MEMS and NEMS
Room Ballroom BC - Session MN-ThP
MEMS and NEMS Poster Session

MN-ThP-1 Statistical Analysis of 3D Printability and Mechanical Performance in Reinforced Polymer Composites*, **Vladimir Milosavljevic**,* School of Physics, Clinical & Optometric Sciences, Technological University Dublin, Ireland*; Alison J. Clarke, Denis P. Dowling,* I-Form Centre, School of Mechanical & Materials Engineering, University College Dublin, Belfield, D04 C1P1 Dublin, Ireland

The study explores the challenges and opportunities in 3D printing continuous fiber-reinforced polymers, with a focus on Polylactic Acid-Stainless Steel Fiber (PLA-SSF) composites. Statistical analysis of the printed parts highlighted deviations from design specifications, especially in acute angles and tight radii, emphasizing the need for optimized printing parameters and tooling paths. Fiber migration and excess polymer deposition were identified as key factors influencing geometric distortions, particularly at smaller radii and more acute angles. The study also developed a curvature bending stiffness (CBS) testing methodology to assess the mechanical performance of PLA-SSF composites, comparing them with neat PLA, nylon with short carbon fibers (Onyx), and nylon with continuous carbon fibers (Onyx-cCF). Results showed that PLA-SSF composites exhibited the highest CBS, with stiffness increasing linearly as radii decreased from 20 mm to 3 mm. PLA and PLA-SSF samples failed by tensile fracture, while Onyx samples deformed without fracturing. By employing statistical techniques, the study achieved a robust analysis of the printability and mechanical performance. The non-parametric Kruskal-Wallis test allows for the comparison of medians across multiple groups, such as different materials or different geometries, providing a reliable way to assess differences in mechanical performance without relying on normal distribution assumptions. Moreover, regression analysis is valuable for modeling relationships between printing parameters and outcomes such as dimensional accuracy or mechanical performance. This technique helps optimize printing parameters to achieve better results. Further, the Wilcoxon Signed-Rank Test, a nonparametric method, is useful for comparing as-printed dimensions with designed dimensions, especially when data does not follow a normal distribution. It provides a robust way to assess deviations from design specifications. The findings highlight the geometric limitations of 3D printing continuous fiber-reinforced polymers and suggest that adjusting printing speeds and tooling paths can mitigate distortions. This work provides critical insights into optimizing the printability and mechanical performance of reinforced polymer composites for advanced manufacturing applications. Moreover, the findings not only provide insights into improving the geometric accuracy and mechanical properties of 3D-printed composites but also suggest potential applications in structural health monitoring and sensor technologies. This work contributes to advancing the understanding of reinforced polymer composites for high-performance manufacturing applications.

MN-ThP-2 Performance of Copper Filled Through Glass Vias for Radio Frequency Applications*, **Jessica McDow**, Scott Grutzik, Matthew Jordan,* Sandia National Laboratories

The material properties of glass such as low dielectric constant and loss, low roughness, adjustable coefficient of thermal expansion (CTE), and low electrical conductivity at high frequencies make it a desired material for high function radio frequency (RF) device interposers.[1] Through glass vias (TGV) are a key technology for incorporating 3D integration techniques into RF devices as a way of improving device performance, increasing I/O per unit volume, simplifying design and assembly, and allowing for a more compact system. Vias are typically filled with copper (Cu) to form an electrical connection from one surface to another. Although TGVs are a promising technology, they are subject to thermo-mechanical reliability challenges due to the interaction between glass and Cu during thermal cycling. The thermal mismatch between copper (CTE_{Cu}= 16.7e^{-6}/°C) and glass (CTE_{glass}= 3.4-9.0e^{-6}/°C) can cause reliability issues, such as glass fractures, Cu protrusion, and Cu via sliding and delamination which are difficult failure mechanisms to predict.

