Alternating Current - Induced Fatigue Damage in Cu Interconnects

박영배, C. A. Volkert*, E. Arzt*
안동대학교 신소재공학부, * 막스플랑크금속연구소

Abstract

It has recently been observed that severe fatigue damage is formed in Al and Cu interconnects due to the cyclic temperatures generated by Joule heating of the metal lines by the passage of alternating currents (AC). However, the effect of the AC frequency on the damage evolution characteristics is not known so far. In this talk, we will summarize our in-situ SEM observations of damage formation during fatigue of polycrystalline sputtered Cu lines (100 to 300 nm thick and 8 um wide) with Ta underlayer on Si (see Fig. 1). Temperature cycles with amplitudes from 100 to 300 °C and frequencies between 100 Hz and 10 kHz were applied (see Fig. 2). Damage appears as surface extrusions and intrusions and initially grows within single grains. As testing continues, the damage spreads to a larger area and eventually leads to crack formation and electrical failure of the line by local melting. The exact nature of the damage evolution depends on the grain size and orientation, which will be discussed in detail (see Fig. 3). We have previously observed that growth of damaged grains often occurs during testing, although the films had been annealed before testing to stabilize the grain structure. Our frequency studies, comparing 100 Hz and 10 kHz, show that this is a general phenomenon but is strongly enhanced by high frequencies. The higher loading frequency not only accelerated grain growth of damaged grains, but also led to earlier failure. Generally, smaller grained films exhibited longer lifetimes. Finally, results from the effect of a soft overlayer on damage formation and fatigue lifetime will be presented. These results imply that thermal mechanical fatigue may be a serious reliability threat to Cu interconnects with soft low k interlevel dielectrics.

References

[1] R.R. Keller, R. Moenig, C.A. Volkert, E. Arzt, R. Schwaiger, and O. Kraft, in AIP *Proceedings of the 6th International Workshop of Stress Induced Phenomena in Metallization,* edited by S.P. Baker, M.A. Korhonen, E. Arzt, P.S. Ho, (AIP, Melville, NY, 2002) 119-132.

[2] C. A. Volkert, R. Moenig, Y. B. Park, and G. P. Zhang, "Fatigue as a Reliability Concern in Microelectronic Interconnects", *Mat. Res. Soc. Spring Meeting,* Symposium E: Materials, Technology, and Reliability for Advanced Interconnects and Low-k Dielectrics (2003).

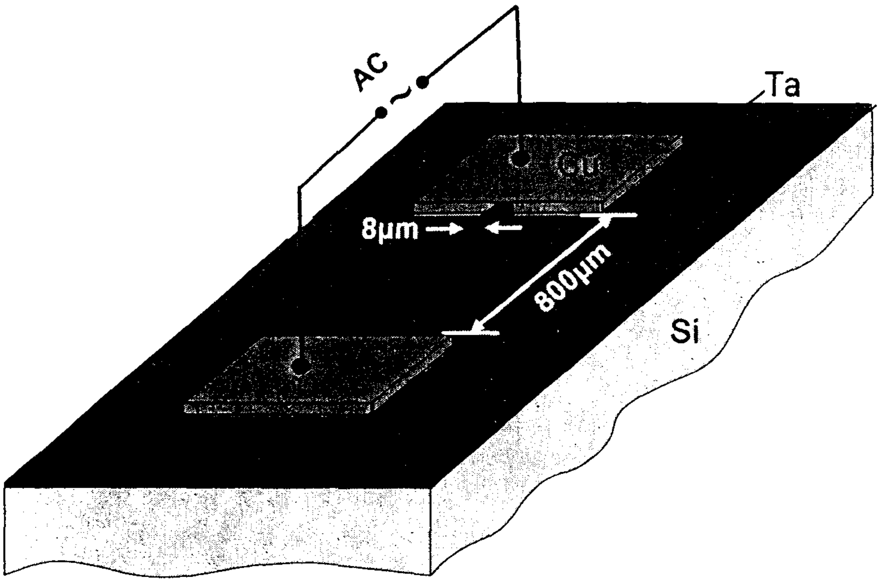

Fig. 1. Schematic of the sample structure used for thermo-mechanical fatigue testing by AC.

