Electrical Reliability Challenges of Advanced Low-k Dielectrics

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We review the latest studies that address the fundamental understanding of low-k dielectric electrical properties and reliability. We focus on the results discussing the nature of process induced defects, leakage currents and breakdown behavior, as they are important factors to reveal material modification and damage. Issues related to the use of porogen based PECVD techniques during dielectric deposition are discussed, where we focus on the selection of matrix and porogen precursors and on the improvements related to post-deposition treatments. During damascene integration, low-k dielectrics are subjected to several processes that induce material damage, where we review recent learning about plasma exposure, barrier deposition and chemical mechanical polishing. In order to have a successful implementation of advanced ultralow-k films in back-end-of-line interconnects, we argue that more research efforts are needed with respect to its material development, integration and reliability and make some proposals for future work.

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The development and integration of reliable low-k materials is a key challenge for next generation interconnect technologies. Driven by the requirement of performance increase, highly porous low-k dielectrics are incorporated in deeply scaled back-end-of-line (BEOL) interconnects. In general, there are three important concerns during the study of low-k dielectric electrical properties and reliability: a) the k-value of the dielectric after integration should maintain relatively unchanged, b) the leakage current of the dielectric between metal lines should be low, and c) the time dependent dielectric breakdown (TDDB) failure time of the integrated BEOL structure at operating conditions should meet its specifications.

Porous SiOCH low-k dielectrics deposited by plasma enhanced chemical vapor deposition (PECVD) techniques are the dominant choice for k=2.2 film depositions and are also potential candidates for ultralow-k (k<2.2) dielectric applications. In the last years, significant efforts have been spent to understand their material properties and integration challenges. The band structures of low-k dielectrics is complex due to the non-equilibrium nature of the PECVD technique. Such amorphous structures are further complicated by the use of porogen, where the porogen based approach is widely used in PECVD processes to produce micro pores in dielectric films. Pure organic molecules are co-deposited with matrix materials as sacrificial porogen. During a curing step, most of this organic material is thermally decomposed, where the original occupied sites are converted into micro pores. A higher porosity in the low-k film can be achieved by increasing the ratio of porogen versus matrix during deposition, where high porosities of around 50% have been reported. Above this value, film shrinkage caused by low mechanical strength starts to limit further porosity increase. The low-k film quality highly depends on the matrix and porogen deposition and the curing conditions. Different matrix and porogen compositions result in various network structures in the final film. Non-optimized curing steps also introduce hazardous contaminants. During the integration of dual damascene copper interconnects, low-k materials are subjected to processes such as patterning, barrier metal deposition and chemical mechanical polishing (CMP) that modify the material structure and introduce damage. The increase of structure defect densities, the change of film's hydrophobicity, metal diffusion, stress accumulation and delamination seriously lower dielectric reliability performance.

In this review paper, we focus on the results where the nature of process induced defects are studied, since they are important factors to reveal material properties. These defects can be directly probed through physical characterization techniques. We also summarize learnings about leakage current and breakdown behaviors of low-k dielectrics, as leakage current and breakdown are sensitive to disordered structures, where low leakage current and long failure time represent a solid matrix arrangement. The dominant conduction mechanism provides information about the nature of electrically active defects. Insights in these mechanisms are useful during the optimization of film development, integration processes and reliability assessment. In addition, low leakage current levels ensure good reliability as more and more literature data point out that BEOL electrical degradation is dominated by charge injection and that energetic charges facilitate both intrinsic chemical bond breakage and extrinsic metal ion diffusion. This paper consists of three parts. We will first explain the basic knowledge of bandgap structures and conduction mechanisms in low-k dielectrics. Deposition related issues, including the influences of porogen residue, intrinsic defects and porosity will be discussed in the second part. The third part will review process induced material modifications and reliability challenges during BEOL integration.

