High Throughput Elastomer Stamp Mass Transfer for High Performance Displays

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ABSTRACT

Efforts to develop microLED displays brought visibility to the importance of mass transfer. Processes compatible with high-volume manufacturing that rapidly integrate billions of micron-scale devices are required for making microLED displays. Device assembly throughput greater than 200M units per hour is demonstrated using a 750 × 750 device array stamp and a ten second stamping cycle time.

1 Introduction

A 2021 report [1] describes strong industry progress toward displays that utilize microLEDs. The future scale of the microLED industry depends on the display manufacturing cost, and the manufacturing cost depends on a mass transfer technology that can assemble very small microLEDs with high yields and throughput.

Pioneered in the mid-2000s [2-3], elastomer stamp mass transfer, also called micro-transfer printing, was used to demonstrate a transparent, deformable, microLED display in 2009 [4]. Subsequent reports described full-color 127 and 254 PPI passive-matrix displays using 8 x 15 μm^2 microLEDs, where the 127 PPI display exhibited over 60% transparency [5], and a 127 PPI active-matrix display that utilized elastomer stamp transferred microICs to drive the microLEDs [6]. Recent reports describe display architectures utilizing transferred microICs that control clusters of pixels [7] and PixelEngine packages that combine microICs with red, green, and blue microLEDs to form printable devices to perform all the pixel functions [8].

In this work, we demonstrate ten second stamping cycle times with stamps that transfer 562,500 microdevices per cycle, equating to greater than 200M units per hour per printhead.

2 Discussion

Fig. 1 is a scanning electron micrograph of a microdevice source wafer prepared for equipment qualification and mass transfer throughput studies. These mechanical devices are prepared using silicon-on-insulator (SOI) wafers and are 20 μm x 24 μm on a 30 μm × 30 μm pitch. The devices are tethered using a silicon nitride tether and are released using by anisotropic silicon etching with a heated aqueous base (TMAH) [9].

Fig. 2 is a photograph of an elastomer stamp that transfers a 750 × 750 array of devices with each stamping cycle. The elastomer stamp consists of an injection molded PDMS layer attached to a glass backing plate. The relief features designed to touch the microdevices are formed against a photodefined master substrate. In this example, the stamp contacts every other microdevice on the source wafer in the X and Y direction, which equates to 423 PPI. The elastomer stamps are transparent, laterally stiff, and compliant in the Z direction. The stamp fabrication process is described in earlier reports [9, 10]. Lifetime studies show that elastomer transfer stamps are robust over tens of thousands of cycles [9, 10]. Stamps with active transfer area of 130 mm have already been demonstrated [10].

The elastomer mass transfer is performed using motion platforms with integrated optics that move and align the stamp relative to the source and destination substrates during the stamping cycle. Fig. 3 is a photograph of three micro transfer printers in a clean room in Research Triangle Park, North Carolina. Fig. 4 is a top-down schematic of a substrate platen designed to chuck both source and destination substrates up to 300 mm × 300 mm. The printing cycle includes the device retrieval step, the aligned transfer to the destination substrate and a cleaning step where the stamp is contacted against a semiconductor grade tape before returning to the source substrate for the next pick-up step. The substrate platen illustrated in Fig. 4 includes an automated roll tape dispenser for the cleaning station. This platen configuration is mounted to precision motion stages with 600 mm x 800 mm travel.

Fig 5 is an optical micrograph showing the destination substrate with the printed microdevices. Fig. 6 is a series of video screen captures during elastomer stamp transfer printing [11]. In Fig. 6a, the stamp is contacting the source substrate during the device retrieval, or pick-up, step. This capture represents the start of the 3rd stamping cycle and begins 21 seconds into the video. Fig. 6b, shows the populated stamp contacting the destination substrate during the transfer cycle. The destination substrate is a 200 mm diameter silicon wafer with a single level thin-film metal alignment marks and a thin (~1.3 μm) layer of a uncured epoxy resin that serves as a adhesion and die-attach layer for the transferred microdevices. Before contacting the destination substrate, the microdevices are aligned to the metal alignment marks using a pattern recognition software package. Fig. 6c shows the stamp in contact with the cleaning pad at the 29 second mark. Fig. 6d shows the stamp starting the 4th transfer cycle at 31 seconds. Each stamping cycle transfers 562,500 devices, equating to a device assembly speed more than 200M units per hour for a single printhead.