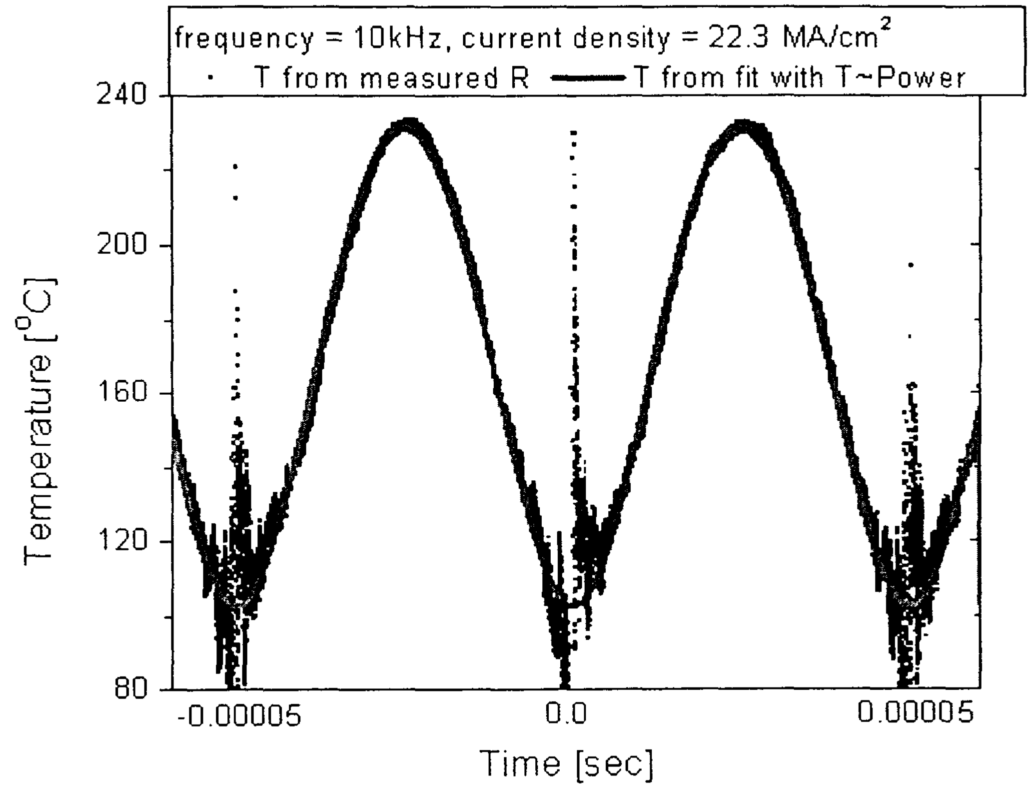

Fig. 2. Measured (dot point) and fitted (solid line) temperatures of 10nm Ta\200nm Cu line at rms current density of 22.3 MA/cm^2 and frequency of 10kHz.