Bandgap and Conduction Mechanisms in Low-k Dielectrics

A bandgap is defined as the difference between the energy of the lowest conduction band and that of the highest valence band in a crystalline solid. As a result, for porous low-k dielectrics, there is no real bandgap. But as King et al. argued, the concept of a bandgap is extendable to low-k dielectrics and has been successfully used to explain a number of empirical measurement results. To characterize bandgap in porous SiOCH type low-k dielectrics, various techniques are being used. The electron energy loss spectroscopy measurements from Cheynet et al. and Singh et al. determine the low-k dielectric bandgap to be 8.5 eV and 10 eV, respectively. This bandgap range of low-k dielectrics is similar to the one of amorphous SiO 2, which is between 8.0 and 8.8 eV. The reflection electron energy loss spectroscopy measurements from King et al., the ellipsometric data from Marsik et al., the vacuum ultraviolet (VUV) spectroscopy measurements from Zheng et al. and the X-ray photoelectron spectroscopy analysis from Nichols et al. support that the bandgap of most porous SiOCH type low-k dielectrics (k = 2.0–3.5) are in the range between 7.5 to 10 eV. In addition, the barrier height at both the low-k/metal and the low-k/Si interfaces can be measured with internal photoemission experiments. Shamultia et al. and Atkin et al. suggest that this value is around 4 eV for both interfaces. This value further proves that the bandgap of most of the SiOCH type low-k dielectrics is similar to that of SiO 2, indicating that the carbon content in low-k films is not incorporated in the matrix network but primarily exists

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as terminal methyl groups. If carbon would be present in the network bonds by forming Si-C-Si, the bandgap value would drop dramatically. The study from King et al.\textsuperscript{18} indicates that the barrier height at the copper/low-k dielectric interface is dependent on the amount of network carbon in the film and is in the range from 1 to 4 eV.

Three conduction mechanisms have been commonly reported for low-k dielectrics. Schottky emission (SE) and Poole-Frenkel (PF) emission describe field-enhanced thermal excitation of electrons entering the conduction band from the low-k interface and the trap states with coulomb potentials respectively. Fowler-Nordheim (FN) tunneling conduction is caused by electrons tunneling from the metal Fermi energy or trapping sites in the material itself into the low-k dielectric conduction band. The equations describing SE, PF emission and FN tunneling are listed below.\textsuperscript{9,19}

Schottky emission

\[ J_{SE} = A^* \cdot T^2 \cdot \exp \left( \frac{-q(\psi_{SE} - \sqrt{qE/4\pi\varepsilon_0\varepsilon_r})}{kT} \right) \tag{1} \]

Poole – Frenkel (PF) emission

\[ J_{PF} \sim E \cdot \exp \left( \frac{-q(\psi_{PF} - \sqrt{qE/4\pi\varepsilon_0\varepsilon_r})}{kT} \right) \tag{2} \]

Fowler – Nordheim (FN) tunneling

\[ J_{FN} \sim E^2 \cdot \exp \left( -\frac{8\pi\sqrt{2\varepsilon_r(q\psi_{FN})^{3/2}}}{3qhE} \right) \tag{3} \]

where \( J \) is current density, \( A^* \) is Richardson constant, \( T \) is temperature, \( q \) is the elementary charge, \( \psi \) is barrier height, \( E \) is electric field, \( \varepsilon_r \) is dielectric constant, \( \varepsilon_0 \) is permittivity of free space, \( m^* \) is effective electron mass and \( h \) is Planck’s constant. An efficient way to determine the dominant conduction mechanism is to study the leakage current behavior as a function of field at different temperatures. As suggested by equation 1 and 2, the slope extracted from the relation between \( \ln(J) \) or \( \ln(E) \) versus \( E \) should be similar to the theoretical value as suggested by Equation 4, if either SE or PF emission dominates.

\[ \beta_{PF} = 2\beta_{SE} = \sqrt{\frac{q^2}{\pi\varepsilon_0\varepsilon_r}} \tag{4} \]

FN tunneling current exhibits a strong field dependency and is independent of temperature. The plot of \( \ln(E/J) \) and \( 1/E \) should also yield a straight line. In addition, in each conduction mechanism, trap depth or barrier height \( \psi \) can be extracted by employing simple fitting procedures.

Due to the high barrier height being around 4 eV at the low-k dielectric interface, the interface controlled SE only happens when there are strong modifications at the interface or when there are changes of emission paths due to the existence of other low barrier height interfaces, such as the etch stop layer/metal interface (less than 2.0 eV).\textsuperscript{8} Instead, PF emission is more likely the dominant conduction mechanism in low-k dielectrics especially at low fields.\textsuperscript{6,7} FN tunneling conduction can occur at high field ranges.\textsuperscript{20,21} It is shown that leakage currents can be used as a direct measure of dielectric structure quality so that the influences of deposition conditions and integration processes can be examined. Several examples will be given in the following sections to further emphasize the importance of leakage currents and we will show its application to probe process induced modifications and damages of dielectric properties.

