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Invited

Current Status and Future Trend of Analytical Instruments for Failure Analyses in Si Process

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Introduction

Failure analysis plays a very important role in the development of future devices and achievement of high yield in the volume production. Failure analysis, however, is becoming increasingly difficult as analytical instruments are not able to keep up with the level of analysis required, as device dimensions suddenly decrease. A schematic diagram of the current status and future trend of analytical instruments for failure analyses is shown in Fig. 1. The feature size of G-bit level devices is less than 150 nm. As some device failures occur in a portion of the gate or the interconnecting wire, the failure area itself is much smaller than 150 nm. With the continuing reduction of device dimensions, the failure area can be expected to shrink to 1 nm or below in the near future. To study failures of such scale, analytical instruments with high spatial resolution of less than 1 nm, or atomic level for device structure or crystalline defect observation, and high sensitivity of atom or ppq (parts per quadrillion: 10^{-15}) level for composition and contaminants analysis, are urgently required. To satisfy such severe requirements, new concept analytical instruments are needed.

New Analytical Instruments

With the reduction of device dimensions, chemical bond analysis in nm level area is becoming more important in thin film deposition and etching. However, the current level is inadequate, especially in relation to spatial resolution (Fig. 1). The cause is that the creation of a small X-ray beam in XPS is difficult, even if synchrotron radiation beam is used. A new method using an electron beam, which can be minimized to 1 nmϕ, was investigated (TEM-EELS: transmission electron microscope with electron energy loss spectrometer [1], Fig. 2). The chemical bond can be identified by measuring the energy loss when an accelerated electron passes through a sample.

The need to evaluate the electrical characteristics in actual circuits is also increasing as it is difficult to make test elements which have the same electrical characteristics and micro structures in deep submicron devices as in the actual circuits. In this study, a new prober which can inspect a transistor I-V and metal resistivity in actual circuits is investigated (Nano-prober [1], Fig. 3).

Dopant or contaminant analysis requires highly sensitive detection in a small area, such as $(10^{16}/cm^3)/100$ nmϕ, which means the ability to detect 10 atoms. SNMS (sputtered neutral mass spectrometer [1]) in which the focused ion beam for small area analysis and the post ionization using laser beam for highly sensitive detection are coupled, is investigated.

For gas analysis, sensitivity at ppt-ppq level is required. APIMS (atmospheric pressure ionization mass spectrometer) with highly efficient ionization by ion-molecule reaction can detect impurities in gases at the 10 ppq level [1].

For rapid composition analysis, GDS (glow discharge optical emission spectrometer [2]) was developed. A depth profile can be got within 3 minutes, even with a sample exchange.

For 3-dimensional observation of crystalline defect, CT-TEM (computed tomography-TEM) with atomic number contrast imaging, specimen tilting and computed tomography, has been developed [1].

Failure Analysis in G-bit Devices

These new analytical instruments were applied to the analysis of failures in sub-quarter micron devices.

A failure which showed a high interconnect resistivity in DRAM was pinpointed to one contact between the first-level metal wiring and the substrate using the Nano-prober.

This contact had been formed by a CVD-W plug with CVD-TiN and sputtered Ti. Figure 4 shows a cross sectional TEM image and the energy loss line profiles by TEM-EELS at the bottom of the contact. The energy loss in Ti edge indicates the existence of $TiSi_2$, and the small energy shift, indicating TiO_x, was detected above the $TiSi_2$ layer. These results suggest that the cause of the high resistivity is the formation of TiO_x film and oxygen donor comes from the upper region to the $TiSi_2$ layer.

The formation of the TiO_x film can be explained by the presence of titanic acid (TiO_xH_2O). Titanic acid is produced after TiN-deposition from titanium, water (from the cleanroom air) and chlorine (from $TiCl_4$ gas for CVD). The titanic acid absorbs a large amount of water and titanic acid gel ($TiO_x(H_2O)_n$) is produced. In a thermal process after W deposition, the H_2O of the gel moves to the $TiSi_2$ layer through the TiN film, since the W film density is high and the TiN film is porous.

