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Effect of dynamic electric field on dielectric breakdown in Damascene Cu interconnects

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For the damascene Cu interconnect, aggressive nano-scaling to achieve higher performance and higher circuit density give rise to applying harsh electric field on back-end dielectrics. As device is operated under high electric fields, time dependent dielectric breakdown (TDDB) become a significant reliability issue and prediction of the dielectric lifetime is crucial issues. TDDB models have been evaluated by applying static electric field condition on dielectrics (DC condition), however, most of devices are applied to pulse shaped-dynamic electric field under operating condition. There have been reported that unipolar and bipolar electric field effect on dielectric breakdown, but the results are still controversial as well as uncertainty of TDDB model under DC condition. Therefore, development of TDDB model considering dynamic electric field and verification of the suggested model is vitally needed for device reliability. We investigate the effect of dynamic electric field on damascene Cu interconnects. According to various polarity of pulse, temperature, and pulse frequency, characteristics changes of dielectric breakdown failure were measured.

Comb-serpentine pattern were fabricated using a 0.1 μm-node standard damascene Cu process to conduct the TDDB experiments. Applied electric field is 6.5 MV/cm with bias shapes are DC, unipolar pulse, and bipolar pulse.

Duty cycle of unipolar and bipolar pulse is fixed as 50 % and frequency (f) range is from 1Hz to 100 kHz. During applied electric field, substrate temperature is maintained as, and which range is 200~225 ^{o}C. Time to failure (TTF) was defined as the time at which the leakage current reached the 10^{-5} A.

Figure 1 shows the TDDB results under 6.5 MV/cm (f=1 kHz)-225 ^{o}C condition.

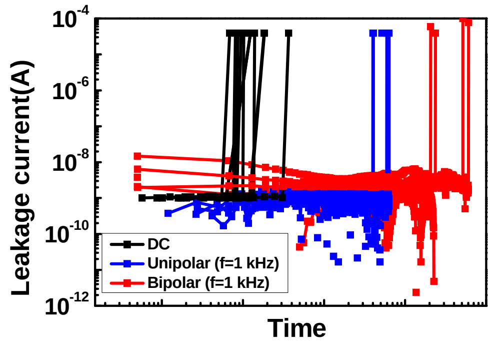

Figure 1 Log-log plot of leakage currents during TDDB tests under 6.5 MV/cm-225 ^{o}C.

TTFs of bipolar and unipolar pulse conditions are enhanced compared to that of DC condition, and the increment of lifetime is larger for bipolar condition than for unipolar condition.

When Cu migration into SiO_2 is dominant failure mechanism of dielectric breakdown, TTF under bipolar condition is longer than that under DC condition.[1] As direction of Cu migration is changed during the opposite electric field is applied, extraction of Cu migration into SiO_2 occurs under bipolar pulse condition. In contrast to bipolar pulse condition, Cu migration effect on dielectric breakdown would be same under DC and unipolar pulse condition because direction of Cu migration under unipolar pulse condition is same for that under DC condition.

It is suggested that intrinsic dielectric breakdown significantly affect the dielectric lifetime in addition to Cu migration effect under the stressing condition. Interestingly, when the temperature is down to 200 ^{o}C and other conditions are fixed, the order of TTF is the longest for unipolar pulse condition, then for bipolar pulse condition, and DC condition. Moreover, when unipolar pulse frequency increases from 1 to 10 kHz, TTF is around ten times increased than $TTF_{1\ kHz}$.

To elucidate the pulse shape and frequency dependence of TDDB, we modified the thermochemical E-model [2] by adding a fatigue concept.

The details of thermochemical-fatigue model and additional TDDB experiments to verify the model will be discussed. Our suggested model will provide the fundamental solution to estimate the reliability of dielectrics in Cu damascene interconnect.

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