Dielectric Properties after Deposition

Low-k dielectrics free of porogen residues.— Lately, a scheme to fabricate porogen residue free low-k dielectrics is proposed by Urbanowicz et al.\textsuperscript{28} After co-deposition of porogen and matrix, an \( H_2 \) after-glow treatment is applied prior to UV curing. Similar to the photomask removal mechanism, hydrogen atoms promote the transformation of high mass porogen chains to volatile short chain molecules. This step enables complete removal of porogen without scission of Si-CH\(_3\). Such porogen residue free low-k dielectrics exhibit enhanced mechanical properties due to more cross linked oxygen atoms in the network. Recent electrical characterization results from Wu et al.\textsuperscript{21} suggest that \( J-E \) relationships in this type of low-k dielectric are insensitive to temperature in the high electric field range. A barrier height of 4 eV of low-k/metal interface is calculated based on the theory of FN tunneling. This value suggests that the backbone of this particular low-k dielectric is similar to SiO\(_2\).

The influence of porosity has been studied on this porogen residue free low-k dielectric. The trend of leakage current versus porosity is different from the one characterized from low-k dielectrics containing porogen residues, where higher leakage currents are observed in higher porosity films. Vanstreels et al.\textsuperscript{27} reported the leakage and breakdown behavior of porogen residue free films with 30%-50% porosity, where it was shown that the leakage current is independent of porosity. However, increasing porosity results in lower breakdown fields, which is explained by a higher amount of cage structures in the film. We extended this film porosity range to 10%-45%. FN treatments leaving the pores behind. If non-optimized UV curing conditions are applied, the formation of nonvolatile graphitized-carbon residues is likely to happen. Porogen residues are the major defects in low-k dielectrics. The existence of sp\(_2\) hybridized carbon like porogen residues is well studied using UV spectroscopic ellipsometry. As reported by Baklanov et al.,\textsuperscript{22} the amount of porogen residue increases with increasing curing time as more original porogen is transformed into porogen residues. The increased amount of porogen residues enhances the leakage current level since these graphic like structures are conductive. In the same study, the self-assembled low-k material prepared without porogen and UV curing shows lower leakage currents compared to low-k dielectrics prepared with porogen and curing. In the study from Van Besien et al.,\textsuperscript{23} the high leakage currents and low breakdown fields in higher porosity low-k films are also attributed to the presence of porogen residues; to prepare higher porosity films, more porogen is added during the deposition, and consequently more porogen residues remain inside the pores.

The presence of porogen residues in low-k dielectrics is also reported by other authors. For different wavelengths used during UV cure, the efficiency of porogen removal is also different, where UV penetration depths play an important role.\textsuperscript{24} In general, depositing thinner low-k dielectrics is more favorable as thin films are cured by the UV treatment over the whole depth of the film. The electron-spin resonance (ESR) results from Afanas’ev et al.\textsuperscript{24} show that signals associated with a carbon dangling bond in a cluster are observed for 500 nm thick low-k dielectrics but are absent for 60 nm thick low-k dielectrics, where King et al.\textsuperscript{18} pointed out that the defect band between 2–6 eV in the bandgap of the low-k dielectric is attributed to these carbon dangling bonds from porogen residues. Also, the UV and UUV irradiated results from Lauer et al.\textsuperscript{25} show that the defect centers originating from porogen residues are able to capture and exchange electrons. In addition, Ren et al.\textsuperscript{26} reported using ESR measurements that increasing porosity result in an increased defect density in low-k films due to the presence of porogen residues. These defects were later interpreted by Pormorski et al.\textsuperscript{27} as carbon dangling bond centers again using ESR measurements, which confirms the findings of Afanas’ev et al. Their studies further indicate that this type of defect plays a dominating role in the electrical transport at low fields. In conclusion, porogen based PECVD processes should incorporate an improved curing step to avoid porogen residues as they have a negative impact on electrical properties of low-k dielectrics. High defect numbers and leakage currents result in an insufficient reliability performance.
tunneling current of higher porosity film is significantly lower as shown in Figure 1, indicating a better matrix quality which has a lower defect density. FTIR results in Figure 2 confirm that high porosity films have a better matrix quality as more network bonds are formed and the bonds related to the sub-oxide peak are reduced. Since the sub-oxide peak is associated with oxygen deficiency related defects, it is argued that it can explain the low leakage current in the high porosity films deposited with the above mentioned process scheme.

