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FAILURE ANALYSIS IN FOCUSED ION BEAM (FIB) TECHNOLOGY OF ION CHANNELLING CONTRAST (ICC) AND ELECTRON CHANNELLING CONTRAST (ECC): A REVIEW

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ABSTRACT

This paper is review on the failure analysis in semiconductor area, especially in the integrated circuit (IC) design. Firstly, the literature review is done based on the keyword of focused ion beam (FIB). The FIB is one of the important micro-/nano-fabrication tools preparation of and transmission electron microscopy (TEM) tool. In FIB, two different channelling contrast techniques can be used. The first one the ion channelling contrast (ICC) and second one is the electron channelling contrast (ECC). These two techniques are using in different situation and had been different effect at the sample. The several previous works on this ICC and ECC techniques by several researchers are reviewed in this paper.

Keywords: focus ion beam (FIB), ion channelling contrast (ICC), electron channelling contrast (ECC), failure analysis, liquid metal ion source (LMIS).

INTRODUCTION

Each product has in manners of failure and effect to the producer or the factory cost. For example, in semiconductor, the integrated circuit (IC) are design in more complicated with many smaller components that effect of more failure of the fabrication physical, the connection and the material used. Some technology applies the deep-sub-micron or nanometer that effect more to shrink the IC from smaller to smaller. In other side, it also can cause of the human error or other caused that only know at the time. This condition makes the failure is more complex that effect the more time and cost to the company.

Failure analysis (FA) is the important component that consists in integrated circuit in semiconductor area. In manufacturing process, this failure analysis is involving several failure situations. This FA scope that contains electrical characteristics, maximum performance of chemical and physical technique with the analysis of the equipment to define the way to solve the problems of quality and reliability improvement in manufacturing or application scope area that aimed of the customer needed [1].

In the several previous issues, several failure analyses can be review in this paper. Firstly, in [2], it stated on the FIB circuit edit and electrical characterization analysis for two cases of the invisible defect issues. The first issue is on the SRAM units manufactured with 90 nm technology in SOI wafer unpleasant from single bit failure. Besides that, the second issue is focused on the 0.13 um technology for communication device that suffered low yield due to high sleep current.

Researcher basically develops the several improvement techniques to quantify the effects and influences of failures to avoid customer dissatisfaction. In the focused ion beam (FIB), it reported that, there are two types of channelling contrast than been reported, basically ion channelling contrast (ICC) and electron channelling contrast (ECC). These two are caused by variety in flag coming about because of changes in the point of the occurrence shaft and the precious stone cross section as for the objective.

In paper is stated on the failure analysis on the focused ion beam (FIB) that have two different technique included ion channelling contrast (ICC) and electron channelling contrast (ECC). Some example and literature had been presenting to show the several failure analyses.

Focused ION beam (FIB)

In semiconductor industry, the focused ion beam (FIB) is one of the important subjects that been research while its one the popular micro-/nano-fabrication tools preparation of and transmission electron microscopy (TEM) tool that been research by various researcher. This is because the FIB is applying many areas of engineering, technologies and sciences, especially in material and chemistry part.

Focused Ion Beam (FIB) is a crucial instrument in contemporary conduct of the distrusted defective circuit with that of a semiconductor FA laboratory. FIB is applying for the preparation of electron microscopy specimens and also used in the fabrication of nano and micro components. This focused ion beam is one of the surface levels that usually castoff for locating ion and electron channelling contrast images. It suitable for describing and portraying the, grain morphology, grain size and using in the grain boundary positions for the materials of crystalline.

This FIB project introduces by Krohn [3] in 1975, stated in his paper on the ion source of high brightness using liquid metal ion source (LMIS). This FIB begins as the failure tool for semiconductor, especially as the circuit modification process. After the several years, it had been used on outside area of the semiconductor [4]. FIB indeed turns into a nanofabrication tool ensuing the starter used of the liquid metal ion sources (LMIS) [5]. Figure-1 shows the schematic of liquid metal ion source.

