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Advanced Organic Polymers for the Aggressive Scaling of Low-k Materials

M. Pantouvaki[1], L. Zhao[2], C. Huffman[1], N. Heylen[1], Y. Ono[3], M. Nakajima[3], K. Nakatani[3], G. P. Beyer[1] and M. R. Baklanov[1]

[1] imec
Kapeldreef 75, B-3001, Leuven, Belgium
Phone: +32-16281861, E-mail: Marianna.Pantouvaki@imec.be
[2] INTEL Corporation
Kapeldreef 75, B-3001, Leuven, Belgium
[3] Sumitomo Bakelite Co, Ltd
Yokohama, Kanagawa, 245-0052, Japan

1. Introduction

Due to the hybrid nature of organo silicate glasses (OSG), loss of the Si-CH_3 bonds during plasma exposure is a fundamental weakness of this materials class. This effect is compounded by the need to increase the porosity to achieve even lower k-values. Organic polymers offer the advantage of a rather homogeneous bond structure and a lower polarization for the same degree of porosity. Dense organic polymers are resistant to Cu diffusion. Cu/dense organic damascene structures without barrier were fabricated with a dielectric spacing of 90 nm [1, 2].

In order to investigate the scalability of organic polymers both in terms of k-value and dimension, we have been reducing the k-value of an organic polymer down to 2.2 by adding porosity. Furthermore we have been building single damascene structures with dielectric spacings ranging from 75 to 30 nm, thus spanning the range of spacings of 3 technology nodes. Structures with and without Cu diffusion barriers were fabricated to study the dependence of Cu diffusion on porosity.

2. Integration

The properties of the organic low-k material used in this work are described in Table 1 and in [3]. The advantages of this material include the low pore radius and low coefficient of thermal expansion. Films of 200 nm thickness were prepared on 300 mm wafers by spin-coating followed by thermal cure of 5 min at 350ºC, for study of 75 nm spacing. The film thickness was reduced to 100 nm for studying narrower spacings.

The integration flow is shown in Figure 1. The patterning approach is using 193 nm lithography and double dielectric hard-mask, similar to that presented in [4], with the exception of an additional resist-trimming step, that enables the study of the material performance in narrow spacings without changing the mask. After patterning, the trenches were filled by electro-plated Cu. For 75 nm spacing, two cases were examined, with and without a ~10 nm PVD TaN/Ta barrier. For comparison of narrow spacings a similar PVD TaN/Ta barrier was applied. Chemical-mechanical polishing removed the excessive metal and the structures were passivated before electrical characterization.

3. Results

Figure 2 shows a comparison of the yield of meanders with TaN/Ta and with no barrier for 75 nm spacing. Cu lines both with and without barrier sustained CMP stress, with only ~15% of yield lost for the case of no barrier. TEM images showed that the corners of the trenches consisted weak adhesion points when there was no barrier (Figure 2(b, c)). A comparison of the RC for Cu lines with TaN/Ta and without barrier is shown in Figure 3(a). A clear reduction of the RC product was observed in the case of no TaN/Ta barrier. This was only partially justified by differences in dimensions and by a resistivity reduction of $\delta\rho \sim 0.2\ \mu$Ohm·cm for the case of no barrier (Figure 3(b)). The remaining contribution is attributed to low-k damage induced by the PVD barrier deposition process, which impacts the integrated k-value. Time-dependent dielectric breakdown (TDDB) measurements were performed at 100ºC. The median times-to-failure versus field and the extrapolation to low fields, which was done using the conservative E-model, are shown in Figure 4. For the lines with TaN/Ta barrier, 10 years lifetime was achieved for a field greater than 1.5 MV/cm. The no-barrier case had a lifetime just below 10 years at the field of 0.1 MV/cm. This result is much better than for SiO_2 or OSG materials processed without a Cu-diffusion barrier [5]. However, when the test temperature for TDDB was increased to 200ºC, a temperature that promotes Cu diffusion, the lifetime of the no-barrier case was dramatically degraded. Consequently the organic dielectric requires a barrier to prevent the Cu diffusion. PVD Ta based barriers, however, inflict some modification to the polymer due to the kinetic deposition.

For the study in narrow spacings resist trimming was applied for various times. The yield of the lines was preserved and the capacitance scaled accordingly up to long trim times when shorts were observed (Figure 5). Figure 6 shows examples of the different spacings achieved. Current versus field measurements at 100ºC indicated a breakdown field of ~6 MV/cm for spacing down to 50 nm (Figure 7). This was reduced to ~4.5 MV/cm for 30 nm spacing. Further process optimization is required to improve the performance of such narrow spacings.

4. Conclusions

The integration of an organic low-k has been studied in single damascene structures of spacing varying from 75 nm to 30 nm, with and without a PVD barrier. For the case with barrier, no degradation of the dielectric breakdown characteristics was found for spacing down to 50 nm.

