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Semiconductor Technology Challenges in High Volume Manufacturing of Semiconductors

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In this paper we are going to discuss about technical challenges of semiconductor device in high volume manufacturing. We have seen huge DRAM and Flash memory design evolution in decades. In the case of DRAM, there was about ten times of design shrinkage in 15 years, and now we are making 10nm node. In Flash case, there was about ten time of stack layer increase, and now we are expecting nearly 200 hundred stacking layers. Those design shrinkage and 3D stack increase are essentially followed by MI challenges [1].

MI changes are increasing. Especially nondestructive method is necessary in high volume manufacturing environment. We can summarize those challenges in five categories, small defect inspection, high aspect ratio structure analysis, buried defect, locality, and interface characteristics. Less than 10nm defect inspection challenges have been shown in inspection after photo development or etch process as the shape of shallow bottom bridge and small particle. HAR (High Aspect Ratio) structure analysis requires non-destructive bottom defect and vertical profile inspection. Buried defect inspection is also big challenge especially bottom metal and inner void. Local measurement both in 2D and 3D profile is increasingly necessary. Interface characteristic such as crystal/grain size and interface electrical property is a kind of new MI challenges.

There is dilemma of resolution and speed in MI challenges. It means that it is very hard to increase measurement speed of high resolution technique and increase resolution of high speed technique. So we usually use it only in the appropriate application and also means that there is a limit in usage. When we look at the inspection area, there are gaps between high resolution e-Beam inspection and high speed optic inspection. And until now we are still struggling to find the solution to replace the gap. In optical inspection case, there is detection limit of small defect that should be detected on current device. In about ten years, reducing wavelength and increasing light source power, detect resolution of optic technology has been developed from 40s to 10s nm level. However this value is still not enough.

As the complexity of 3D structure on device is increasing, the sensitivity of 3D structure or underneath defect is getting important but still remains as big challenges. Especially as stack layers are increasing and cell on the peripheral structure is developed in VNAND structure, non-destructive way shows its limitation. In high aspect and cell peripheral stacking structure we should have enough sensitivity of trench bending, etch stop condition, cross talking effect caused by stair etch, and alignment of stacked structure. Current 3D measurement technique is not able to satisfy the requirement from newly developed device. As the process technology goes higher, it is necessary to monitor the atomic layer thickness and molecular crystallinity. Particularly, as technologies that make structure with complex layers are introduced, techniques to monitor interfacial properties and electrical properties are also required. Those are usually done by out-of-fab analysis, which mean that out-of-fab analysis technique is definitely moving to in-fab monitoring.

When looking at the overall MI technology development, it has been expanding the scope of the spectrum usage widening to short and long spectral bandwidth. Physical property like crystallinity, underneath structures, chemical bonding, and material resistivity which shows the sensitivity from outside of visible light regions is need to be monitored. So such as short wavelength (UV, X-ray) and long wavelength (IR, THz) may be a solution for monitoring those properties and technology has been developed in that area. Like the previously described technologies, this spectrum application technology should be developed in parallel with the automation technology along with the extension of the scope in high volume manufacturing. Until now we explored fundamental and technical challenges along with the device evolution and what kind of technologies are developed to overcome. From now on we will discuss about what kind of future role MI should cover beyond conventional role.

"From data, information, knowledge, to wisdom", this is the well-known insight about data evolution by professor Ackoff [2]. Change form data to Information means understanding relations and it is statistic-based data processing focused on 'Phenomena'. The information role of MI is process monitoring. It could be process of obtaining statistical information from measured data, use of average and standard deviations to check process health, and process control system with data access and SPC interlock. Change from information to knowledge means understanding patterns and it is knowing rules between process and data and find defect source. The knowledge role of MI is weakness analyzing. Those are: finding risky processes and weaknesses that cause potential defects. Also, complex statistics processing and regression analysis of multiple variables can be used to identify patterns of defectiveness.

Change from knowledge to wisdom means understanding principles and it is forecasting product defectiveness and yield from process data. The wisdom role of MI is quality prediction. For the prediction, it is necessary to analyze various aspects of data sets and extract hidden meaning using AI[3][4]. Also new types of data that has not been used or qualitative information could be key factor. For MI data to be wisdom, MI data should be basement for cognitive prediction and preventive action. To do that, as we mentioned earlier, AI technology and System are essentially necessary. However we need to understand what AI and System should do right things for wisdom.

Here, we discussed about challenges of MI in semiconductor manufacturing. MI has fundamental role of defining process window, finding cause of defectiveness, and monitoring process quality. To overcome MI challenges various spectral rage has been used and the use of spectrum is enlarged for development. Now we are expecting the expansion of MI role. MI data is expanding from information to wisdom. And as wisdom we should understand principles for quality prediction by extracting hidden meaning from AI technology. Finally MI role will expand for cognitive prediction and preventive action in the future.

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