Topical Symposia

Room Pacific Salon 3 - Session TS3+4-2-MoA

Surface Engineering for Lightweight Materials & Thin Film Materials for Flexible Electronics

Moderators: Klaus Böbel, Bosch GmbH, **Oleksandr Glushko**, Erich Schmid Institute of Materials Science, **Nicholas Glavin**, Air Force Research Laboratory, Materials and Manufacturing Directorate, USA

2:20pm **TS3+4-2-MoA-3 Electro-mechanical Reliability of Flexible Electronics: An Overview of Testing and Characterization Techniques**, ***Oleksandr Glushko**, M Cordill,* Erich Schmid Institute of Materials Science, Austria

In this presentation an overview of three main mechanical test concepts will be given along with numerous examples of the reliability parameters which can be gained from these tests. Monotonic tensile test is a standardized technique which is used for characterization of general mechanical reliability parameters of a flexible system under tension. It will be shown how to describe general material behavior (from brittle to ductile), determine the crack onset strain or estimate the density and lengths of cracks with the help of tensile test combined with in-situ measurements of electrical resistance. Cyclic tensile (fatigue) testing is a well-established method to examine the stability of flexible components when small amounts of mechanical strain are repeatedly applied. Examples of different types of damage development with the cycle number will be given for materials with different microstructures. Finally, bending tests are required to prove the mechanical performance under conditions which closely simulate the real usage conditions of a flexible electronic device. Because there is no unified approach or standard for flexible electronics, different available bending test methods will be reviewed along with the typical cases of mechanical response. A special emphasize on the correlation between mechanical damage and the degradation of electrical conductivity will be made. It will be shown that, under given conditions, significant topological changes in metallization layers might occur without pronounced growth of measured electrical resistance.

2:40pm **TS3+4-2-MoA-4 Bending Fatigue of Al/Mo Bilayers on Polymer Substrates with Varied Al Layer Thickness**, ***Patrice Kreiml**, M Rausch, V Terziyska,* Montanuniversität Leoben, Austria*; J Winkler,* Plansee SE, Austria*; C Mitterer,* Montanuniversität Leoben, Austria*; M Cordill,* Austrian Academy of Sciences, Austria

In traditional display technologies for rigid flat panel displays, magnetron sputter deposited Mo thin films, acting both as diffusion barrier and adhesion layer, are often used in combination with Al thin films, acting as charge carrying layer. With the increasing demand for flexible displays, for instance for the application in foldable smartphones, the mechanical limitations of these systems have to be systematically investigated and fully understood. *In situ* straining experiments, combining optical and electrical failure analyses, demonstrated the dominance of the brittle Mo layer on the bilayer fracture and increasing the Al-layer thickness has proofed to lighten its impact. Although general trends can be made visible from that approach, no quantified lifetime predictions under conditions close to reality can be drawn. Due to that a series of Al/Mo bilayers was magnetron sputter deposited on polymer substrates, keeping the thickness of the Mo layer at constant 30 nm and varying the thickness of the Al layer on top from 30 over 75 to 150 nm. These thin films were then tested on a custom-built bending device at different modi: (i) 20,000 cycles of compressive bending strains, (ii) 20,000 cycles of tensile bending strains and (iii) alternating 10 cycles compressive and 10 cycles tensile bending strains, leading to overall 20,000 cycles of mixed applied bending strains at strains of 0.5, 1.3 and 3.1 %. In combination with intermittent optical and resistance measurements, a quantification of the electro-mechanical behavior could be conducted. The data gained from these experiments reveal the physical limits of the Al/Mo system. It will be shown that an optimized thickness ratio, an adequate choice of bending load and bending strain lead to acceptable lifetimes for flexible back-plane electrodes.

3:00pm **TS3+4-2-MoA-5 Enabling High-Power Flexible Devices through Tailored Nanocomposite Interface Materials**, ***Katherine Burzynski,*** University of Dayton, USA*; N Glavin,* Air Force Research Laboratory, Materials and Manufacturing Directorate, USA*; E Heller, M Snure, E Heckman,* Air Force Research Laboratory, Sensors Directorate, USA*; C Muratore,* University of Dayton, USA

