Continuous roller transfer-printing of QVGA semiconductor micro-pixel arrays

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***Abstract*— We demonstrate an automated roll-transfer printing method for the parallel integration of >75k devices in a single shot. Automated high resolution metrology shows semiconductor micro-pixel array transfer with 1.43 μm printing accuracy and 95 % yield.**

Keywords—roll-transfer printing, heterogeneous integration, mass transfer, pixel arrays

I. INTRODUCTION

The development of advanced opto-electronic systems, micro-displays, and flexible and wearable systems has required the integration of multiple different photonic materials at micron scales. In particular, high resolution micro-displays require the hetereogenous integration of large numbers of semiconductor pixels onto non-native substrates and electronic back-planes. A number of complementary methods have been developed for this purpose, including wafer bonding and substrate removal [1], laser assisted device transfer [2], flip-chip bonding [3], and planar transfer printing [4]. In order to scale the fabrication of large arrays of optoelectronic devices to manufacturing levels, mass transfer methods are required with high throughput, high placement accuracy and high yield at wafer levels. To address this challenge, we have developed a custom, automated roller-transfer printing method which enables the parallel printing of thousands of devices in one continuous mechanical roller translation at high speed, a schematic of which is shown in Fig.1(a). In this work, we present a full single-shot printing of an array of semiconductor micro-pixels at a quarter VGA (QVGA) resolution (320 x 420 pixels) by using this method.

II. METHODOLOGY AND RESULTS

A. Semiconductor pixel array fabrication

To facilitate transfer printing of the individual pixel devices, they are fabricated on a donor wafer in a suspended membrane format commonly used in planar transfer printing methods [5]. The suspended membranes comprise a GaN light-emitting diode (LED) device structure emitting at 450 nm, grown on a silicon substrate. The membranes were fabricated by using UV photolithography and ICP dry etching followed by an anisotropic KOH wet etching to release them from their native substrate. To aid the mechanical pick-up of the devices a single anchor 'bridge' is used between the membranes and the surrounding material, which is positioned in the middle of one side of each pixel and has a bow-tie shape with minimum dimension of 3 μm in width. The final chip is a quarter-VGA pixel array (320 x 240 elements) with individual pixel elements of size 30 x 30 μm^2 on a 50 μm pitch, producing a 508 dot per inch (dpi) arrangement. Selected areas of the fully fabricated array are shown in Fig.1(b).

B. Automated roller-printing setup

The printing head makes use of a commercially available roller with an elastomeric silicone rubber surface. The roller has a diameter of 40 mm and an axial length of 60 mm. The roller is mounted on a high-load vertical translation stage which enables the control of its height and contact pressure. Both donor and receiver are mounted on an automated 150 mm linear translation stage with 2 μm on-axis accuracy and maximum speed of 30 mm/s. During the printing process, the roller is held stationary in the x,y,z directions with the only free motion being the rotation around the roller axis. By bringing the roller into contact with the stage, the stage/roller friction induces relative motion between the two, producing a continuous process of both picking up the devices from the donor substrate and releasing them to a silicon substrate (receiver) coated with a thin layer of fast-cured adhesive optical polymer (Norland NOA 85). Fig.1(c) shows devices on the roller surface after pick-up and Fig.1(d) shows an SEM image of a section of the printed array.

C. Characterization

In order to rapidly access the printing accuracy and yield of our method, we use a custom optical microscopy based metrology system presented in our previous work [6]. We used this method both to characterize the as-fabricated donor, prior to any printing process, and to characterize the receiver substrate with the roll-printed devices. Fig.1(e) shows a processed section of the printed array, with the individual pixels highlighted with red circles and the lines showing center to center measurements. A full analysis of the printed array was carried out using the automated metrology tool and returns a transfer yield of 95 %. The inter-pixel pitch in both x and y directions was extracted, with a measurement limit of resolution of 720 nm. Across the full pixel array a mean pixel pitch error of 26 nm is found, with a standard deviation of 1.43 μm.

