300mm wafer, affording simultaneous cross-wafer sampling. Column performance simulations and system architecture are presented. Also provided are examples of high throughput, more efficient, multiple-column wafer inspection.

Keywords: Wafer Inspection, E-Beam, EBI, Multibeam, Small Defects, Multiple Columns, High Throughput, Inspection Efficiency

1. INTRODUCTION

With each new semiconductor technology node, smaller critical dimensions and defects drive the demand for higher resolution in wafer defect inspection. While 32nm and 28nm node devices are being produced, small physical defects are impossible to detect with optical inspection due to resolution limits. Industry is increasingly turning to electron-beam inspection (EBI).

Today's EBI systems are very similar to scanning electron microscopes (SEM). While they offer high resolution, it takes many hours to sample one 300mm wafer. EBI throughput continues to plummet as smaller beam sizes are needed to detect ever-smaller defects with each new process generation.

Single-column systems are severely limited in throughput. As pixel sizes shrink to detect smaller defects, fewer electrons are collected per pixel resulting in greater shot noise as well as lower throughput. Higher electron current could boost throughput. But in a conventional system, the electron current is limited by electron-electron interaction in the column. The broadened beam loses high resolution.

A new way must be found to meet upcoming requirements in high-throughput wafer defect inspection.

2. E-BEAM INSPECTION (EBI)

In EBI, a beam of electrons is focused on a small spot on the wafer to be inspected; and an image is formed by scanning the e-beam over the area and collecting secondary and/or backscattered electrons with an electron detector. The image data is then processed to identify defects that may impact device yield.

EBI today is widely used in production for electrical defect detection using voltage contrast techniques. EBI can detect electrical defects with a high rate of success at high throughput (Figure 1), whereas optical inspection is totally incapable of this. Optical detection is also incapable of detecting very small physical defects due to optical resolution limits.

While EBI acting like SEM can detect small physical defects, it is too slow for use in production as all EBI systems in use today employ a single column with a single electron beam. And the inspection time worsens with each technology node because smaller defects requires smaller pixels to detect, and the beam current must be reduced to produce small pixels, further slowing throughput. In EBI, high throughput is at odds with high resolution.

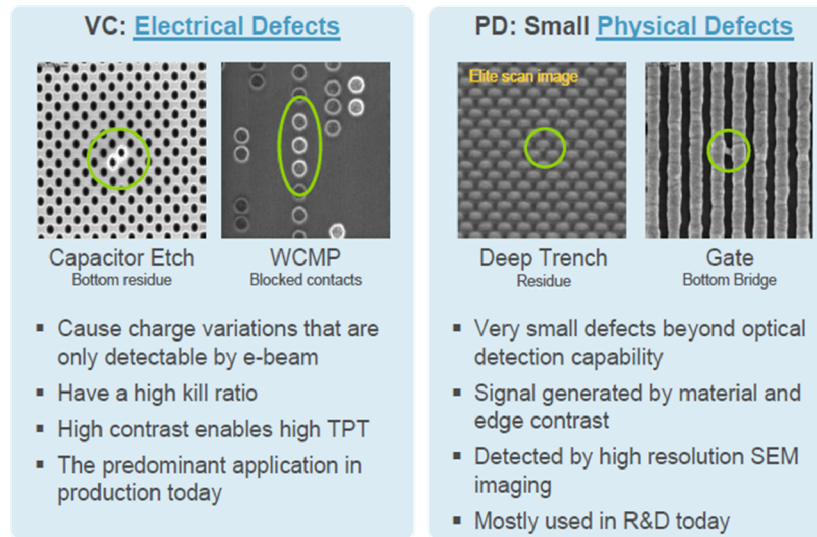


Figure 1: E-Beam Inspection, from Ref [1], courtesy of Wolf Staud, Ido Holcman, Vladislav Kudriashov, Juergen Frosien, "Wafer [Mask] Inspection for Sub-20nm Patterning", FCMN, Grenoble, May 2011; p. 11.

3. MULTIPLE MINI-COLUMN APPROACH

The solution to higher throughput is multiple columns. In a single-column inspection system, if beam current is increased, electron-electron repulsion can lower the resolution due to beam broadening. Multiple columns overcome the conflict between resolution and throughput. While each beam may have a small current for improved resolution, in the aggregate, multiple columns enable much higher total current for faster inspection. By acquiring images in parallel with multiple columns, throughput is significantly increased.

Multibeam Corporation has developed an all-electrostatic column technology and multiple-column architecture. In an all-electrostatic column, there are no magnetic fields. The elimination of the magnetic coil from an otherwise conventional e-beam system design makes the column footprint very small. The mini-column has a diameter of only 22mm. In the absence of magnetic fields and magnetic hysteresis, the e-beam can be deflected at higher speeds. The beam is focused with an electrostatic lens and deflected by electrostatic deflectors.