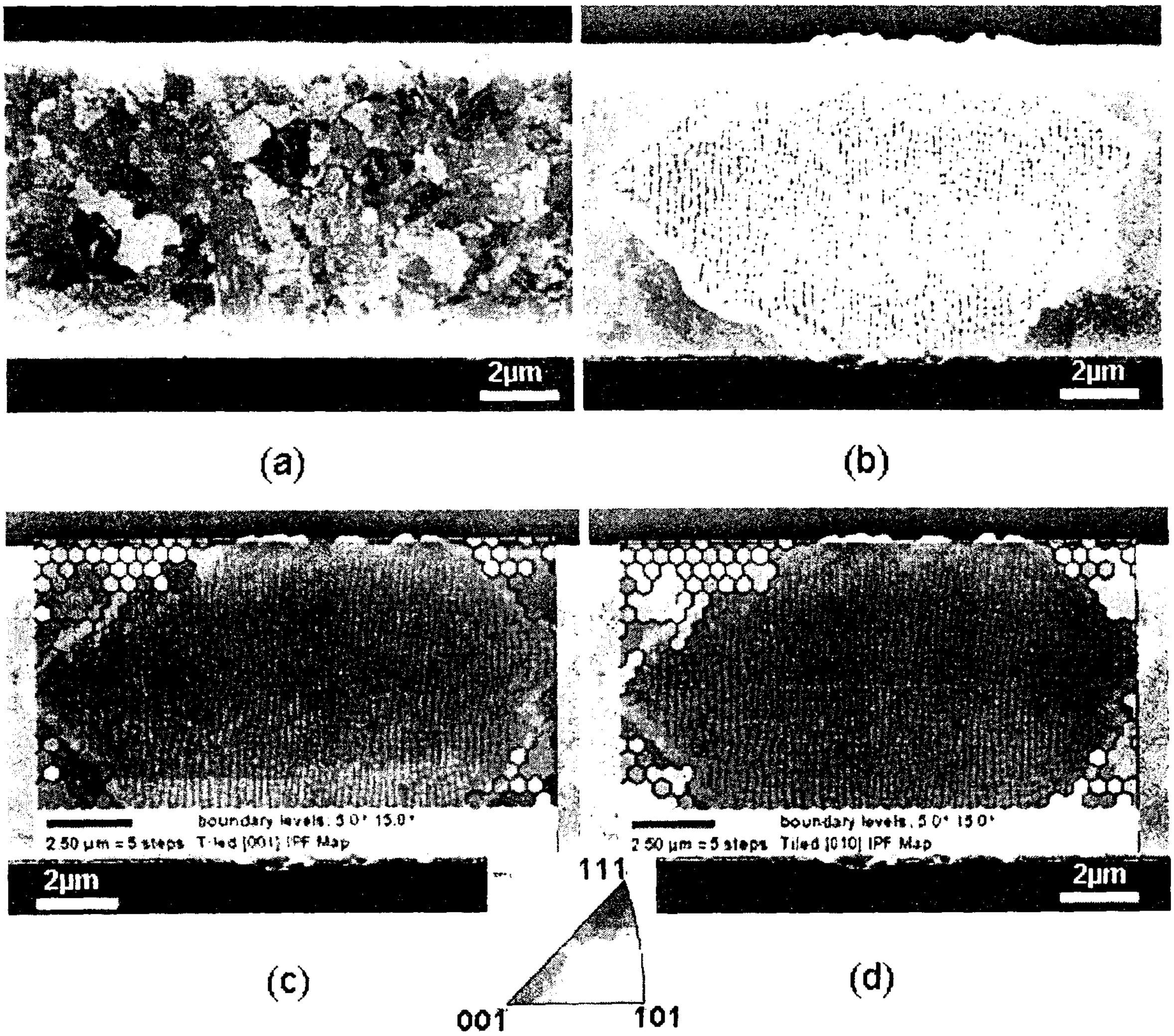

Fig. 3. Damaged (100) grain microstructure of 10nm Ta\200nm Cu line (a) BSE image of the line before AC test, (b) SEM image, (c) EBSD map of out-of-plane orientation, and (d) EBSD map of in-plane transverse (line) orientation for a big damaged (100) grain after AC test at 10kHz frequency, Δ = 190°C, and $7.5X10^5$ cycles. Here, [001] and [010] directions marked in EBSD pictures corresponded to out-of-plane orientation and in-plane line orientation, respectively.

