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High Aspect Ratio Via Milling Endpoint Phenomena in Focused Ion Beam Modification of Integrated Circuits

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Introduction

As integration level of semiconductor devices increases, thickness of the internal features within microelectronic circuits reduces concurrently with the shrinkage of lateral dimensions. Therefore precision detection of endpoint after the milling has reached targeted conductor during the process of circuit modification by Focused Ion Beam (FIB) system becomes increasingly important. One method for detecting endpoint during FIB milling is based on monitoring the yield of secondary electrons [1, 2] generated as the ion beam strikes the material being removed. Access vias, used in editing circuits using FIB are scaling with circuit dimensions and as a result the aspect ratio requirements are increasing.

While the sensitivity of the endpoint detection can be enhanced by improved secondary electron collection [3] and by monitoring the sample absorbed [4,5] current, a detailed understanding of the endpoint signal distribution within a High Aspect Ratio (HAR) via is of great interest for further enhancement of the endpoint sensitivity.

Methods and Analysis

Experimental Observation

Real time image acquisition, concurrent with the via milling by Gas Assisted Etching (GAE) process is available on the FIB tools manufactured by former Micrion, and on the FIB systems from FEI Company running "Microsurgery" software. This image acquisition feature allows to observe the spatial distribution of the secondary electron endpoint information within the via. Saving the FIB image immediately after the detection of endpoint and prior to re-scanning the Field Of View (FOV) can capture spatial distribution of endpoint information within HAR via. As via aspect ratio increases, the distribution of the endpoint information within the via area also changes. It is apparent (Fig. 1), that as aspect ratio of the via approaches 10:1 the endpoint information becomes available primarily in the peripheral area of the HAR via, while the central area carries no endpoint information

Proposed Endpoint Mechanism

While observed spatial distribution phenomenon can be explained based on the negative wall charge model, as suggested by Wang et al. [2], alternative model can also be proposed. Properly chosen GAE agent, used for the HAR via milling in dielectric, does not enhance milling of the material comprising the targeted metal line. Once the line is exposed, metal is sputtered from the line by a primary ion beam. As the line is located at the bottom of the HAR via, sputtered metal is unavoidably re-deposited on the sidewalls of the via. Recently published research indicates [6], that measurable amounts of re-deposited material from the metal line at the bottom of the access via is observed on the via sidewalls at all heights, up to the very aperture of the via at the surface of the sample. This re-deposition of the metal, sputtered from the line at the bottom of the via onto the via sidewalls (Fig. 2), creates somewhat conductive path along the sidewalls and facilitates supply of the electrons from the buried metal line. Once the re-deposition approaches via aperture, increased amounts of secondary electrons are generated during continuous bombardment of the via sidewalls by the repetitive rasters of ion beam. This increased emission of the secondary electrons is detected as the endpoint.