Table I Material Properties of organic low-k

k-value	2.25 ± 0.05
Pore radius	0.49 nm
Refractive index	1.47
Open porosity	~30%
Young's modulus	6.09 ± 0.52 GPa
Hardness	0.48 ± 0.04 GPa
E_{bd}	6.5 ± 0.5 MV/cm
CTE	30ppm/ºC

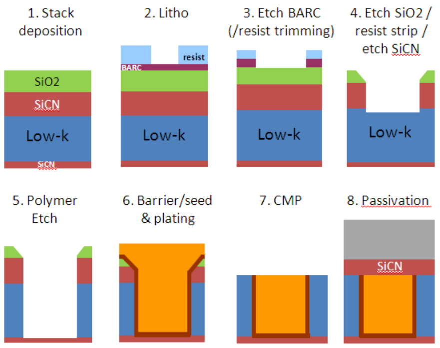

Fig. 1 Processing sequence for single damascene in organic low-k.

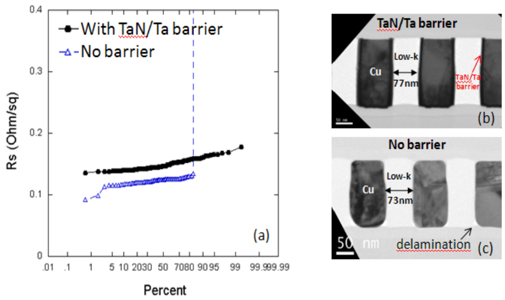

Fig. 2 (a) Meander sheet resistance (Rs) yield comparison of Cu / organic polymer lines with and without barrier; TEM images of lines with (b) TaN/Ta barrier and (c) no barrier.

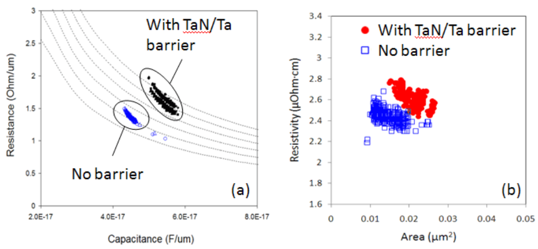

Fig. 3 (a) RC comparison of Cu lines processed with and without barrier and (b) line resistivity.

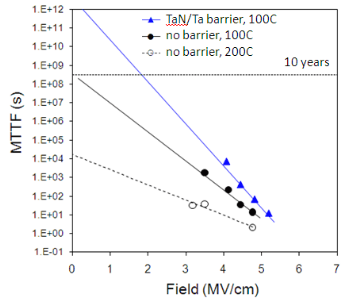

Fig. 4 Mean time-to-failure of Cu lines with and without TaN/Ta barrier, tested at 100ºC and 200ºC.

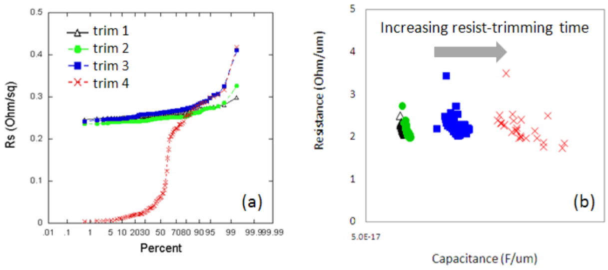

Fig. 5 (a) Meander sheet resistance and (b) RC plot of lines etched for variable resist trimming time.

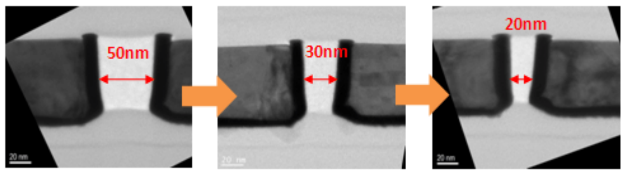

Fig. 6 TEM images of Cu lines with narrow spacings. The arrows indicate increasing resist trimming time.

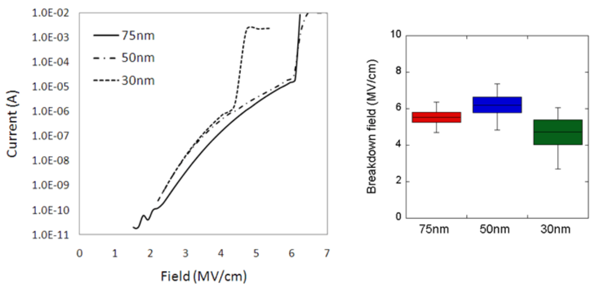

Fig. 7 Current versus field and breakdown field distribution of 75nm, 50nm and 30nm spacing, measured at 100°C.

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