Figure 5 shows a void (bubble) formed in lower BPSG (borophosphosilicate glass) layer after upper BPSG layer annealing. This bubble is formed at gate-gate space on only N^+ layer. The formation mechanism was explained by complicated chemical reactions with As from substrate, F and Cl from etching gases, and P in BPSG.

$$P + 3Cl \rightarrow PCl_3,\quad As + 3F \rightarrow AsF_3,$$
$$AsF_3 + PCl_3 \rightarrow PF_3 + As + 3/2Cl_2,$$
$$4PF_3 + 3SiO_2 \rightarrow 3SiF_4(gas) + products.$$

The diffusion of As from the N^+ layer to the BPSG film was certified using GDS and gaseous components were detected using APIMS.

Acknowledgments

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References

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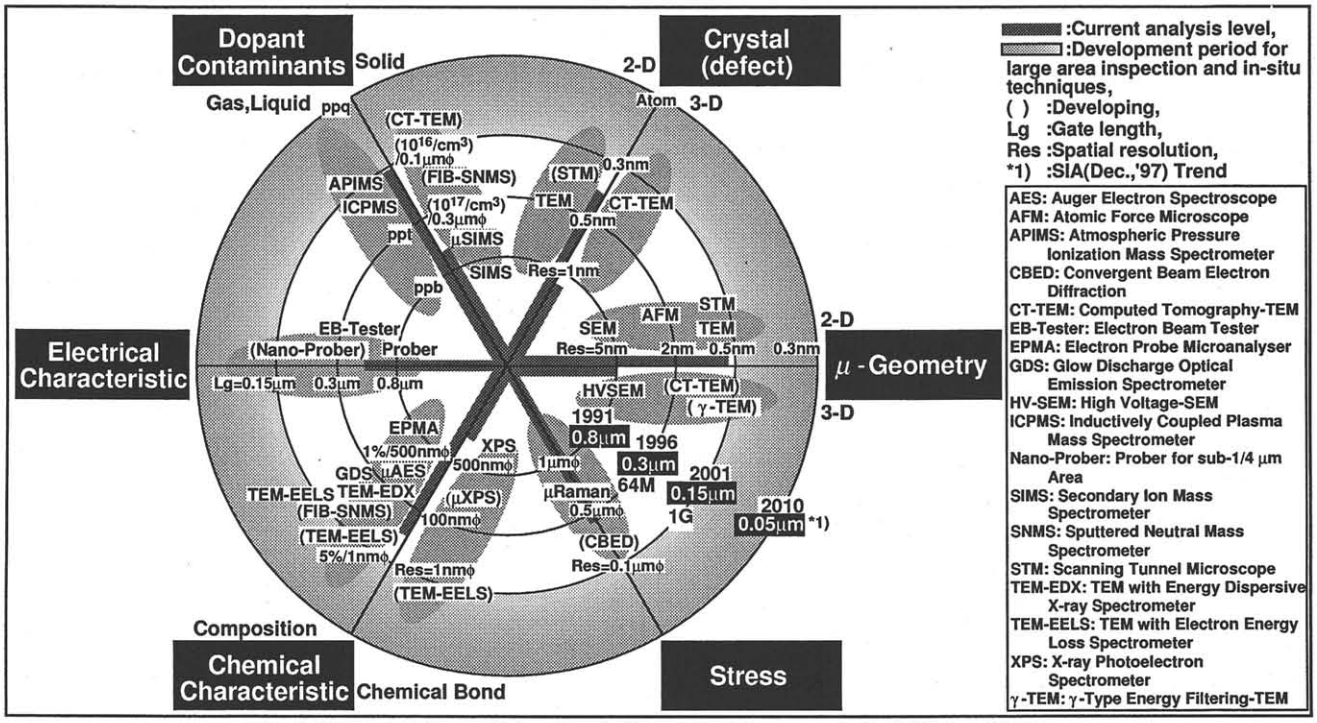


Fig. 1 Current status and future trend of analytical instruments for failure analyses.