Intrinsic defects.— The selection of matrix precursors is an important factor influencing the properties of deposited films. As we suggested, films deposited by matrix only precursors show the highest leakage currents due to the formation of oxygen deficiency related defects. The ESR results from Pomorski et al. further explain the defect natures caused by matrix only precursors, where a dense film (deposited without porogen and curing) and a porous film (deposited with porogen and curing), deposited with the same matrix precursors, are compared. The dense as well as the porous film contain dangling carbon bonds (in terminal organic groups attached to silicon) and E centers (silicon dangling bonds attached to silicon atoms bonded to three oxygen atoms). The presence of these two types of defects are attributed to the use of alkoxysilane as the matrix precursor and are not related to porogen or curing. The authors also emphasized that if specific matrix precursors containing unsaturated terminal organic groups are used, porogen residue related defects are introduced in the film. In addition, defects like CH radicals and other types of silicon dangling bond are reported in the same paper.

Field enhancement and strength reduction by porosity.— Besides various types of defects in as-deposited low-k dielectrics, porosity itself is also reported to influence leakage conduction. Kayaba and Kikkawa calculated the magnitude of electrical fields in porous low-k dielectrics and showed that the maximum field strength always appears at the air/skeleton interfaces. Hong and Milor used finite element and Monte Carlo simulations to study the electrical field and conduction mechanisms inside porous low-k films. Different shapes and interconnectivities of pores change the local field distribution. These local enhanced fields increase with porosity and therefore, poorer insulating properties are expected in higher porosity films. Similar results were reported by Lee et al. suggesting that pore related field enhancement facilitate transportation of charged species and bond breakage, where at operating conditions, this field enhancement is relatively small compared to high fields.

Ogawa et al. used the percolation model to understand the effect of porosity in low-k dielectrics. In the percolation model, dielectric breakdown happens when a single column of defective cells is generated between electrodes. Based on the calculations, the authors showed that the pores reduce the time required to generate a percolation path, reduce the breakdown strength and lower the Weibull shape parameter. A smaller Weibull slope limits the failure time prediction at low percentiles. Barbarin et al. reported similar data based on the electrical measurement results of various low-k films. Figure 3 and 4 show the impact of porosity and thickness on the Weibull slope and the maximum allowed electrical field to meet a 10 year life-time. It is clear that both increasing porosity and decreasing thickness weaken the electrical robustness of low-k films. Their simulations employing an extended percolation model well fitted the measurement data.

Reliability after Integration

Integration of low-k dielectrics involves many processes that can seriously degrade material properties and reliability. Change of film hydrophobicity and generation of electrically active defects during plasma exposure have been widely reported. Dielectric reliability is also weakened by adsorption of moisture and metal diffusion as well as CMP process induced damages and contaminants. Stress accumulation and dielectric delamination could also potentially facilitate breakdown. This section provides a closer look at these aspects.
Plasma damage.—Plasma contains vacuum ultraviolet (VUV) and UV photons, energetic ions, and highly reactive radicals. Exposure to plasma introduces physical damage and chemical modifications in low-k dielectrics. During such processes, methyl groups are extracted from the network leading to densification and k-value increase. Since most of low-k dielectrics rely on methyl groups for keeping hydrophilic, severe plasma damage makes them hydrophobic which facilitates moisture uptake during the following integration processes. In order to understand the complex damage mechanisms in low-k dielectrics, the effects of photons, ions, and radicals must be separately clarified.

Jinna et al. suggested that photon irradiation plays an important role in the damage process and enhances the breakdown of Si-C bonds. In their study, Ar and SF₆ plasma irradiation was first compared with Ar and SF₆ neutral beam irradiation. The plasma irradiations in both Ar and SF₆ cases cause drastic extraction of methyl groups due to the presence of photons. The effect of photons was further confirmed with experiments combining an SF₆ neutral beam and a 172 nm excimer lamp. In both radical irradiation and neutral beam/radical irradiation cases without photons, no damage was observed while the irradiations with photons created damage. The effect of VUV and extreme ultraviolet (EUV) photons on low-k film modification was systematically studied by Rakhimova et al. The wavelengths studied were 13.5 nm (EUV) and 58.4 nm, 106 nm, 147 nm (VUV). Figure 5 shows that the most severe damage over the whole film thickness occurs after exposure with 147 nm light since this emission has the smaller photoabsorption cross section and enables deep penetration into low-k films. In Figure 6, the effective quantum yield was calculated based on the VUV exposure results of the low-k dielectrics with porosity ranging from 20% to 55%. The effective quantum yield in the range between 0 and 1 quantifies the efficiency of CH₃ escaping from the porous film with a possible reattachment of –CH₃ back to dangling Si-bonds. This figure shows that high interconnectivity in low-k dielectrics also facilitates photon penetration, therefore leading to a stronger degradation.

