Investigation of "low-k" material using EFTEM, Z-Contrast imaging and low-loss spectroscopy

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Résumé : La sensibilité des matériaux dits « low-k » aux effets de contamination et aux effets d'irradiation fait que leur investigation chimique physique et structurale est délicate en utilisant des méthodes de microscopie analytique conventionnelles. Ce travail illustre la pertinence de la spectroscopie de pertes d'énergie des électrons couplée à la l'imagerie EFTEM et à l'imagerie de Z-contraste pour suivre simultanément des variations de composition chimique et des variations de gap à travers des couches nanométriques de BD_2X élaborées par différentes techniques de dépôts et destinées à remplacer les matériaux à constante diélectrique trop élevée dans les structures « Back-end ».

1. Introduction

The dimensions of features in advanced integrated devices in semiconductor industry at the backend level are such that the dielectric constant of traditional insulators like SiO2 is not low enough to prevent cross talk between metal lines. Hence a novel kind of "low k" material is about to be implemented in the process flow. The "low k" material is deposited by CVD and consists mainly of Si, O, C and H. The most important feature of this type of material is its porosity, which allows to further reduce the dielectric constant. But these pores give also rise to the main disadvantage of this material class, the mechanical fragility. To implement these materials successfully into the process flow, measuring the impact of process steps like via etch and CMP on the low k and diffusion of Cu or Ta atoms into the low k is crucial, since chemical changes or density changes leads to a change in the dielectric constant. Analytical TEM is the only technique, which provides the necessary spatial resolution combined with chemical analysis capacities. However, the material is extremely sensitive to the electron beam and is damaged easily (shrinking). In this presentation several TEM based methods are explored (Core loss EELS, EFTEM and low loss EELS) Low loss EELS seems to be the most promising method at the moment, because the low intensity electron beam in STEM mode introduces minimum damage.

2. TEM and STEM images of the structures

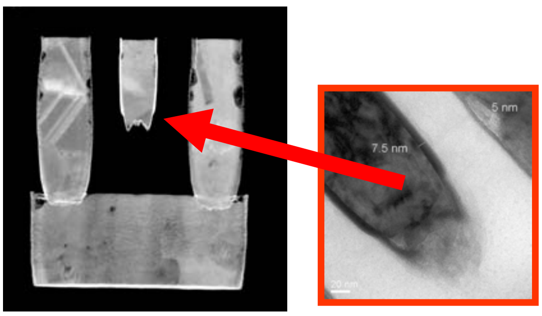

***Figure1** : STEM images showing the diffusion* of *Ta inside the low-k material*

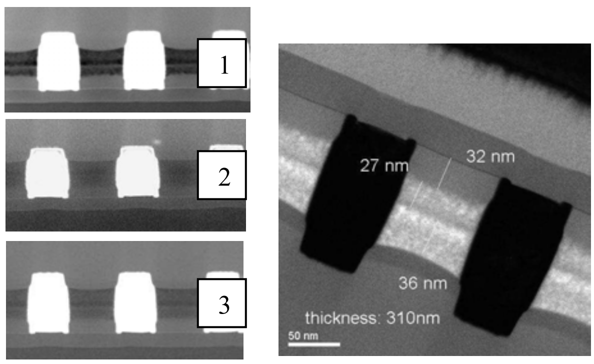

***Figure 2 :** Bright field TEM images showing the shrinrage induced by electron irradiation according to the thickness of the TEM sample.*
1: very thick 2: thick 3: thin

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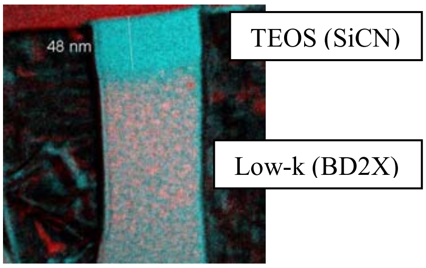
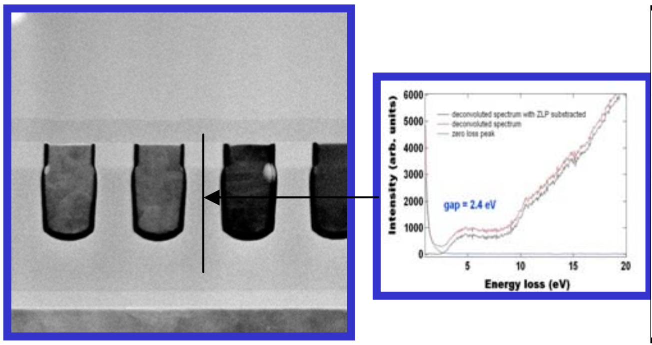


Figure 3: *EFTEM image (green: oxygen, blue: carbon). Only macroscopic chemical changes can be observed. No thin oxygen enriched layers are observed along the via edges.*

3. Low-Loss analysis of low-k



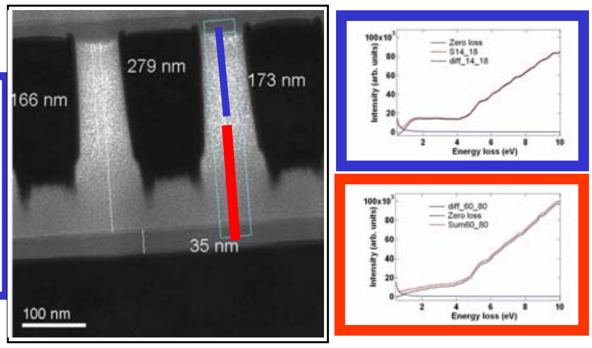


Figure 4: *Low-loss spectrum recorded in the "low-k" capped with TEOS. Band gap is equal to 2.4 eVin all the low-k thickness.*

Figure 5: *Low-loss spectrum recorded in the Chemical Mechnical Polishing (CMP) "low-k". Band gap varies from 1.6 eV to 2.5 eVfrom the top to the bottom*

4. Conclusion

The irradiation damages occuring in the low-k materials prohibit core-loss analysis. No reproducible profiles can be obtained for C and O.

On the contrary from low loss analysis reproducible spectra acquisition is possible. The small changes in the spectrum at low energy might indicate changes in porosity in the case of "CMP low-k". Regarding the band gap, constant values are obtained for "TEOS low-k" whereas variations from 16 to 2.5 eV are measured for "CMP low-k" indicated a severe damage in the dielectric material through this process. In the future, band gap profiles recorded in the low k material will be used as input parameters for electrical capacitance calculations.

5. Acknowledge

To Jaysen Nelayah for spectra treatment using the Richardson Lucy's method.