Plasma Science and Technology
Room 315 - Session PS2-WeM

Plasma Applications in Packaging and Wafer Bonding

Moderators: Prof. Kenji Ishikawa, Nagoya University, Japan, **Dr. Jeffrey Shearer**, TEL Technology Center, America, LLC

11:00am **PS2-WeM-13 Etch Opportunities in Advanced Packaging, Silicon, and Optical Photonics*, Brittany Hedrick,*** Tokyo Electron America **INVITED**

Advanced Packaging grows more complex as the ever-increasing need for bandwidth, power, and memory persists and drives down feature geometries: from the transistor to the electrical routing line/space, and out to the assembled system through ever-finer plated interconnects and optical interconnects. Interconnect density pitches for conventional electrical interconnects are teetering between the realm of plated micropillars and Cu-Cu bonding down into D2W and W2W pitches enabled by direct Cu Hybrid bonding. Ever thinner HBM layers drive unique TSV integration for ultra thin die and singulation methods to handle these devices with high yield.

Meanwhile Si photonics features have been added to the mix to handle data for long haul and short haul tele-com/data-com and are finding traction in Quantum and AI applications as well.Introducing new materials into standard CMOS flows, Si photonics and Quantum computing devices are driving new tooling applications, novel processes, and research and development activities seeking advances in performance improvement.Waveguide materials and designs, for telecom and datacom, continue to be refined for improved propagation loss performance, and the optical interconnect features themselves are etched, milled, and engineered to reduce insertion loss to as close to 0 as possible.

In the consumer electronics sector personal devices are evolving from cell phones to AR glasses, with top makers looking to bring fashionable, functional, lightweight, and efficient devices to market for mass adoption. Optical photonics now drives glass and SiC wafer device fabrication across traditionally Si wafer/CMOS semiconductor tools.Depositing thin films on glass, litho, etch, and encapsulation to fabricate optical gratings for AR lenses provide new challenges the industry is rapidly rising to address.

Tokyo Electron (TEL) is working across these spaces to develop processes and equipment to keep pace with the ever-evolving packaging world. Throughout the presentation we will highlight recent process developments and practical adaptations in etch technology that respond to these growing industry applications.

11:30am **PS2-WeM-15 Impact of Surface Activation Plasma Chemistry on AlN - Oxide Wafer Bonding for BSPDN Applications*, Chetan Jois,*** *Ryan Allen, Yusuke Suzuki, Andrew Tuchman, Christopher Netzband, Rinus Lee, Ilseok Son,* Tokyo Electron America, Inc.

In Backside Power Delivery Network (BSPDN) process flows, a carrier wafer is bonded to enable wafer thinning and backside access. When the carrier is retained for packaging, the bonding interface plays a dual role as both a mechanical support and a thermal transport pathway. Conventional oxide bonding dielectrics, such as SiO_2, introduce a thermally resistive layer between the carrier and device wafers, motivating the use of alternative bonding materials with improved thermal properties. Aluminum nitride (AlN) has emerged as a promising thermally conductive dielectric for carrier bonding. For integration, bonding interfaces must exhibit bonding energies greater than 1.5 J/m^2 to enable downstream processing and ensure mechanical reliability. However, achieving high bonding energy with AlN based films at low thermal budgets remains a key integration challenge. In this work, we investigate the bonding behavior of a thin AlN based bonding stack consisting of 30 nm PVD AlN capped with 5 nm ALD Al_2O_3, bonded to a thermally grown 100 nm SiO_2 carrier wafer. The surface activation plasma (SAP) process window is systematically studied with direct comparison between O_2 and N_2 plasma chemistries. Bonding energy measurements show a strong dependence on SAP gas chemistry, with O_2 plasma activation yielding higher bond strength than N_2 plasma under comparable process conditions, achieving a bond energy of 2.8 J/m^2 at optimized settings. Surface chemical analysis reveals that O_2 SAP results in a higher concentration of H_2O and hydroxyl related species compared to N_2 activated surfaces, indicating enhanced surface hydration that promotes stronger interfacial bonding. Post–anneal bond energy is found to correlate well with bond propagation speed and surface contact angle, suggesting that improved initial surface adhesion directly translates to increased final bond strength. Finally, the impact of SAP conditions on post–bond lithography overlay (PBLO) is evaluated for BSPDN integration.

11:45am **PS2-WeM-16 Optimization of Dielectric Plasma Activation for Wafer to Wafer Fusion Bonding*, Christopher Netzband,*** Tokyo Electron America Inc.,*; Andrew Tuchman, Ilseok Son, Angelique Raley,* Tokyo Electron America, Inc.

