Silicon Oxide Nanoparticles Effect on the Nanomechanical Properties of Hybrid (inorganic-organic) Barrier Materials

I. Zyganitidis[1], S. Logothetidis[1], A. Laskarakis[1], S. Amberg-Schwab[2], U. Weber[2] and C. Gellermann[2]
[1]Laboratory for Thin Films-Nanosystems & Nanometrology (LTFN), Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[2]Fraunhofer-Institut für Silicatforschung, 97082 Würzburg, Germany

Session: Flexible substrates & encapsulation methods & materials
Contribution: Oral

Introduction: To meet the demanding requirements of reliability on flexible electronic devices the engineered substrates are likely to be multilayer structures with increased barrier properties against atmospheric oxygen and water vapour diffusion. Several combinations of inorganic and organic coatings have been used as barrier layers for the encapsulation of these devices. Among them, ORMOCER® based hybrid coatings with silicon oxide (SiO_2) nanoparticles were found to significantly improve the barrier properties of polymeric substrates (e.g. polyethylene terephthalate - PET, polyethylene naphthalate - PEN). In this work we study the effect of silicon oxide (SiO_2) nanoparticles on the mechanical performance of ORMOCER® coatings deposited on PET polymeric substrates with an inorganic interlayer of SiO_x or AlO_x.
Experimental Details: The mechanical properties of elastic modulus (E), hardness (H) and creep displacement (h) of the layered systems were investigated through depth sensing nanoindentation (NI) method. A series of nanoindentation tests using a Berkovich diamond tip was applied on multilayer barrier systems containing SiO_x nanoparticles in different sizes (60nm and 100nm diameter) and percentage concentrations (5 to 30%). All the NI measurements were conducted at a maximum load of 6mN with a constant load rate of $(dP/dt)/P=0.05sec^{-1}$ (Continuous Stiffness load Method, CSM). The hold segment between the load and unload segment was chosen to have a wide time range of 200sec in order to assure the transition from time dependant to steady state creep rate.

Results and Discussion: Key influencing factors of mechanical properties relevant to nanoparticles are their diameter, percentage concentration and the combination of substrate type with inorganic interlayer. Increasing nanoparticles concentration leads to analogous changes in the values of E and H for all types of hybrid barriers (Fig.1). For ORMOCER®-system H38% deposited on PET MELINEX-401 substrate with an inorganic SiO_x interlayer ($PET401/SiO_x$), nanoparticles concentration affects the mechanical properties only close to the surface (depth up to 400nm) whereas for PET ST-504 substrate with an inorganic layer of AlO_x ($PET504/AlO_x$) the nanomechanical properties were upgraded for the whole depth. Regarding the influence of nanoparticle diameter, ORMOCER® with 60nm diameter nanoparticles exhibited the best mechanical properties for 5% concentration independently of the substrate type, but increasing the concentration to 10% and for $PET504/AlO_x$ substrate it had the lowest hardness and elastic modulus values. On the contrary, ORMOCER® with 100nm diameter nanoparticles had the lowest mechanical performance for 5% concentration for all substrates and the highest for 10% concentration and $PET504/AlO_x$ substrate.

Conclusions/Summary: Examination of the variations of the mechanical properties of multilayer barrier systems leads to the conclusion that the main factors which can positively influence them are the concentration and the diameter of nanoparticles additives.

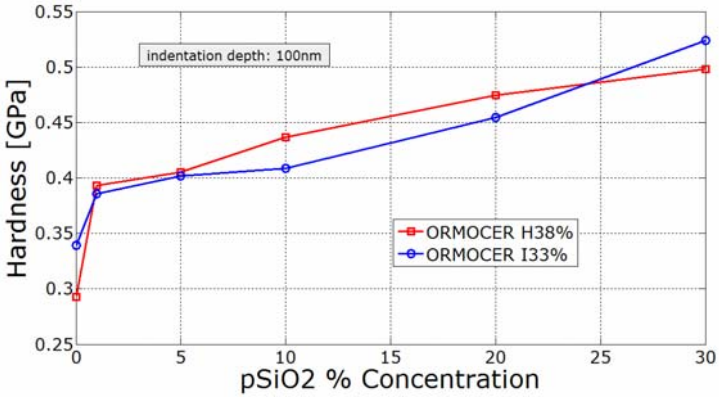

Fig.1. Hardness as a function of concentration for ORMOCER® H38% and I33%