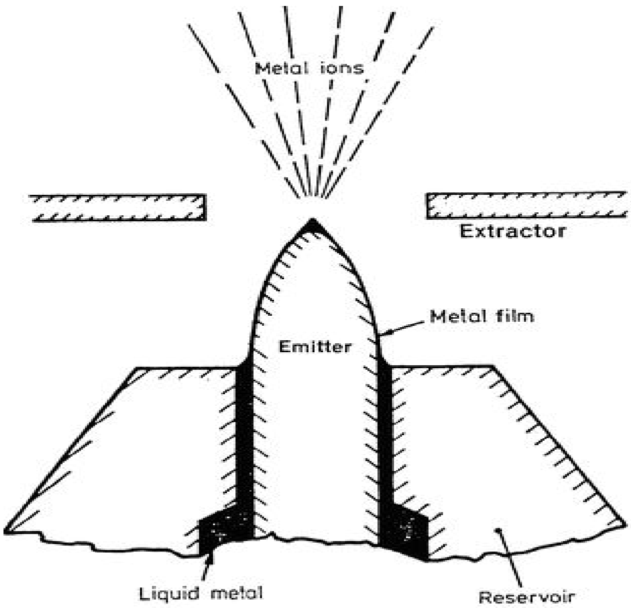

Figure-1. Schematic of liquid metal ion source. [5].

The general properties of the LMIS are the virtual source size that available are using ion of Ga, Au, Si, and Ge, while the typical pattern 10 - 20 nm is Si and Ge ion. For sputter yield, the ions can be used is Pr, Pt, Rb, Sb, Sm, Sn, U, Y and Zn [6-8].

Besides that, the first systems based on field emission technology that apply the proton scanning microscopy were developed by Levi-Setti [9] in 1974 while Orloff [10] had been studies in the year of 1975 on the suitability of the field-ionization source for microprobe applications.

FIB devices are intended to engrave or machine exteriors, a perfect FIB may machine away one particle layer with no disturbance of the molecules in the following layer, or any remaining interruptions over the surface [11]. FIB lithography is alike to EBL but delivers more competences such as create a pattern in resist layer, locally milling away atoms while using a direct ion-induced mixing modification [12].

The main important part in FIB is ion beam column that purpose to deliver a focused beam of ion to the samples. In the integrated of the cross-beam system, this ion column is also combined with the electron column that also focused the beam into the sample. These two columns basically aligned at 52^0 to each other to get the exactly stable performance result. Figure 2 shows the schematic of dual-beam focused ion beam system with ion column and electron column.

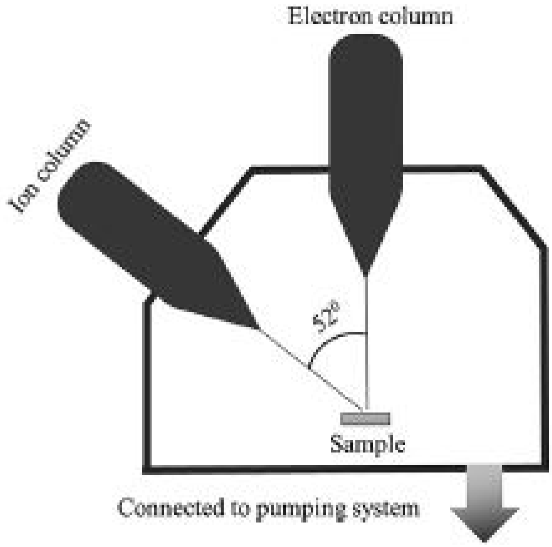

Figure-2. Schematic of dual-beam focused ion beam system [13].

Prenitzer [14], 1998 in his paper had been reviewed on the FIB milling techniques for TEM specimen preparation. In his paper, he started the operation with a liquid metal ion source (LMIS). To form an electrospray to form ions, a liquid metal ion source (LMIS) is applied. This ion source is heated the liquid state [15].

Characteristically, the preferred suitable material that use in low melting point is gallium. Besides that, the gallium is located at the middle of the periodic table that no overlap with other elements while this material is low vapour pressure, sufficiently heavy for ion milling and its relatively unreactive nature. Other advantages of using Ga is because its near room temperature while it can be focused to a very fine probe size (<10 nm in diameter).

Figure-3 shows the schematic diagram of LMIS of FIB. In this case, the wet gallium (Ga) is used and it had a positioned with the sharp Tungsten (W) needle. Basically, the most FIB use this LMIS with material of gallium while the FIB has the capability to eliminate the material surface. The FIB is naturally worked with an accelerating voltage between 5 and 50 keV. Besides that, in other Prenitzer [16] paper, he stated the correlation between ion beam / material interactions and practical FIB specimen preparation.