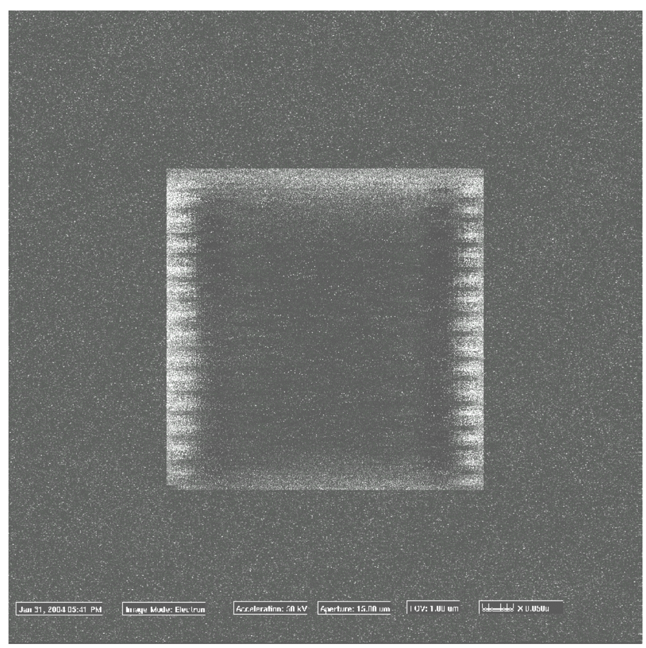

Figure 1: Image of the spatial distribution of the endpoint information within the aperture of 0.5 μm X 0.5 μm HAR via, acquired in FOV 1 μm concurrently with endpointing at the end of milling through 5 μm thick SiO_2 dielectric.

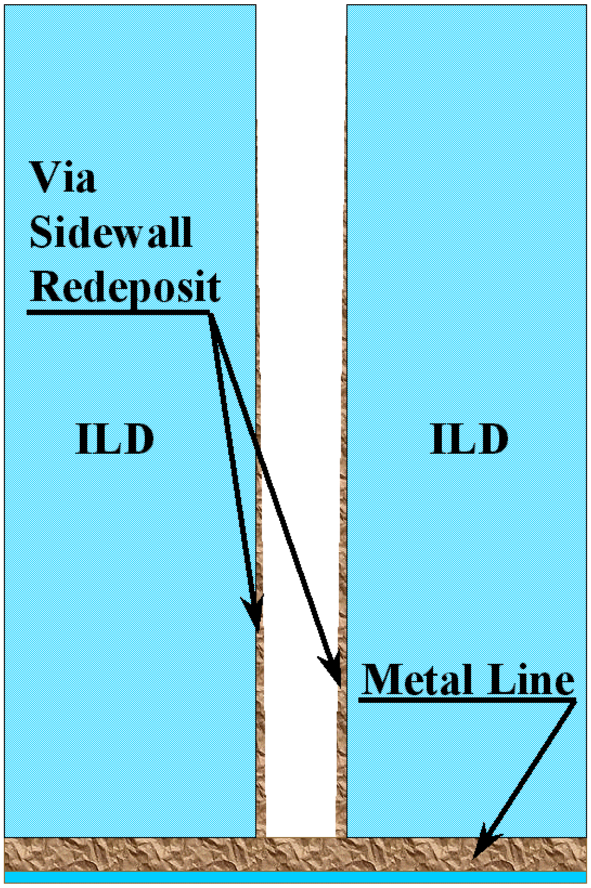

Figure 2: Schematically represented cross-section of HAR via, illustrating proposed endpoint mechanism that is based on re-deposition of the metal from the targeted line on the via sidewalls. When this conductive re-deposition is struck by the primary ion beam, increased emission of the secondary electrons from the sidewalls is detected as the endpoint.

Future Experimental Verification Concept

Proposed model of HAR via milling endpointing mechanism could be experimentally verified. The model is based on the assumption that milling of the targeted metal line is not enhanced by the GAE precursor chosen for producing HAR via in dielectric. Therefore preferential distribution of the endpoint information along sidewalls of the HAR via on Cu devices should be observed in cases of via milling assisted by TFA, XeF2, Cl2 and other halogens. On the Al devices the same spatial distribution should also be observed incase of TFA and XeF2 milling. Cl2 and other halogens enhance milling of the Al, and as the enhancement for the Al milling with halogen precursors is typically higher then for the SiO2 based dielectrics. Therefore described spatial distribution of the endpoint information is not expected to appear in case of HAR via milling on Al device with Cl2 or other halogen precursors

Conclusions and Acknowledgments

A phenomenon of spatial distribution of the endpoint information within the HAR via is explained based on sputtering of the material from the targeted metal line and re-deposition of the spattered material on the via sidewalls. Increased emission of the secondary electrons, resulting from the subsequent bombardment of this conductive re-deposition by the primary ion beam, is detected as the endpoint.A methodology for the future experimental verification of the proposed model is also described.

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