Below are some examples of wafer defect inspection using Multibeam's miniature electrostatic columns.

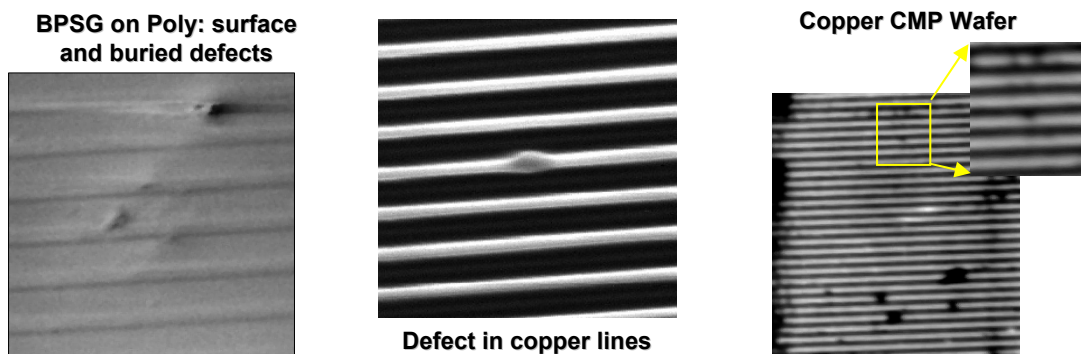


Figure 2: Inspection with early-generation Multibeam electrostatic e-beam columns showing topographic features and small physical defects.

Multiple columns are assembled into a 2D array with approximately 100 columns spanning a 300mm wafer (Figure 3). The column-array is extendable to any wafer size, including 450mm wafers.

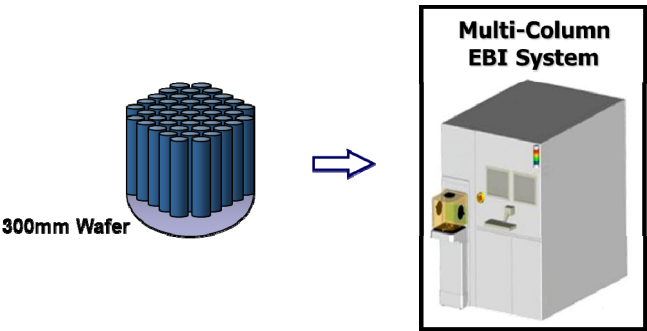


Figure 3: Multiple columns are assembled in an array. A 10-column array increases throughput 10X. A 100-column array spans entire 300mm wafer. The array is scalable for any wafer size, including 450mm.

Each mini-column includes its own electron source, electron detector, and column controller. Each column controller has its own CPU and local data storage. Thus, each mini-column is capable of high-resolution e-beam inspection, acting as an independent SEM.

The mini-column is capable of producing a 12nm spot size (Figure 4). The beam landing energy is adjustable to meet application requirements such as material and aspect ratio. For landing energy of 3 keV, for instance, the mini-column produces a beam with 15 nm size at 21 nA beam current (Table 1). The optimum column operating window is shown in Figure 5.

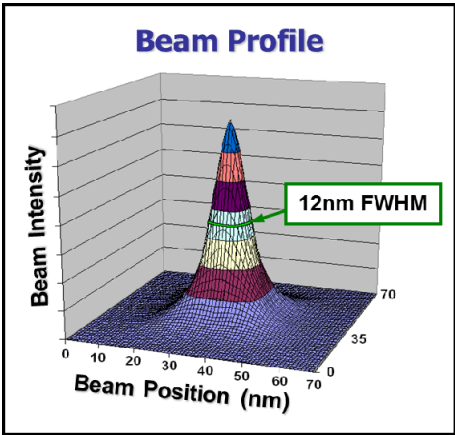


Figure 4: High-resolution beam profile from all-electrostatic mini-column, from Ref [2], Enden D. Liu and Ted Prescop, "Optimization of e-beam landing energy for EBDW", Proc. SPIE 7970, 79701S (2011).

Table 1. Beam Size (nm) vs. Beam Current (nA) and Landing Energy (keV).