Consumers and military personnel are demanding faster data speeds only available through fifth generation (5G) wireless communication technology. Furthermore, as wearable sensors and other devices become more ubiquitous, devices demonstrating enhanced flexibility and conformality are necessary. A fundamental challenge for flexible electronics is thermal management. Even on rigid substrates with significantly higher thermal conductivity than polymeric and other flexible substrates, the full potential of semiconducting materials is often thermally limited. The flexible gallium nitride (GaN) high electron mobility transistors (HEMTs) employed in this work are grown on a two-dimensional boron nitride (BN) release layer that allows the conventionally processed devices on sapphire wafers to be transferred using a polymeric stamp and placed onto a variety of rigid and flexible substrates. Characterization of the GaN device behavior on the as-grown sapphire wafers (prior to transfer) provide a baseline for evaluation of the thermal performance of engineered interfaces and substrates. With conventional substrates, device performance (specifically, the saturation current) is reduced when the device is transferred to polymeric substrates. The thermal dissipation is further restricted due to the addition of an adhesive layer to the substrate. Thermal imaging of devices in operation reveals that the current passing through an as-grown GaN transistor on a sapphire wafer reaches the target operating temperature at approximately five times the power of the same device transferred to a flexible substrate. Printable, thermally conductive nanocomposites integrating 1D, 2D, and 3D forms of carbon in a flexible polymer matrix, as well as metal nanoparticles, were developed to maximize heat transfer from GaN devices. The thermal conductivity of the candidate substrate materials was measured experimentally to have more than a 300 percent increase in thermal conductivity, and the performance of devices transferred to these novel flexible composite substrates was characterized. The measured thermal data was used in computational simulations to predict flexible substrate architectures effectively promoting point-to-volume heat transfer to further improve device performance. Additive manufacturing for engineered architectures of the flexible, thermally conductive substrate materials was demonstrated to substantially reduce the thermal limitation of high-power flexible electronics.

3:20pm **TS3+4-2-MoA-6 Plasma Polymers…A Family of Materials that is Full of Surprises**, ***Rony Snyders,*** University of Mons, Belgium **INVITED**

Through the years, plasma polymerization has become a well-established technique for the synthesis of almost atomically flat functionalized organic thin films which are nowadays mostly used in the biomedical field. Nevertheless, in order to further extend the application fields of these materials (supports for nanoparticles, active surface for the detection of biomolecules…), a large surface area is often necessary. In this work, we develop plasma-polymer based platforms for the stabilization of gold nanoparticles that are active in the degradation of VOC molecules. In addition to the approach consisting to grow this material onto powders or paper substrates in order to increase the surface to volume ratio, we also develop strategies allowing for a structuration, at the micro/nano-scale, of these surafces. The present presentation will focus on this part of the work. It will be described how we have established a method that allow the self nano-structuration of plasma polymers coatings by adapting their mechanical properties. Specifically, it is demonstrated that a fine control of the latter by tuning of their crosslinking degree is a promising strategy to generated wrinkling phenomenon in these materials. In this context, our results unambiguously reveal the key role of the growth temperature on the mechanical properties of the deposited layer. Particularly, it has been reported that soft viscoelastic plasma polymer layer can be synthesized by depositing the coating at temperature below 273 K. Taking advantage of this discovery, it was possible to design nano/micro patterned surfaces by combining such a viscoelastic plasma polymer surfaces with a more elastic (plasma polymer) layer. The obtained patterns are generated by complex wrinkling and degassing mechanisms that will be discussed in the presentation.

4:00pm **TS3+4-2-MoA-8 Environmental Challenges of Thin Film Systems on Polymer Substrates for Space Applications*, Barbara Putz,*** Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, Leoben, Austria*; G Milassin, C Semprimoschnig,* European Space Research and Technology Centre*; M Cordill,* Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, Leoben, Austria

Multilayer thin film systems on flexible polymer substrates build up optical solar reflectors (OSR) for thermal insulation of satellites and spacecraft. During one year of operation a satellite in low earth orbit (LEO) typically encounters 6000 thermal cycles of +/ 100°C. Due to the different coefficients of thermal expansion between the individual layers and the substrate it is important to investigate the thermo-mechanical stability of the composites as a function of the cyclic heat load. Scanning electron microscopy and focused ion beam cross-sectioning revealed, that the Inconel-Ag-Teflon system, currently used as OSR material in orbit, forms through thickness cracks and cavities in the Ag layer during thermal cycling of +/- 150°C in a gaseous N_2 atmosphere. Crack and cavity formation start at very low cycle numbers, which is detrimental to the reflectivity (Ag) corrosion protection (Inconel) and considerably diminish the insulation capacity of the OSR. Combined in-situ surface imaging, film resistance (4 Point Probe setup) and film stress measurements (X-ray diffraction + $\sin^2\psi$) during straining revealed that also electro-mechanical properties of the bi-layer system are dramatically influenced, emphasizing the need to improve multilayer design and resistance of versatile metal-polymer compounds against thermal cycling. In this work, sputter deposited thin film metallic glasses (TFMG), combining metallic bonding and an amorphous microstructure, are introduced as novel coatings to overcome the problems of current multilayer OSR systems. Results indicate that this new and innovative type of thin films are ideal candidates to withstand the extreme thermal cycling as well as the harsh space environment.

