Effect of Functionalized Hex-Boron Nitride Particle Washing on Electrophoretic Deposition Coating Yield and Uniformity

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ABSTRACT – Low-cost electrophoretic deposition (EPD) has been utilized to apply targeted hBN coating of TO247 transistor package at controllable manner. The current paper investigates the effect of hBN particles washing on the electrophoretic deposition (EPD) coating after Poly(diallyldimethylammonium chloride (PDADMAC) functionalization. EPD yields and coating coverage condition were obtained using weighing method and optical microscopy imaging. Usage of washed PDADMAC-functionalized hBN particles improved EPD yield and surface coverage of EPD coatings at 0.3-0.6 wt% PDADMAC concentrations range.

1. INTRODUCTION

Hexagonal Boron Nitride (hBN) has a potential application as thermal conductive and electrical insulating interface materials because of its high thermal conductivity and high dielectric strength. The rare combination of the both properties places the hBN material as a promising candidate for the next generation thermal management material for the semiconductor packages [1]. Herein, electrophoretic deposition (EPD) is a potential coating technique for targeted deposition of hBN coating on semiconductor packages for electrical isolation, and at the same time allows efficient heat dissipation.

hBN is utillised in form of hBN composite, by combining the hBN particles (i.e. as a filler) with a lower-cost polymer matrix binder. A low-cost synthesis technique to produce large area and single crystalline hBN material is still not commercially available [2]. Filler functionalization is commonly used for a better coupling between the filler and polymer matrix. However, ionic functionalizing agents had been used as charging agents for low-cost electrophoretic deposition process to increase electrophoretic behavior of suspension particles [3-4].

The current paper investigates the effect of hBN particles washing after functionalization by PDADMAC ionic functionalizing agents, on the EPD yield and coating's uniformity. Uniform hBN coating with a yield equivalent to the minimum thickness of 20 µm is required for the electrical isolation of TO-247 transistor package application.

2. EXPERIMENTAL DETAILS

Firstly, as-received h-BN particles (Nova Scientific, 0.6~1.2 µm) was dispersed by ultrasonication in deionized water (DI water, solids loadings of 5 g hBN in 600 ml water). The particles dispersion process helped dissolved and dispersed impurities into water. Then, the washed hBN particles were collected on filter paper using filtration sets (FAVORIT 40/38) consisted of a receiver flask, 300 ml glass funnel, hose connector, filter paper (1442-042, pore size = 2.5 µm, Whatman) and vacuum pump (ROCKER 2 motors). Then, the filtered hBN particles was dried in a drying oven at 60 °C for 30 minutes before functionalization process.

Next, washed h-BN particles (i.e. in dried-formed) was stirred and ultrasonicated with Poly (diallyldimethyl ammonium Chloride) (PDADMAC, Sigma-Aldrich) functionalizing agent in DI water using same solids loadings. The hBN particles suspensions were prepared in a batch consisted of different PDADMAC concentrations (i.e. 0.3, 0.4, 0.5, 0.6 wt% of the hBN particles basis). These particles suspensions were filtered using the similar filtration setup. After the hBN particles were collected from filter paper, they were dispersed in a new DI water and underwent two more filtration cycles. The repeated washing removed excess PDADMACs from washed particles. The excess PDADMACs were free PDADMAC molecules that unable to form chemical bonding with functionalized hBN particles and were easily removed by water dissolution together with small-sized hBN particles (size less than 2.5 µm).

Cathodic EPD set-up and 1 mg/ml solids loadings aqueous-based suspension containing functionalized hBN particles were used for EPD. Depositing substrates were polished and washed galvanized irons (GI) with dimensions of 1.4 × 4 × (0.050 ± 0.004) cm were used. Counter electrode was a titanium plate (dimension = 1.6 × 3.5 × 0.2 cm). EPD was performed at 60 V for 15 min at electrode separation of 1 cm and substrate's immersion length of 1.70 ± 0.05 cm. Coated substrates were dried in oven at 90 °C for 15 minutes before underwent weighing.

EPD coatings prepared using post-filtration functionalized hBN particles were labelled as *washed functionalized* coatings. Controlled EPD samples (i.e.

non-washed functionalized coatings) were prepared using particles underwent functionalization process but did not undergo second-step washing.

Weight gain (i.e. deposit yield) of coated substrate after EPD were measured using electronic balance (0.01 milligram resolution, Mettler Toledo). Surface coverage image of the EPD coating was captured by a digital camera phone (Apple iPhone 4s).