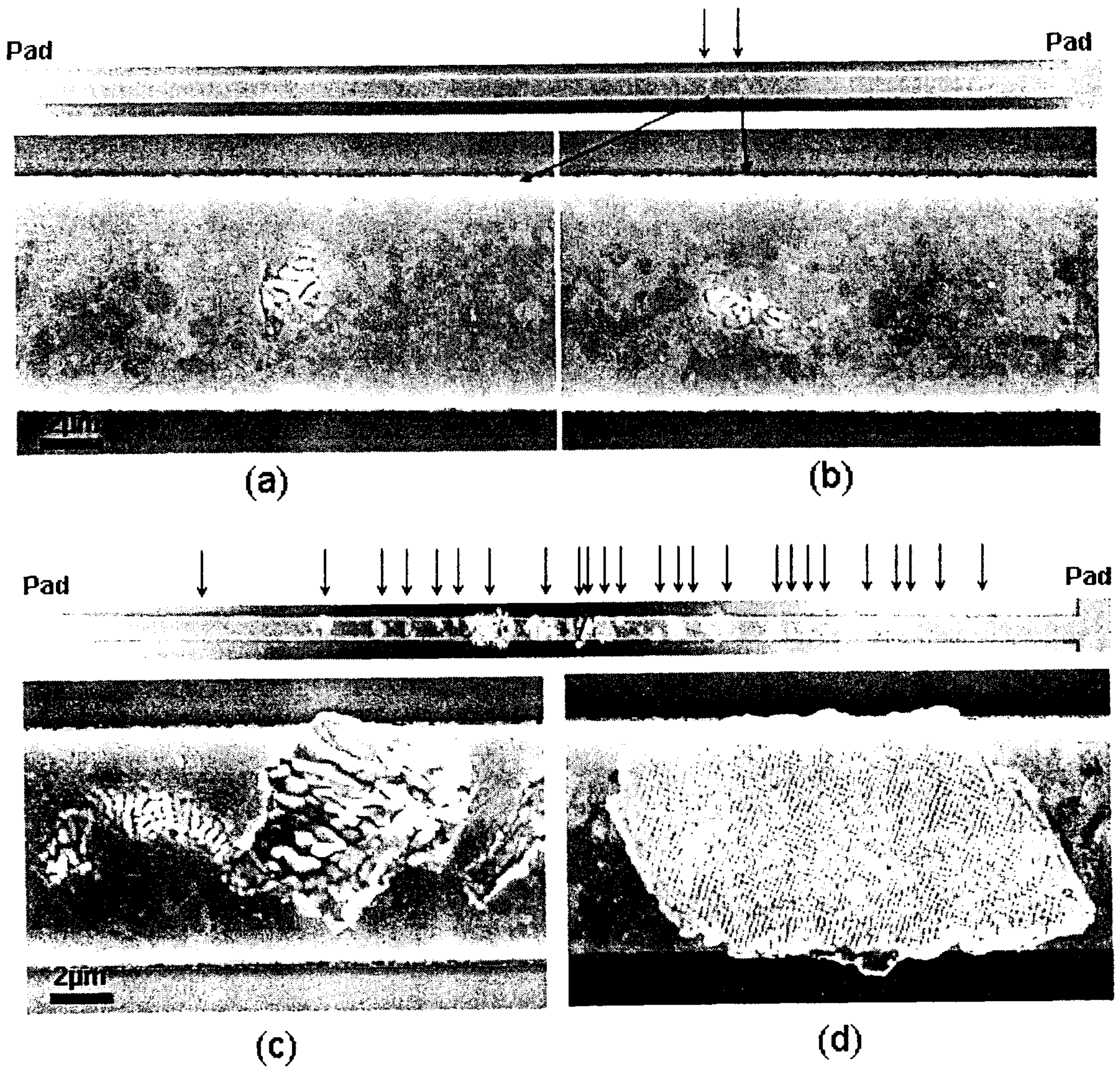

Fig. 4. Loading frequency effect of coarse-grained 10nm Ta\200nm Cu lines SEM pictures of tested whole metal lines (upper long lines) and of representative damage morphologies (lower damage pictures) for Δ = 190°C by applying (a), (b) 100Hz and stopped at $8.0\mathrm{X}10^5$ cycles with 0.2% DAF, and(c), (d) 10kHz and failed at $8.0\mathrm{X}10^5$ cycles with 20% DAF. Here, damaged area fraction (DAF) was defined as total damaged area observed from SEM pictures of whole metal line divided by the whole metal line area. Each arrow in upper line means each damage location in whole metal line.