		Beam Current (nA)					
		2.4	5.4	9.6	15.0	21.5	29.3
Beam Landing Energy (keV)	5	12	11	11	12	13	15
	3	12	11	12	13	15	19
	2	12	12	14	17	21	28
	1	15	17	20	24	30	38

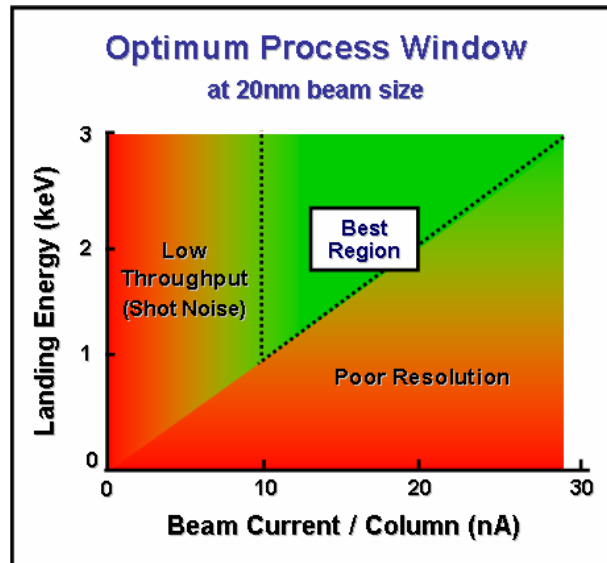


Figure 5: Column Operating Window.

Every column includes an electron detector, positioned between the final focusing lens and the wafer, capable of detecting backscattered electrons, secondary electrons or both, depending on application requirements.

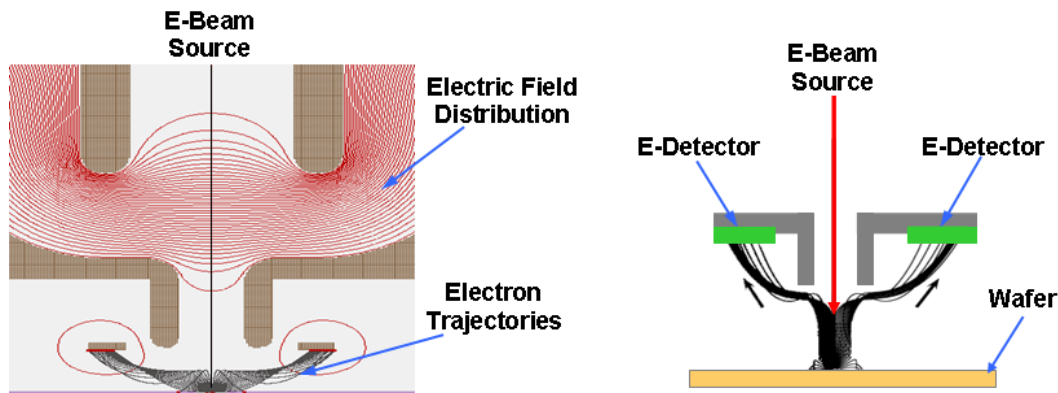


Figure 6: A simulation of the miniature column and detector optics gives rise to the design of highly-efficient column. Each column operates as an independent SEM.

4. MULTIPLE-COLUMN ARCHITECTURE REMOVES DATA RATE BOTTLENECK

Each column in a multi-column array has an identical parallel datapath (Figure 7); about 100 columns cover the entire surface of a 300mm wafer. As the electron beam scans, images from each column are collected by its detector and the image data is transferred to the column controller. Data volume and data rate per column is manageable because each controller has its own microprocessor and local storage; parallel processing with multiple column controllers mitigates the bottleneck.

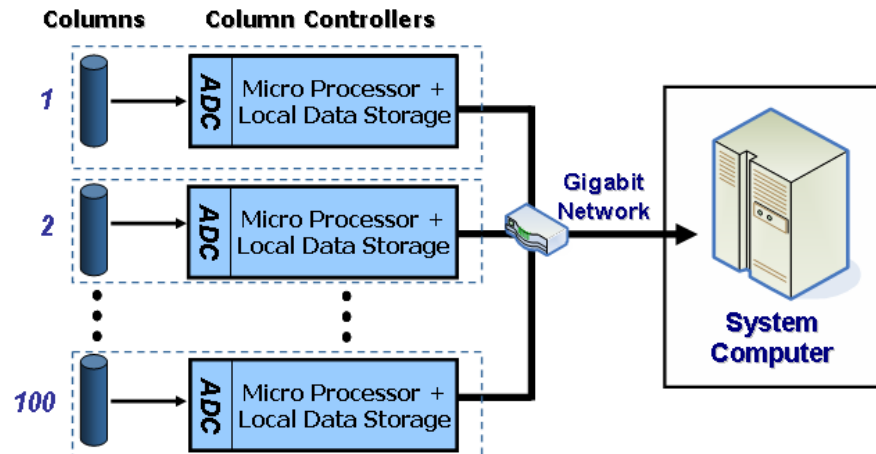


Figure 7: Each column has an identical parallel datapath.

5. PRACTICAL USES OF MULTIPLE COLUMNS

The multiple-column EBI increases not only throughput but also efficiency of inspection. Following are three examples: cross-wafer inspection, faster scanner characterization, and in-line after-etch inspection of contacts.

