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Adhesion Independent Transfer Printing Technique Based on Shape Memory Polymers

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Abstract

Transfer printing is an emerging technique for materials assembly and micro/nano-fabrication [1, 2]. It enables heterogeneous integration of different materials into spatially organized, functional arrangements in both individual, deterministic and massive, selective ways, and provides the most promising solution to the assembly of flexible and stretchable integrated devices, curvilinear and transient photonics/electronics, large-area micro-LED display panels, micro solar cell modules and micro-lasers.

In transfer prinitng, myriads of rigid and fragile devices (tens of thousands or more) are retrieved from the donor substrates and then printed onto the receiver substrates by a polymer stamp, and often with the requirements of selective retriveal/printing. Previous studies mainly focused on addressing the controversial adhesion demands for a successful transfer printing of planar devices, i.e., strong stamp/device adhesion for retrieval and weak stamp/device adhesion for printing, through outer stimuli such as peeling speed [3], lateral movement [4], laser pulse [5] or preload [6]. Those adhesion-based designs achieved great success in terms of planar devices at the cost of the stamp simplicity. However, the relatively large residual forces on the planner devices at smaller scales (<100 um) render the printing process challenging. Besides, these adhesion-based methods failed for nonplanar and irregular devices due to small and uncertain adhesion forces resulting from the small contact area with the stamp, and the devices might slide on the stamp during the retrieval and transporting process without lateral constraints.

To address the above-mentioned problems, we proposed a novel concept for transfer printing, where the stamp is a simple shape memory polymer (SMP) block as shown in Fig. 1 A. As an emerging smart material, SMP can be actuated to be soft with the elastic modulus of 0.1-10 MPa [7] upon outer stimulus such as heat [8] and light [9] to deform freely, which enables easy embedding of arbitrarily shaped devices (Fig. 1B). SMP becomes stiff with the elastic modulus of 0.01- 3 GPa [7] to fix the temporary shape and lock the devices upon the removal of outer stimulus (Figs. 1C-F), which offers a large grip force due to the interlocking, friction and suction effects for retrieval and manipulation. Upon re-stimulation, the deformed SMP recovers to the permanent shape, which enables the release of the devices (Figs. 1G-H). This protocol is completely different from previous adhesion-based SMP stamp for planar objects [10, 11], which is impossible for multi-scaled devices with arbitrary shapes.

In this protocol, reliable retrieval is realized by embedding the devices into the soft-state SMP stamp and then locking at the stiff-state, and releasing by the shape recovery through the shape memory effect of the SMP. Now that the retrieval is adhesion-independent, we can simply get rid of it by some surface modification [12] if necessary, this would be of great help at the microscale, where adhesion has always been an annoying factor for releasing.

The embedding of the devices constrains the lateral movement of these non-planar objects and keeps the predefined alignments, which may bring new possibilities for the assembly and the development of unconventional functional devices such as spherical solar cells, vertically grown pillars, belts, rods or wires.

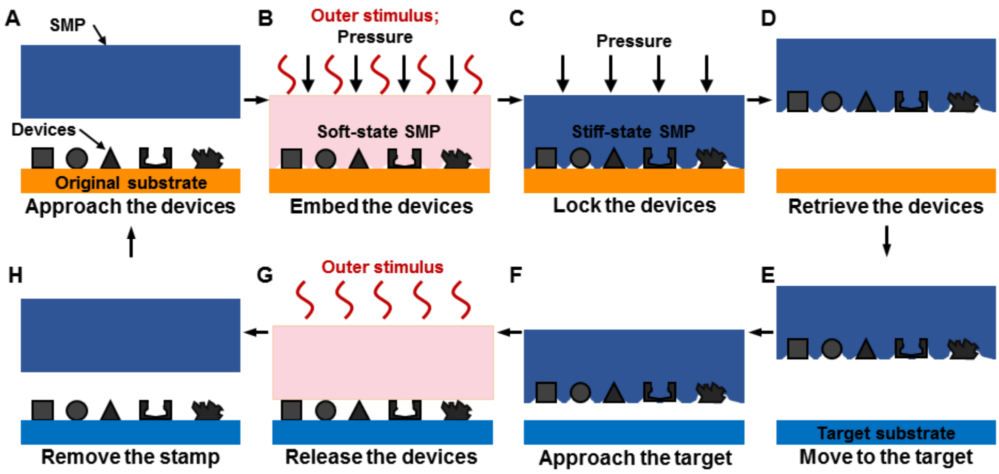

Figure 1: Schematic illustration of the transfer printing process using the adhesion-independent SMP stamp.

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