As reported by Nichols et al., dielectric failure times and charges to breakdown decrease for VUV exposed low-k dielectrics. The same research group also investigated the influence of photon irradiation on leakage currents. Comparison of leakage currents in low-k films before and after UV and VUV exposure show that VUV exposures could have a similar effect to UV cures, where leakage current are reduced due to certain photoactive compounds being decomposed and removed during the exposure. However, the ESR results from Ren et al. show that VUV photon irradiation generates additional defects and twisted bonds in the structure. Increasing defect densities and leakage currents after UV light irradiation are also discussed in other literature reports. Sinha et al. suggested that photon irradiation produces trapped charges inside the low-k material, where such charge accumulation leads to potential reliability problems.

The nature of the defects generated during ion bombardments was studied by Afanas’ev et al. by using three discharging gases: H₂, He, and Ar. Knock-off of atoms from the low-k material network are believed to happen during the ion sputtering process resulting in the formation of Si vacancies like EX centers or dangling carbon bonds, where the carbon related defects contribute to a higher leakage. Furthermore, the results of King et al. show the generation of surface oxygen vacancies, probably due to the removal of terminal organic groups after Ar⁺ sputtering, where two related sub-gap surface states are observed at 5.0 eV and 7.2 eV. Nichols et al. studied the effect of the ion energy in the plasma. The wafer bias in the plasma reactor was adjusted to increase the ion energy. An increase of the ion energy resulted in increased leakage currents and reduced breakdown fields, where the formation of an oxide like layer due to loss of carbon near the film surface was put forward as an explanation. It was further has been suggested that defects are more easily generated inside this oxide-like layer. Sinha et al. suggested that ion bombardments lead...
to ions sticking on the dielectric surface. Similar to their conclusions on photon irradiation, this charge accumulation is considered to have a negative impact on reliability.

The concern of radicals is mainly about the change of the film’s hydrophobicity since radicals could also remove methyl groups from the low-k matrix. Recent results from Zhang et al.58 show that carbon depletion can be significantly reduced at cryogenic temperature due to etch by-product condensation in pores, which blocks active radical diffusion.

**Moisture.**— Process induced dielectric damage makes low-k films hydrophilic, where moisture uptake could happen in subsequent process steps. Due to the high dielectric constant of water (≈80), a small amount of water adsorption significantly increases the effective dielectric constant. Literature reports36 show that the adsorbed moisture degrades reliability performance of low-k films. Attempts were done to characterize the conduction mechanism of moisturized low-k dielectrics, but the exact mechanism remains unknown. The work of Lloyd et al.47 shows that “wet” capacitors could have SE or PF emission type of conduction but Michelson et al.38 suggested a non-linear ln(J)-E5 relationship. A hump in the J-E curve is suggested to be related to the presence of moisture.49 An annealing step is supposed to remove moisture and improve the film reliability. However, Li et al.50 suggested that the removal of physisorbed water by baking at 190°C could only slightly improve dielectric reliability. In contrary, the life-time is significantly improved after annealing at 400°C due to the removal of chemisorbed moisture. The removal of chemisorbed moisture also helps to reduce the thermal activation energy of time dependent dielectric breakdown. However, recent results from Cheng et al.51 point out that annealing at 400°C is still not sufficient. As a result, preventing the generation of Si-OH group in the low-k dielectric is still the best way to reduce the chemisorbed moisture instead of relying on post integration anneals.

**Copper and barrier metal.**— The influence of copper diffusion in the low-k dielectric has been explained in two ways. First, copper could generate shallow energy levels in the bandgap of low-k dielectrics.52 These states act as defect centers facilitating PF type conduction. Second, the penetration of copper atoms or ions also contribute to field enhancement locally inside the dielectric or at the electrode of electron injection.53,55 Since copper surface migration is much easier than bulk migration54 and the copper diffusion process is strongly activated by temperature,55 the copper penetration is enhanced in higher porosity low-k films and at increased temperatures. The deposition of barrier metal prior to copper plating prevents possible copper migration. Recent studies, however, show that barrier metals like tantalum could also be involved in low-k dielectric degradation in a way similar to copper, where the effective dielectric thickness is reduced due to the barrier penetration after deposition.56,57 Zhao et al.58 quantified the metal barrier induced damage based on its impact on the low-k capacitance. The damage caused by PVD (physical vapor deposition) based Ta(N) barrier depositions increases as the low-k porosity increases. Atomic layer deposition (ALD) is promising to replace PVD for a conformal thin barrier deposition in high aspect ratio trenches applicable to more advanced BEOL structures. However, ALD precursors easily penetrate into the low-k film through interconnected pores.49–61 making pore sealing an essential step before the actual ALD deposition. Armini et al.62 reported that self-assembled monolayers (SAM) deposited on porous low-k dielectrics are potential candidates to seal pores, where it was shown that these SAM layers completely prevented metal penetration during ALD barrier deposition.