Device throughput in stamp mass transfer depends on the size of the transferred area, the density of the transferred devices, and the process cycle time. Fig. 7 graphically depicts the throughput of elastomer stamp transfer as stamped area, independent of the transferred device density, as a function of stamping cycle time. The star point represents the ten second cycle time using the 750 × 750 device array stamp described herein. Stamps with 130 mm active areas have already been demonstrated [10] and 200 x 200 mm^2 class stamps can be formed using 300 mm master wafers. Previous reports describe how microLED packages formed on 300 mm diameter wafers support large area transfer and reduce the number of transfer cycles required to make displays [12]. Large area stamps combined with sub 15 second cycle times provide a practical route to stamping more than 10 square meters per hour with a single printhead.

3 Conclusions

Manufacturing of microLED displays depends on the assembly time required to transfer billions of discrete wafer-level microdevices. Mass transfer with scalable, transparent, elastomer stamps on motion-plus-optics platforms provides a path to transferring hundreds of millions of units per hour. Here, we demonstrate ten second stamping cycle times with a 750 × 750 array stamp, which equates to more than 200M units per hour throughput with a single printhead.

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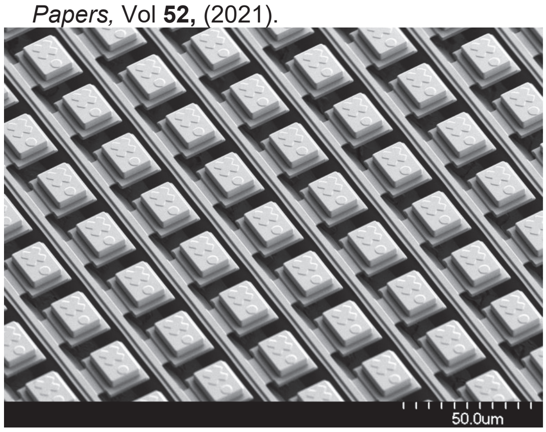

Fig. 1 Scanning electron micrograph of transfer-ready 20×24μm^2 devices on 30×30μm^2 pitch.

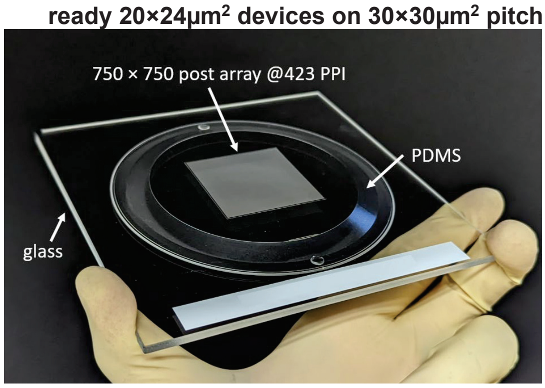

Fig. 2 Photograph of elastomer stamp that transfers a 750 × 750 device array at 423 PPI.

Fig. 3 Photograph of three micro transfer printers.

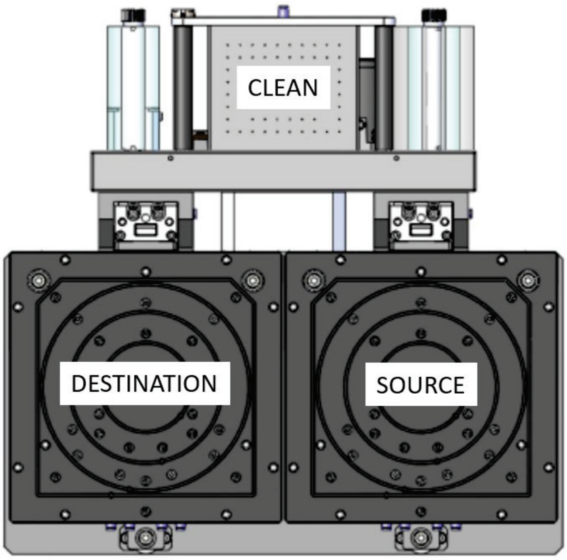

Fig. 4 Top view of substrate platen configured for up to 300 × 300 mm^2 source and target wafers and a roll-fed tape cleaning station.