3. RESULTS AND DISCUSSION

EPD yield showed significantly higher deposition rate by the washed functionalized hBN particles (Figure 1). The result is supported by surface coverage result of EPD coatings deposited using non-washed and washed functionalized hBN particles (Figure 2). The latter sample group exhibited full coating coverage on the depositing substrates for all the PDADMAC concentrations. Whereas, the topographical contrast of coating deposited using non-washed functionalized suspensions indicated coating dissolution.

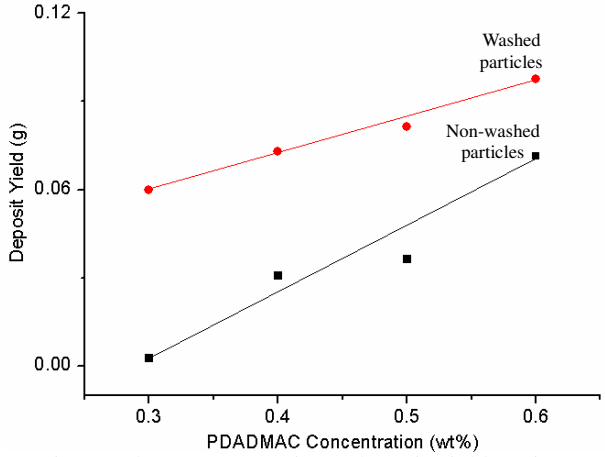

Figure 1 hBN EPD coating's deposit yield against PDADMAC concentration

The coating dissolution could be caused by the competing deposition of excess PDADMACs and functionalized hBN particles onto the substrate. The interposing PDADMACs reduced the adhesive strength between the substrate and hBN particles, caused the disintegration of deposited particles [3]. The deposited PDADMAC also created insulation barrier on the substrate that inhibited subsequent particles deposition by EPD [3]. Less coating dissolution was observed when PDADMAC concentration increased to 0.6 wt%.

A linear increase of the EPD yield with the increasing PDADMAC concentrations implies an increase of hBN deposition rate (unit in gram per second) with PDADMAC concentration. Previous study showed deposition rate of functionalized hBN particles correlated positively with the decreasing stability of hBN suspensions for EPD [1]. The destabilization of hBN suspension was exhibited in form of particles agglomeration, which in turn facilitated deposition of hBN particles on substrate. A decrease hBN suspension stability occurred when average hBN particle size increased due to elimination of small-sized particles by filtration. Larger particles are prone to the influence of gravitational and van der Waal interaction. For non-washed particles, an increase of excess PDADMAC concentration also further destabilized hBN suspension due to compression of electric-double layer (EDL) surrounded hBN particles. The effect of EDL compression had been thoroughly discussed in previous study [4].

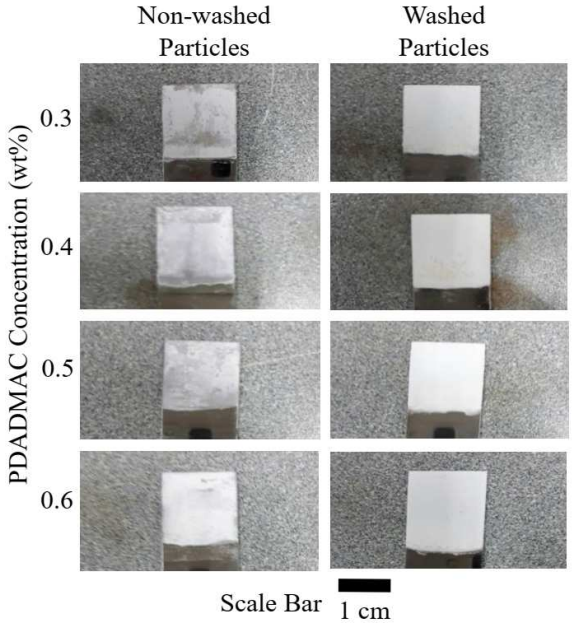

Figure 2 Surface coverage of EPD coating (i.e. hBN in white colour) deposited using non-washed and washed hBN particles after functionalized at different PDADMAC concentrations

4. CONCLUSION

Washing of PDADMAC-functionalized hBN particles improved electrophoretic deposition (EPD) yield of hBN coatings by 37% at 0.4wt% and by 140% at 0.6 wt% PDADMAC concentration respectively. The washing process also resulted in an improved surface coverage of EPD coatings. Fully covered coatings were obtained when using washed functionalized particles. Partial covered coatings were observed with non-washed functionalized particles were used.

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