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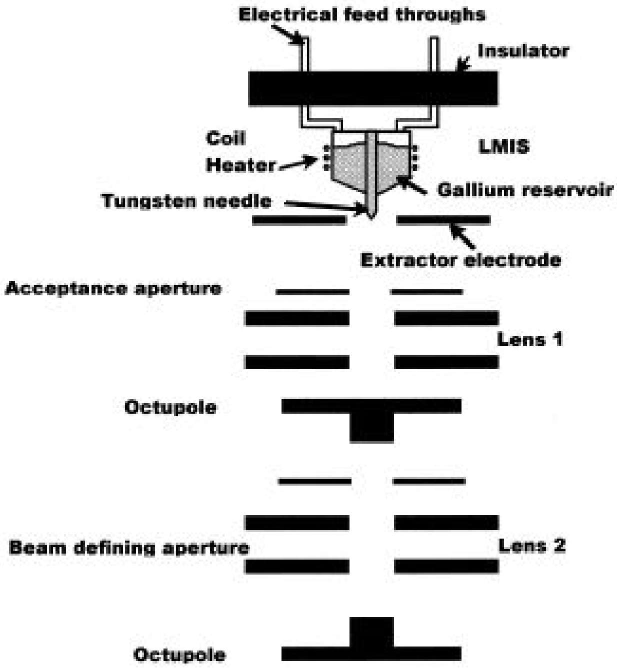

Figure-3. Schematic diagram of LMIS of the FIB by [16].

Canovic [17] in his work are focusing on the grain contrast imaging with several techniques used such as FIB and scanning electron microscopy (SEM). In his work, three various samples are applied, starting with κ-Al_2O_3/TiC, Ti(C,N) and oxidized pure iron sample. It shows that the selection of the technique used is based on the material used, the spatial resolution used and the equipment or system that applies to the desired image.

The next two sub-topics are described on channelling contrast. The channelling contrast is the distinction in the signal level experiential from a crystalline material effect of the alignment of ion beam to the sample [18].

Two different channelling contrasts is the ion channelling contrast (ICC) and electron channelling contrast (ECC). In the theory and the previous work of research, it founded that even for similar targets or crystal orientations, the channelling contrast experiential these two ion and electron is not same and shows the significant variance response between them. Before that, the terms of channelling in FIB is more describe on the propensity of an incident beam of charged particles to penetrate deeper with lower potential energies that can be composed using ion or electron. Ions are unalike the electrons because of it has a heavy mass. For example, a hydrogen ion is 1840 times weightier than an electron itself. Table-1 shows the several differentials between ions and electrons.

Table-1. Different between ions and electrons.

Ions	Electrons
Bigger outer shell reaction	Small inner shell reaction
Less penetration depth	High penetration depth
High mass with slow speed, high momentum	Low mass with high speed for given energy
Positive ions	Negative electrons

ION channelling contrast (ICC)

Ion channelling contrast (ICC) is apply in disclose microscopy to reveal the grains of a polycrystalline structure [19]. Ths ICC is describing in the ion range defined by the nonchanneled fraction and critical angle while the low index channelled direction effect to the dark ICC.

The size of the particle and the incidence angle with the crystallographic atomic spacing of the target it effects to the channelling of any charged particle. In the theory, it shows that the larger atomic spacing effect deeper the penetration charged particle.

Figure-4 shows the particle model for channelling that low index crystallographic planes had been affect the deeply penetration of ion aligned [20]. It shows the how it can be used for imaging in ion channelling. It shows that the ion channelling provides rise to an outstanding contrast, at its presentation dissimilar grain orientations in a polycrystalline metal structure. In this figure, it shows that the blue line show the strong channelling with low brightness, red line shows the weak channelling with high brightness while green line shows the intermediate channelling with intermediate brightness [21].

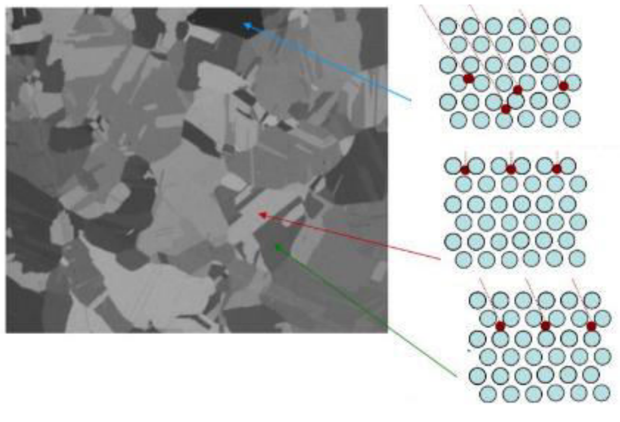

Figure-4. The particle model for channelling [22].