In this work, Corning SG3.4 glass was bonded to an Si carrier with vias fabricated of diameters 30 um, 50 um, and 75 um in both square and hexagonal arrays with three different pitches being investigated 120 um, 160 um, 200 um. These samples were tested in various methods to study the mechanical and thermomechanical stability of Cu filled TGVs. For thermomechanical stability, the vias were filled with Cu through an electrochemical depTosition (ECD) process with a 30 nm platinum seed layer. The variation in TGV geometry was studied to determine the yield strength of glass for the different TGV geometries and densities. This was used to develop optimal design and process parameters for future TGV applications in RF devices. The Cu filled TGV samples were heated in a reflow oven which allows for controlled ramp rates and dwell times while keeping the substrates in an inert environment. Observed fractures and Cu protrusion was recorded to determine yield strength. Mechanical stability was studied through various flexure method tests to understand how the glass performed with the various via densities. This work demonstrates novel design and process parameters for reliability of through glass vias for future generation RF devices. Different via geometries and densities were analyzed to determine the yield strength of a glass interposer, relieving stress and reliability issues within RF devices.

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[1]K. Pan *et al.*, *2021 IEEE 71st Electronic Components and Technology Conference (ECTC)*, pp. 1660-1666, doi: 10.1109/ECTC32696.2021.00263.

MN-ThP-3 3D Microfluidic Integrated Electronic Packaging for Enhanced Thermal Management via Two Photon Polymerization*, **Angel Yglecias**,* University of Texas at El Paso

Thermal management currently stands in the way of optimizing chip performance for the increasingly powerful and compact microsystems needed for heterogenous integration. Utilizing 3D printing, this work addresses these current thermal management limitations by actively cooling a device die mounted directly onto a microfluidic channel, to provide a package level cooling solution. Historically thermal management has been addressed at the board level through heat sinks and lead frames, where the package simply provides a passive thermal conduction conduit between the lead frame and PCB below. Designs to incorporate active cooling onto PCBs have shown promise but require larger systems real estate and are not in direct contact with the die, limiting performance. Alternatively, die level cooling designs use standard microfabrication techniques to etch channels directly onto the backside of semiconductor dies to yield high performance, but at the cost of increasingly the complexity of the cleanroom fabrication steps. The proposed design is a printed microfluidic pin-fin cooling package printed using two photon polymerization (2PP). 2PP uses a laser to selectively cure a photopolymer resin or photoresist, allowing direct writing of polymer microstructures with features down to 200 nanometers. Through 3D printing, not only do structural design options become vast, but optimization of microfluidic effects, thermal resistance, and heterogeneous integration can be performed. We have previously demonstrated metal microfluidic packages using direct metal laser sintering, but this work explores the capabilities and resulting performance of 3D microfluidic packaging utilizing 2PP manufacturing techniques. Where previous work utilized designs with no variable features in the Z-direction, the 2PP packaging work implements spiral topologies to enhance fluidic interactions with the die. Scanning electron microscopy and fluidic cooling performance are explored to characterize the 2PP manufactured microfluidic packages for comparison to the state of the art.

MN-ThP-4 Nanomechanical Response of Magnetic 2D Materials Across Phase Transitions*, **Timofei Savilov**, Makars Šiškins, Konstantin Novoselov,* NUS Institute for Functional Intelligent Materials, Singapore

Recently identified as extremely promising candidates for next-generation nanoelectromechanical systems (NEMS), magnetic 2D materials are particularly well suited to applications where magnetic ordering and mechanical motion are tightly coupled, such as sensors and spintronics. The high area-to-volume ratio of suspended 2D resonators makes them highly sensitive to magnetic phase transitions through strain change detected by mechanical properties such as resonance frequency and dissipation.

We explore the coupling of magnetic ordering to nanomechanical response as a function of external conditions, including temperature and magnetic field. Theoretical modeling is done using Landau phase transition theory to analyze the magnetic behavior. The theory used focuses on the dynamic regime and does not rely on assumptions of small deflections, which makes it suitable for more general applications under extreme conditions. The model is also tested against experimental data obtained on $CrBr_3$ and $FePS_3$ nanodrums.

This work provides the basis for further development of improved NEMS sensors and actuators that use phase transitions to enhance performance.

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