As logic and memory scaling slows, the demand for higher interconnect density and speed has increased, especially among NAND and DRAM companies. Device performance gains are increasingly achieved in the back end of line using wafer-to-wafer (W2W) hybrid bonding for 3D NAND, CIS, 3D-SoC, and eventually bonded CFET architectures. One major hurdle to achieving bonded CFET structures is the strength and reliability of the bonding interface. If the mechanical strength of the bonding is low the wafers will come apart during grinding or etching, while if the chemical strength is low they will be etched apart during subsequent wet cleans. Most dielectric films have poor mechanical bonding strength as deposited they require plasma activation to enable bonding. This plasma activation breaks the surface bonds enabling hydrogen bonding and condensation to covalent bonds after a post-bond anneal. Unfortunately, just running this activation does not ensure good mechanical or chemical bonding strength as the results can vary based on your incoming film.

In this talk we will discuss what properties are most important for high quality bonding across a range of bonding materials. Examples of film properties that influence plasma parameter selection include exposed metal (hybrid bonding), thickness and density. In the case of hybrid bonding the plasma activation must be very low power and confined to the surface to eliminate the chance of leakage pathways along the bonding interface caused by Cu sputtering. Similar considerations are needed for thin oxides. If the interaction depth of the plasma is too deep can impact underlying layers or, if deposited directly on Si, cause hydrogen gas at the film/Si interface. While it is well known that SiO_2 performs better with N_2 plasma versus O_2 plasma, the degree of the difference between these activation gasses is directly correlated to the porosity of the films. In CVD TEOS the difference in bond strength between the two activation gasses is small and the interface after bonding is void free. Conversely, highly dense thermally grown SiO_2 has a 60% lower bond strength when using O_2 gas for the plasma activation and has small voids at the wafer edge caused by the plasma that further reduce the chemical and mechanical strength of the bond leading to quicker stress corrosion than the N_2 case. By understanding how to adjust plasma activation conditions to obtain high quality bonding with a wide range of materials even more opportunities for hybrid and fusion bonding will emerge in advanced packaging.

12:00pm **PS2-WeM-17 Plasma-Induced Surface Modification of Indium for Improved Bonding*, Kristen Steffens,*** National Institute of Standards and Technology (NIST)*; Sujitra Pookpanratana,* National Institute of Science and Technology (NIST)*; Junyeob Song, Marcelo Davanco, Tammy Lucas, John Biesecker, Daniel Schmidt,* National Institute of Standards and Technology (NIST)

Bonding between materials plays an important role in advanced microelectronics integration and packaging by bringing together components and devices produced separately.Surface pretreatments on bonding materials have been consistently found to be crucial to achieving a high-quality bond, despite incomplete understanding of why certain treatments have greater success than others.Our project aims to improve understanding of atmospheric plasma pre-treatment effects to provide information to enable more efficient development of bonding protocols.

Indium is a critical material for conductive interconnects for the fabrication of cryogenic low-temperature electronics and optical detectors for infrared and microwave applications. Since indium is a superconducting material which retains its ductility and adhesion properties during thermal cycling, it sees particular use for Quantum Information and Quantum Sensor applications [1].Certain pre-bond plasma treatments increase the success of In-In bond adhesion.We have observed that plasma chemistries such as H_2/He, which do not include N_2 as a plasma gas, promote more successful In-In bonding.To understand why, we investigate the effects of atmospheric plasma exposure on indium surfaces for several plasma chemistries including He/H_2/N_2, He/H_2 and He/N_2.X-ray photoelectron spectroscopy (XPS) and ultraviolet photoelectron spectroscopy (UPS) are used to characterize indium surfaces prior to and after ambient pressure plasma treatment.All plasma treatments decreased the amount of carbon and increased both the amount of In-oxide present as well as the indium oxide/metal ratio as compared to an untreated film.N-$_2$-containing plasmas resulted in the appearance of an additional high binding energy peak in the N 1s XPS spectrum.We postulate that this may be due to nitrate species formed on the indium native oxide surface. Additional experiments were performed on indium foil both prior to and after Ar sputtering for comparison to treated samples.Nitrogen was found to be confined to the surface and reappeared after eleven weeks of exposure to air at room temperature.

UPS measurements showed that all plasma chemistry treatments lowered the work function compared to the non-treated control.Greater spatial variation in work function was observed for chemistries with high N_2 versus those with little to no N_2.This finding possibly correlates with poorer bonding for N_2 containing plasmas.

[1] T. J. Lucas, J. P. Biesecker, W. B. Doriese, S. M. Duff, M. S. Durkin, R. A. Lew, J. N. Ullom, M. R. Vissers, D. R. Schmidt, J. Low Temp. Phys. **216**, 67 (2024)

Author Index

Bold page numbers indicate presenter