Daudin [22] in his work are using the ion channelling technique with the combination of convergent beam electron diffraction had been determined the polarity of the GaN films layers on Al_2O_3 substrates. The ion channelling measurement setup were made by located 2 MeV He ions. This sample was preserved at liquid nitrogen temperature. This experiment is successfully to define two different polarity of Ga- or N-terminated surface from GaN layers.

Levi-Setti [24] in his work are reported that the ion channelling effect scanning ion microscope using focused beam 60 keV Ga+ probe from liquid metal source. This setup successfully to sense the ion-channelling phenomena in samples of brass and iron, after completing the monitoring process of crystallographic contrast in images found with the secondary electron and secondary ion signals. Figure-5 represents the schematic diagram of 60 keV Ga+ scanning ion microscope.

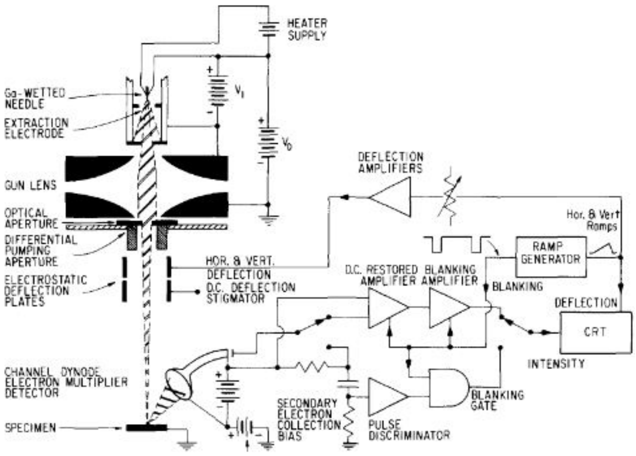

Figure-5. Schematic diagram of 60 keV Ga+ scanning ion microscope [24].

Electron channelling contrast (ECC)

Beside ICC, there is another preferable technique that spready use in the FIB is electron channelling contrast (ECC). Starting in between the 1960s and 1970s, the several researchers recommended to introduce the electron channelling that can be employed as an imaging technique that appropriate for dislocation analysis. [25-26] Dislocations can be defined as line defects in crystalline solids that can effect and changes the properties of the material [27].

Electron channelling contrast imaging is an appropriate technique for imaging expended faults in crystals. It taken a certain benefit It combines some and specific advantages of dislocation imaging and identification from transmission electron microscopy (TEM) while combine a strength of the rapid image acquisition and easy sample preparation in the scanning electron microscopy (SEM) [28]. This ECCI is a compatible, and in several situation a potentially superior, the technique to TEM as it offers a replacement, high-throughput appeal for imaging the same expanded defects [29].

This is the suitable technique to observing crystal defects, such as the stacking faults, grain boundaries in the scanning electron microscope while other solution for dislocations and twins' structure In Scanning Electron Microscope (SEM), the ECC is dissimilarities of composed backscattered electrons (BSEs) intensity as a purpose of main electron beam place on sample exterior [30].

The ECC is initiate due to backscattering effects that appear at the sample surface. In this technique, the wave nature of the electron is ideal to employ. This channelling effect may then be considered as a diffraction phenomenon. Use of the wave nature of the electron is the preferred approach, and the channelling effect may then be inspected as a diffraction phenomenon [31].

Kaboli [32] in his paper had been equated the Electron Channelling Contrast Imaging (ECCI) technique in Scanning Electron microscope (SEM) with Electron Back Scattered Diffraction (EBSD) using Hitachi SU8000 FE-SEM. Besides that, Deitz describe in his paper that using the ECCI for Rapid III-V heteroepitaxial layers of GaP grown on Si (001) substrates characterization. In this work, it displays the benefit of the ECCI method that needs slight to no sample grounding work, and certainly can use large area, as formed samples. It also significantly better output characterization process than TEM. It stated that, the

Here, ECCI was exhibit over the characterization of misfit displacement at the lattice-mismatched crossing point of heteroepitaxial GaP-on-Si specimen, however, it has huge range of relevance and suitable for other defect condition and crystalline structures. In other work, Naresh-kumar [33] studies on the nonpolar nitrides using a scanning electron microscope using ECC technique.

CONCLUSIONS

The reviewed of the several keywords of focused ion beam (FIB) technology of ion channelling contrast (ICC) and electron channelling contrast (ECC) had been done. It shows that these two techniques of ICC and ECC have different characteristic and provide a different effect of the material samples. The used of the any technique is depends on the desired application and the objective of the researcher. By apply the failure analysis for both techniques, it can effect to reduce the cost by saving the unwanted failure defected material and also reduce the time to solve the problem in the integrated circuit area in the semiconductor industry.

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