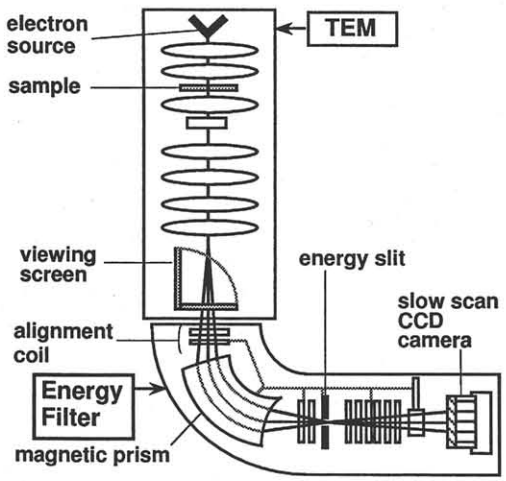


Fig. 2 Schematic diagram of TEM-EELS. Spatially-resolved EELS provides plural spectra at different points simultaneously.

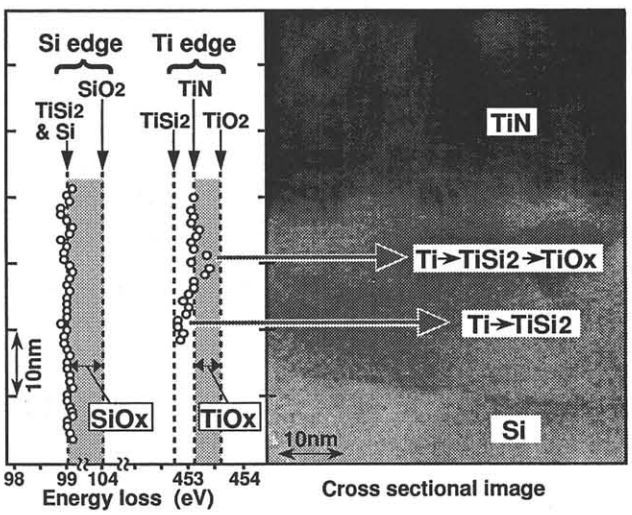
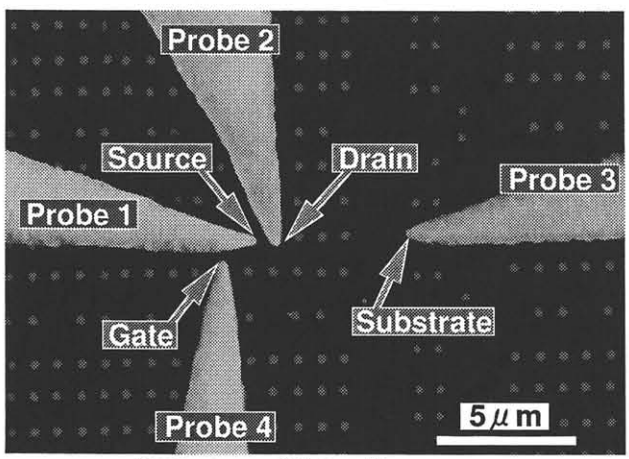
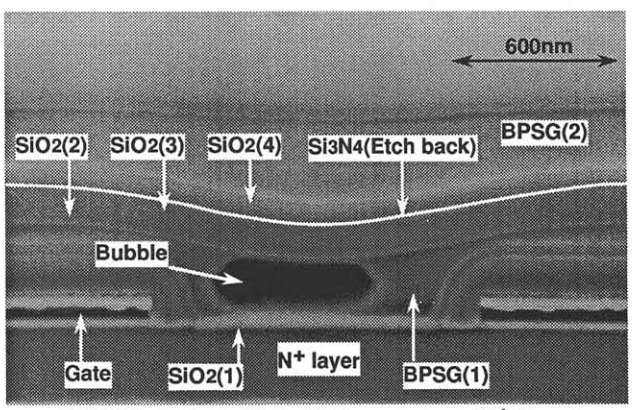


Fig. 4 TEM image and line profiles of core-loss edge energies at a contact bottom with high resistivity (k Ω). Chemical shifts of Ti reveal that Ti is partially oxidized.



Probes on a 0.2 μ m Processor

Fig. 3 Electrical inspection on actual circuits (Nano-Prober).



BPSG bubble in Gate-Gate space on N + layer

Fig. 5 Void (bubble) formed in BPSG layer