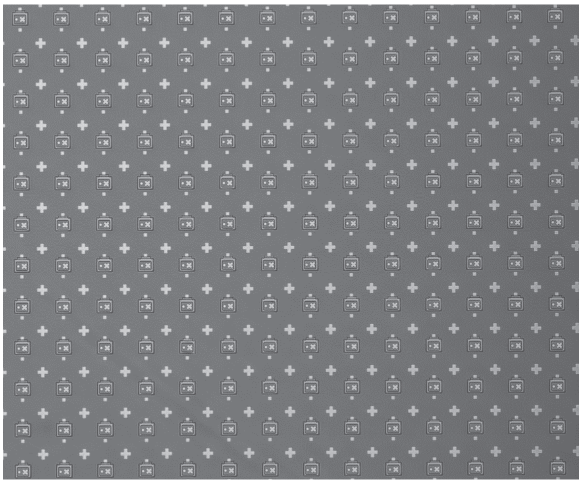

Fig. 5 Micrograph of the destination substrate populated with the microdevices at 423 PPI.

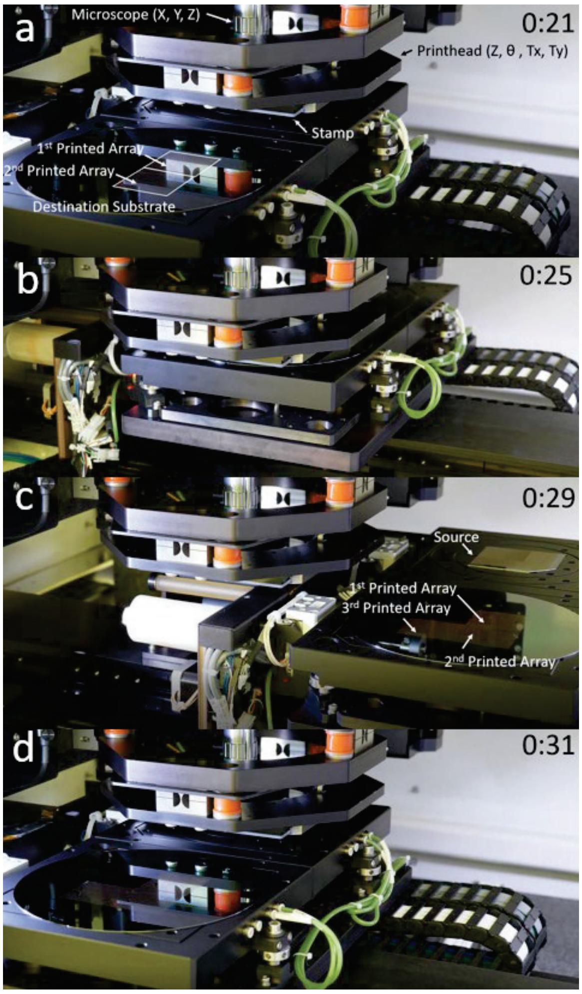

Fig. 6 Video captures from 10 s cycle mass transfer with a 750 × 750 device array stamp. (a) retrieval of the 3rd device array at 21 seconds. (b) alignment and transfer to the destination substrate at 25 seconds. (c) touch down onto the cleaning pad at 29 seconds. (d) device retrieval of the 4th array at 31 seconds.

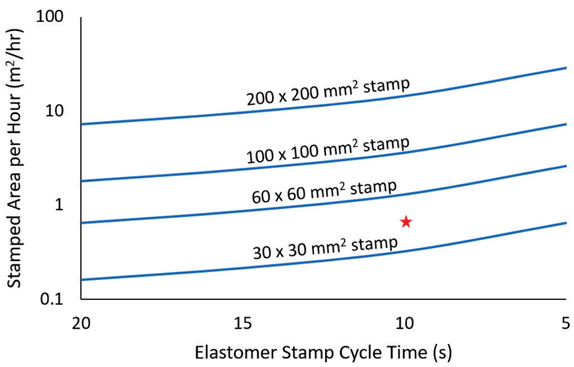

Fig. 7 Elastomer stamp transfer throughput depicted as the stamped area per hour for a single printhead versus the process cycle time. The red star represents the 10 second cycle time printing with the 750 × 750 array stamp.