**Chemical mechanical polishing.**— Chemical mechanical polishing is a process using mechanical polishing, assisted by chemical reaction to produce a topography with improved planarity.63 The V-shape of low-k trenches in advanced BEOL structures leads to field enhancement along the CMP interface which is a potential critical path for low-k dielectric breakdown. Therefore, the quality of this interface after CMP is crucial for BEOL dielectric reliability. Poor reliability performance is obtained when using unsuitable polishing slurries and post-CMP cleaning solutions.64–66 As suggested by Izumitani et al.,67 porosity increase influences the film resistance to CMP damage. CMP interface quality degradation involves three concerns: dangling bonds generation, metal contaminants and moisture presence. As discussed in previous sections, these three factors inevitably increase leakage current and shorten dielectric life-time. Yamada et al.56 reported that the presence of bond defects introduced by CMP increases PF type leakage currents. Dissolved copper atoms and moisture at the surfaces facilitate electrochemical reaction induced copper ion migration and accelerate dielectric breakdown. Heylen et al.68 showed a direct correlation between post-CMP surface metallic residues and dielectric reliability. Other issues like surface roughness and polishing scratches also degrade BEOL reliability performance.69,70 Ways to recover bond defects, to minimize copper residues and to restore film hydrophobicity during CMP or after CMP are proposed in several literature reports.71,72 It is evident that developing optimized CMP processes in BEOL integration is crucial for advanced interconnect technologies.

**Mechanical stress and delamination.**— During chip bonding and packaging processes, large thermal and mechanical stresses occur in BEOL structures. Yang et al.73,74 studied the influence of mechanical stress on J-E relations of low-k dielectrics, where it is shown that tensile stress leads to decreased energy barrier heights and increased PF conduction. On the contrary, compressive stresses increases energy barriers and reduces leakage currents. Tan et al.75 investigated delamination induced dielectric breakdown in copper/low-k interconnects. Instead of mechanical stress, they attributed weak adhesion of interface between SiC(N) and SiOCH to be the cause of delamination initiation since weak adhesion facilitates electrons breaking interfacial bonds.76 PF emission is determined as the dominant conduction mechanism at the delaminated interface. Delamination is further expanded by Joule heating and eventually leads to breakdown.

**Summary**

We reviewed recent research work on electrical properties and reliability of SiOCH type of low-k dielectrics. During dielectric deposition, the use of porogen based PECVD techniques introduces potential reliability issues. Appropriate selection of matrix and porogen precursors and improvements of post-deposition treatments are key to produce robust dielectrics without porogen residues or other intrinsic defects. A delicate balance between low bulk dielectric constant and sufficient intrinsic reliability performance is required when scaling porosity, where increasing porosity in the dielectric material results in local field enhancement. Also, porosity weakens the electrical robustness of the film leading to reduced failure times and breakdown fields. During damascene integration, low-k dielectrics are subjected to processes that create material damage, where plasma exposure is one of the critical processes. During such processes, methyl groups are extracted from the network which leads densification and k-value increase. Plasma damage could make the dielectric hydrophilic which facilitates moisture uptake, where moisture adsorption degrades reliability performance and cannot be solved by a post annealing step. A stable barrier/metal system is needed to ensure reliable electrical performance. Copper and barrier metal penetration inside the dielectric during barrier deposition or electrical stress are fatal as they facilitate electrical conduction and enhance local fields. Also, optimal CMP processes are necessary since the potential introduction of dangling bonds, metal contaminants and moisture significantly shorten the failure times. In order to have a successful implementation of advanced ultralow-k films in future BEOL interconnects, more research efforts are needed with respect to material screening and integration optimization. As shortly discussed in this paper, fabrication of porogen free low-k dielectrics with robust matrix arrangement is a first step to ensure sufficient reliability. However, high porosity and large pore sizes in conventional PECVD low-k dielectrics make them sensitive to integration induced damages. Therefore, optimization and
innovation of integration approaches have to overcome to achieve the reliability challenges, such as plasma damage, moisture adsorption and CMP damage etc..

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