Quantifying Interfacial Adhesion in Transfer Printing via a Cantilever Peel Test

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INTRODUCTION

Transfer printing has been demonstrated as a fabrication method for flexible organic electronics.[1-7] The transfer printing process relies on the differential adhesion of a printable layer (PL) that is pressed between two substrates: the transfer substrate (TS) and the device substrate (DS). Transfer of the printable layer from the transfer substrate to the device substrate requires that the adhesion of the printable layer be higher at the interface with the device substrate (interface DS/PL) than at the interface with the transfer substrate (interface TS/PL). This requirement can be satisfied by chemical treatment of the substrates,[1,2] heating of thermoplastic materials[6,7] as well as kinetic control of adhesion.[5] Although the principle of transfer printing is straightforward, the success of the technique involves screening of specific chemistry and materials combinations, which is currently done with a "trial and error" approach. To accelerate the development of this technique, a thorough understanding of the transferr mechanisms is necessary. The key to developing this understanding is a reliable measurement of adhesion at the transfer interfaces.

The present work seeks to develop an adhesion test for quantifying adhesion at interfaces relevant to transfer printing. For this purpose, a single cantilever peel test is used to measure the adhesion energies of a model system that simulates the transfer printing process. The model system consists of a silicon (Si) wafer transfer substrate, a poly(methyl methacrylate) (PMMA) transfer layer, and a poly(ethylene terephthalate) (PET) device substrate. Appropriate specimen geometry is determined for precise estimation of the fracture energy. The fracture energy of the Si/PMMA/PET multilayer is measured as a function of surface energy of the substrates and PMMA, and the locus of failure is determined by SEM and XPS.

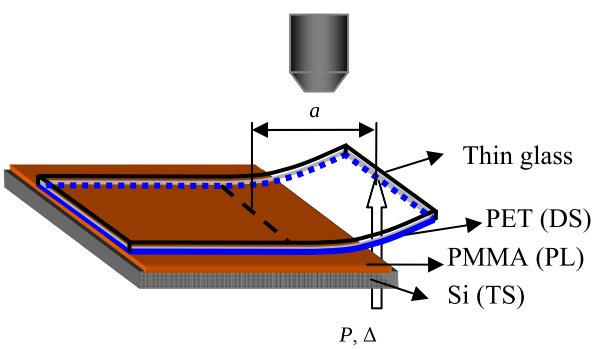

Figure 1. Specimen geometry of a single cantilever peel test.

RESULTS AND DISCUSSION

A single cantilever peel test was used to evaluate the fracture energy of a printable layer (PMMA) on a transfer substrate (Si) as well as that of the printable layer on a device substrate (PET). Fig. 1 illustrates the specimen geometry, where a thin PET film is bonded with a rigid substrate by pressing it at an elevated temperature and pressure typically used for transfer printing. A thin glass backing was then adhered to PET with a fast-cure epoxy. The PET film supported by the thin glass plate forms a flexible cantilever beam on the rigid silicon substrate. The cantilever beam is peeled from the free end to initiate a crack. The force (P) and the crack length (a) are measured as a function of displacement (Δ). This geometry is chosen such that the beam only undergoes small bending during peeling. The small bending of the beam allows for a precise estimation of the interfacial fracture energy directly from the force versus displacement measurements.[8,9] An advantage of this test is that the specimen geometry simulates the real situation of transfer printing. Fig. 2 is a picture of the setup. To find out the critical condition where the PMMA film can be transferred from the silicon substrate to PET substrate, we are using a specific set of surface treatments for the substrate and PMMA such that the crack initially occurs at the PMMA/PET interface. The treatment of either PET or PMMA can then be varied to decrease the fracture energy until the fracture energy reaches a plateau value at which the crack always occurs at the PMMA/Si interface. This value would be the critical fracture energy for transfer of PMMA film.

Figure 2. Experimental set-up of the single cantilever peel test.

REFERENCES

1. Loo, Y.L.; Willett, R.L.; Baldwin, K.W. Rogers, J.A. *Appl. Phys. Lett.* **2002**, *81*, 562.
2. Zaumseil, J.; Meitl, M.A.; Hsu, J.W.P.; Acharya, B.R.; Baldwin, K.W.; Loo, Y.L.; Rogers, J.A. *Nano Lett.* **2003**, *3*, 1223.
3. Hur, S.-H.; Khang, D.-Y.; Kocabas, C.; Rogers, J.A. *Appl. Phys. Lett.* **2004**, *85*, 5730.
4. Memard, E.; Lee, K.J.; Khang, D.-Y.; Nuzzo, R.G.; Rogers, J.A. *Appl. Phys. Lett.* **2004**, *84*, 5398.
5. Meitl, M.A.; Zhu, Z.-T.; Kumar, V.; Lee, K.J. Feng, X.; Huang, Y.Y.; Adesida, I.; Nuzzo, R.G.; Rogers, J.A. *Nat. Mater.* **2006**, *5*, 33.
6. Hines, D.R.; Mezhenny, S.; Breban, M.; Williams, E.D.; Ballarotto, V.W.; Esen, G.; Southard, A.; Fuhrer, M.S. *Appl. Phys. Lett.* **2005**, *86*, 163101.
7. Hines, D.R.; Ballarotto, V.W.; Williams, E.D.; Shao, Y.; Solin, S.A. *Appl. Phys. Lett.* **2007**, *101*, 024503.
8. Ghatak, A.; Mahadevan, L.; Chaudhury, M.K. *Langmuir* **2005**, *21*, 1277.
9. Chung, J.Y.; Chaudhury, M.K. *J. R. Soc. Interface* **2005**, *2*, 55.

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