DAMASCENE PATTERNED METAL/ADHESIVE WAFER BONDING FOR THREE-DIMENSIONAL INTEGRATION

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An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

DOCTOR OF PHILOSOPHY

Major Subject: Electrical Engineering

The original of the complete thesis is on file
In the Rensselaer Polytechnic Institute Library

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February 2008
(For Graduation May 2008)

ABSTRACT

Wafer bonding of damascene patterned metal/adhesive surfaces is explored for a new three-dimensional (3D) integration technology platform. By bonding a pair of damascene patterned metal/adhesive layers, high density micron-sized vias can be formed for interconnection of fully fabricated integrated circuit (IC) dies at the wafer-level. Such via dimensions increase the areal interconnect density by at least two orders of magnitude over current package and die-stacking approaches to 3D integration. The adhesive field-dielectric produces a high critical adhesion energy bond and has the potential to produce void-free bonded interfaces.

This new technology platform has been demonstrated by fabricating and characterizing inter-wafer via-chains on 200 mm diameter Si wafers. Copper and partially cured divinylsiloxane bis-benzocyclobutene (BCB) are selected as the metal and adhesive, respectively, and unit processes for this demonstration are described. Typical alignment tolerance is ~2 μm, and baseline bonding conditions include vacuum of 5×10^{-4} mbar, bonding force of 10 kN, and two step bonding temperature of 250 ^{o}C for 60 min followed by 350 ^{o}C for 60 min. Integration issues associated with the damascene patterning and the wafer bonding processes are discussed, particularly the resulting topography of damascene patterned Cu/BCB. Cross-sectional investigation of bonded and annealed inter-wafer interconnections provides insight into the Cu-Cu and BCB-BCB bonding interfaces. Inter-wafer specific contact resistance is measured to be on the order of 10^{-7} Ω-cm^2 for these via-chains.

Several material characterization techniques have been explored to evaluate partially cured BCB as an adhesive field-dielectric. To investigate the critical adhesion energy, G_c, four-point bending is utilized to compare surfaces bonded after chemical-mechanical planarization (CMP) and various post-CMP treatments. The G_c of bonded 50% partially cured BCB is measured to be in the range of 32-44 J/m^2. The elastic modulus of the BCB is investigated by monitoring film stress behavior for temperatures just below that needed for crosslinking (i.e. the temperature where BCB-BCB bonding begins). The film-stress temperature dependence is then used as an indicator for phase transitions in the BCB that affect elastic modulus. Surface analysis techniques are used to explore the surface chemistry of the BCB and measure its surface energy over the temperature range

required for bonding. The surface energy of partially cured BCB at both 50 and 90% crosslinking is measured to decrease by ~30% when the temperature is raised from 35 ^{o}C to 230 ^{o}C. The surface analysis and mechanical properties studies provide insight into the capability of BCB to close gaps when in contact during bonding, a necessary condition for forming void-free bonding interfaces.

One important aspect for implementing wafer-level 3D integration is the ability of a technology platform to accommodate topography on fully fabricated wafers. The aforementioned metal/adhesive 3D platform has strict requirements in this regard if void-free surfaces are to be attained. A bonding protocol that eliminates the copper and tantalum interconnect structure is utilized to investigate the deformation capability of partially cured BCB during bonding. The results indicate that the defect density of such BCB-BCB bonds depends on material parameters such as the degree of crosslinking and surface energy, the pitch of the features, and the depth of the topography to be accommodated. For 70-90% crosslinked BCB, accommodation was observed for lines ~120 nm deep and ~100 μm in pitch. Furthermore, 70-90% crosslinked BCB lines with pitch ~1 μm and depth ~12 nm were accommodated during bonding. When the BCB crosslinking is reduced to 50%, additional accommodation is observed. In such cases, lines with pitch ~100 μm and depth ~500 nm, and those with pitch ~1 μm and depth ~50 nm were accommodated. Additional work has shown that accommodation of some topography is possible even with zero down-force during bonding.

The accommodation of topography has been evaluated by extending previously published models that focused on Si-Si bonding to this new 3D integration technology platform. Accommodation prediction through use of this first-order model is found to agree with experimentally observed results when the BCB is crosslinked to a degree of 70-90%, with increased accommodation observed in the experiments that use 50% crosslinked BCB. This disagreement is attributed to the elastic modulus of the 50% BCB decreasing when passing through its glass transition temperature.

The feasibility of a new 3D integration technology platform has been demonstrated with critical unit processes characterized. Key results include the demonstration of inter-wafer via-chains, material characterization for partially cured BCB for this new bonding application, and quantification of topography accommodation.