5.1 Cross-Wafer Inspection

A column spacing of 30x30mm enables 88 columns to be packed above the surface of the wafer. Each column inspects a 30x30mm area of the wafer (Figure 8). The entire wafer is sampled at multiple points simultaneously. The wafer stage moves at low speed and extends only 30mm in x and y directions to cover the area of one grid. Because defects tend to concentrate near the edge of the wafer, multiple columns enable more efficient cross-wafer sampling to garner yield-impacting defect data at the outer regions with design of experiments.

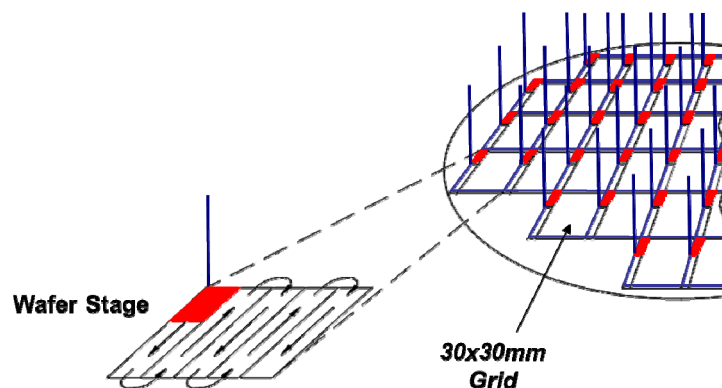


Figure 8: Each e-beam column scans the wafer simultaneously. The column array remains stationary while the stage moves under the e-beam column array.

5.2 Scanner Qualification

For scanner qualification, column spacing is 26mm x 33mm, so each column covers one scan field (Figure 9). The scan field is divided equally into 100 grids with each beam sampling a different one-hundredth of the field. Simultaneous sampling by all the beams enables fast characterization of the scanner and accelerates production ramp.

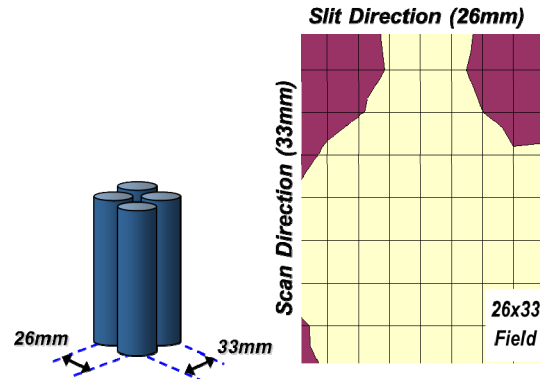


Figure 9: When column spacing equals the reticle field, the multiple-column approach enables faster scanner qualification, accelerating production ramp.

5.3 After-Etch Inspection for Contacts

Multiple-column EBI enables high-throughput in-line inspection of contacts. Figure 10 shows a simplified inline setup for contact inspection following lithography, where after-etch inspection is highlighted. Multiple column controllers make die-to-database comparison in parallel, providing not only defect information at a higher rate but also feedback to database for yield improvement.

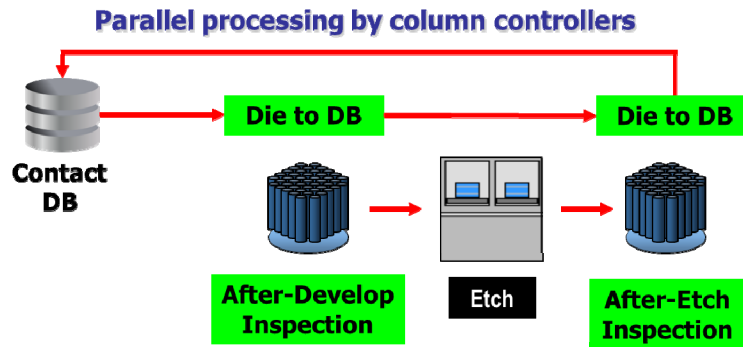


Figure 10. Multiple-column EBI with die-to-database comparison.

6. CONCLUSION

The semiconductor industry needs high throughput electron-beam wafer inspection of sub-20nm physical defects. EBI with multiple non-magnetic columns is a viable solution. These all-electrostatic columns are small in footprint and can be assembled in an array to cover the entire surface of a 300mm wafer. They can detect small defects and provide details of topographical features. The mini-columns offer high resolution and are operated independently and simultaneously within a wide process window. Large data rate, a common concern, can be mitigated with system architecture and parallel processing. In addition to higher rate, multiple columns also improve the efficiency of inspection. Multiple columns enable new applications not practical with today's single-column EBI.

REFERENCES

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