4:20pm **TS3+4-2-MoA-9 Sputtered Thin Film Sensors for Self-sensing Composite Materials*, Florian Cougnon***, *A Lamberti, W Van Paepegem, D Depla,* Ghent University, Belgium

The wide-spread use of fibre-reinforced composite materials in big structures such as planes, windmills or pedestrian bridges, combined with the unacceptably high cost of material-failure, has vastly pushed the demand for structural health monitoring of composite materials. Structural health monitoring nowadays evolved from periodic quality inspections and surface-bounded sensing networks towards continuous monitoring of the entire in-service life time by sensing networks embedded in the material. In order not to degrade the structural integrity of the host material, the spatial dimensions of the embedded sensors should be as small as possible. Therefore we focus on the development of embedded thin film sensors – deposited by magnetron sputtering – such as thermocouples for measuring temperature and antennas for wireless measurements of strain and temperature through shift in resonance frequency. It is a challenging task to deposit well-performant thin film sensors onto temperature sensitive polymeric substrates. On the one hand, the electrical properties of the thin films mainly scale with the energy flux delivered towards the growing film. The temperature sensitivity of the substrate however demands tuning of the energy flux in order not to degrade the quality of the polymer. On the other hand, tuning the energy flux is often unambiguously correlated with an increased impurity flux towards the substrate. These impurities originate from residual gasses in the vacuum chamber and outgassing from the polymeric substrate and can have a large impact on the overall film properties as well. In this work, the link between energy flux, impurity flux and electrical properties of thin films grown by magnetron sputtering is unraveled from a fundamental point-of-view and exploited to fine-tune embedded thin film sensors towards applications for smart composite materials.

4:40pm **TS3+4-2-MoA-10 A New Method for Influencing Coating Properties on Polymer Substrates at Low Temperature: High Power Impulse Magnetron Sputtering (HIPIMS) with Positive Voltage Reversal*, Ambiörn Wennberg,*** Nano4Energy SL, Spain*; M Simmons,* Intellivation, USA*; F Papa,* GP Plasma, Spain*; I Fernandez,* Nano4Energy SL, Spain

Current engineering and material advances are shifting manufacturing in many areas from solid bulk materials to flexible lightweight materials. Although these materials, such as polymers, are lightweight, flexible and tough, there are challenges to engineering coatings on such substrates as they insulating and not able to withstand high temperatures. This gives rise to the challenge of how to deposit high quality thin film coatings on such substrates. High Power Impulse Magnetron Sputtering (HIPIMS) has shown many advantages over conventional sputtering which is commonly used to deposit metals, metal nitrides and metal oxides on polymer web. With HIPIMS, a fraction of the target material will be ionized while the ion energy distribution function will shift to energies about 10 times greater than those for DC discharges. However, this increase in ionization and energy will give only modest changes on an unbiased substrate. With the addition of a positive voltage reversal pulse adjacent to the negative HIPIMS sputtering pulse, these ions can be accelerated towards the substrate providing energy for film nucleation and densification.

In this study, an industrial scale (330 mm wide web) web coater was used to deposit TiO2 and Cu coatings as well as other metal nitride and metal oxide coatings on PET at room temperature. Improvements in film density and grain size can be clearly seen compared to DC or pulsed DC sputtering. The effect on the index of refraction, extinction coefficient and barrier properties are also investigated.

5:00pm **TS3+4-2-MoA-11 Tribological Challenges and Surface Engineering Solutions for Extreme Environments and Lightweight Materials*, Andras Korenyi-Both,*** Tribologix, Inc., USA **INVITED**

Moving mechanical assemblies that are used in extreme environments are often coupled with unique challenges for maintaining intended operational requirements. Conventional material selection becomes narrow and often native surfaces are not robust enough to handle extreme requirements. Surface modification techniques that are uniquely suited for special materials and their relevant operating environments must be carefully chosen from trusted knowledge bases or heritage based know-how. To further assure mission success modeling through simulation and specialized mechanical testing becomes critical. Surface analytical techniques, including in-situ data monitoring become an integral part of testing and simulation . To help offset the high costs often associated with placing moving mechanical assemblies in to extreme or high distance environments the choice of materials is further narrowed by intentional light-weighting for gains in economy. Lightweight material performance also needs to have careful attention placed on surface interactions and coating techniques to improve these surfaces are typically novel in nature. With a clear understanding of interacting surfaces, environmental factors, available options for treatments/coatings, risks associated with wear can usually be successfully mitigated. Several interesting and challenging extreme environment tribological cases are highlighted to provide further in-sight in to this area of science and engineering.

Author Index

Bold page numbers indicate presenter