STRAIN RATE INFLUENCE ON THE THERMO-MECHANICAL DEFORMATION BEHAVIOR OF ALUMINUM THIN FILMS

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Thin metal films used as top metallization in power semiconductor applications may repetitively undergo rapid temperature changes with heating rates reaching 10^6 K/s. It is well known that the mismatch of the coefficients of thermal expansion between metal and substrate causes stresses in the films, and this effect may lead to their thermo-mechanical fatigue.

The stress vs. temperature behavior of such film-on-substrate combinations is mostly analyzed using X-ray diffraction or wafer-curvature-based methods. Both classes of methods can generally only be applied for analyzing materials undergoing slow temperature changes, either due to experimental constraints, e.g. measurement times in the XRD, or due to problems with stress calculation, e.g. Stoney formula being only valid for homogeneously heated specimens. It is questionable if the material response at low and high heating rates is comparable; hence, the development of methods to monitor the material behavior in a situation close to the application conditions is needed.

A novel setup which allows measuring wafer curvature during rapid temperature changes has recently been developed 1, allowing the rapid heating of the tested metallizations using Joule heating and the simultaneous measurement of specimen curvature using either a high speed camera or laser scanning Doppler vibrometer. Using this setup, heating rates between 10^2 and 10^5 K/s can be utilized, to study the effect of cyclic heating with various temperature amplitudes and repetition rates on the metallization behavior. The stress-temperature behavior measured in such films is compared to the results obtained by standard wafer curvature experiments conducted at heating rates of less than 1 K/s.

When comparing films cycled at 10^2 K/s and 10-1 K/s, the measurement results show that below 85 °C the coatings deform elastically and an identical deformation behavior is observed. The good comparability of the material behavior in the elastic regime proves that the novel setup is able to correctly measure curvature at high heating rates. At temperatures above 85 °C, where plastic deformation sets in, significant differences are seen in the specimens, which are caused by the influence of the different time-dependent relaxation mechanisms active at such temperatures. Microstructural changes in the films undergoing cycling at various heating rates are monitored using scanning electron microscopy and confocal laser scanning microscopy.

Finally, the advantages and disadvantages of the application of fast temperature cycling to measure the stress-temperature behavior are discussed.

1 T. Islam, J. Zechner, M. Bernardoni, M. Nelhiebel, and R. Pippan, Rev. Sci. Instrum. 88, 24709 (2017).