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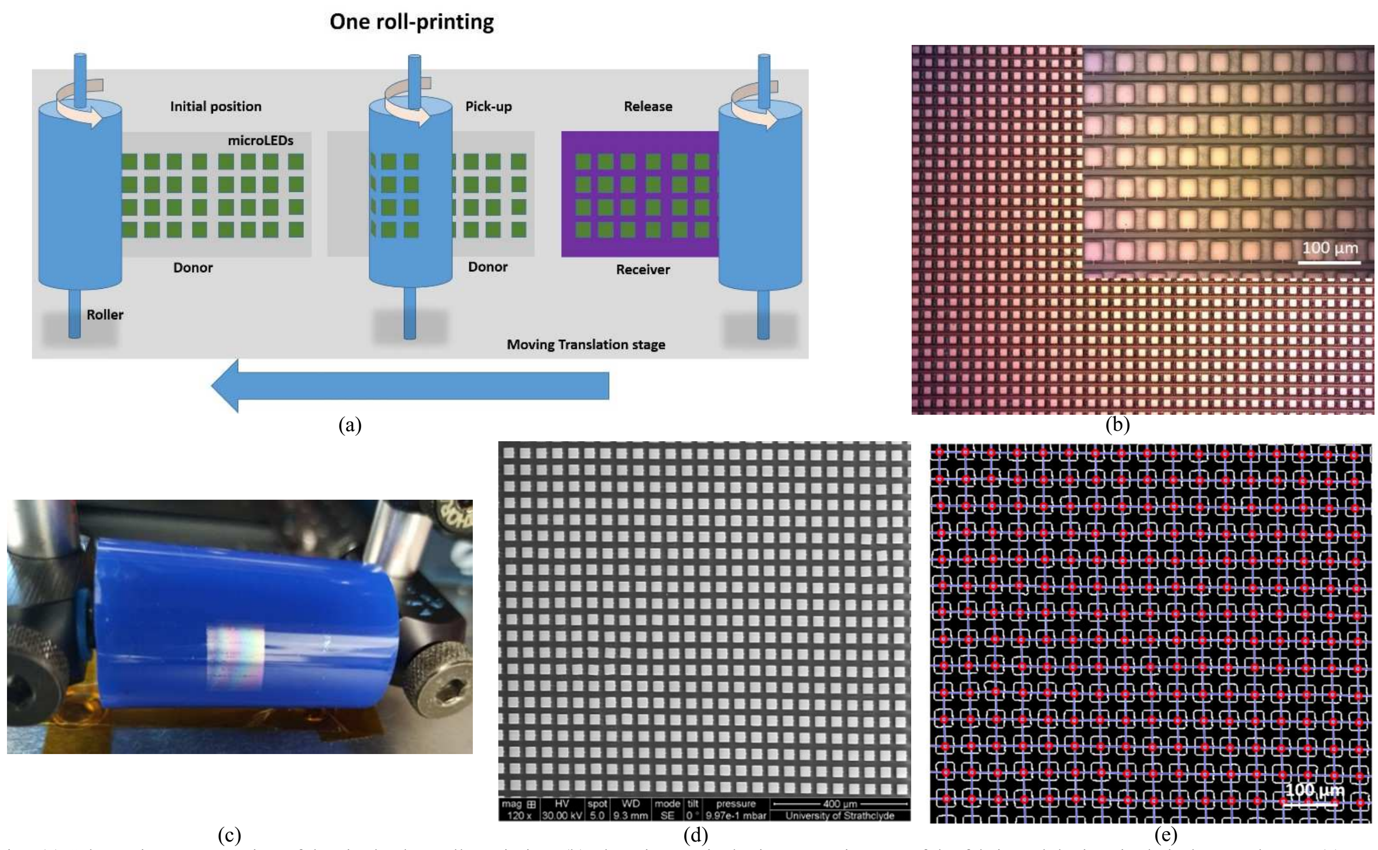

Fig.1(a) Schematic representation of the single-shot roller printing, (b) plan view optical microscope images of the fabricated devices in their donor substrate,(c) photograph of the roller with the picked-up devices,(d) SEM image showing the scale and uniformity of the roll-printed devices and (e) processed metrology image of the printed devices, highlighting the centers of each device (red dots) and the pitch values (blue lines).

III. CONCLUSIONS

We have presented a custom roller printing tool, using standard mechanical parts and commercially available roller in order to mass-transfer thousands of semiconductor devices in a single roller motion with less than 1.5 micrometer relative placement accuracy. In this example, we used a full quarter VGA device, however, this printing tool can be used for the heterogeneous integration of any membrane format devices.

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REFERENCES

[1] L. Q. Zhang L, Ou F, Chong WC, Chen Y, “J Soc Info Display - 2018 - Zhang - Wafer-scale monolithic hybrid integration of Si-based IC and III V epi-layers A mass.pdf,” *J. Soc. Inf. Disp.*, vol. 26, no. 3, pp. 137–145, 2018.

[2] R. Saeidpourazar, M. D. Sangid, J. A. Rogers, and P. M. Ferreira, “A prototype printer for laser driven micro-transfer printing,” *J. Manuf. Process.*, vol. 14, no. 4, pp. 416–424, 2012, doi: 10.1016/j.jmapro.2012.09.014.

[3] Z. J. Liu, W. C. Chong, K. M. Wong, and K. M. Lau, “360 PPI flip-chip mounted active matrix addressable light emitting diode on silicon (ledos) micro-displays,” *IEEE/OSA J. Disp. Technol.*, vol. 9, no. 8, pp. 678–682, 2013, doi: 10.1109/JDT.2013.2256107.

[4] J. F. C. Carreira *et al.*, “Direct integration of micro-LEDs and a SPAD detector on a silicon CMOS chip for data communications and time-of-flight ranging,” *Opt. Express*, vol. 28, no. 5, p. 6909, 2020, doi: 10.1364/oe.384746.

[5] A. J. Trindade *et al.*, “Nanoscale-accuracy transfer printing of ultra-thin AlInGaN light-emitting diodes onto mechanically flexible substrates,” *Appl. Phys. Lett.*, vol. 103, no. 25, 2013, doi: 10.1063/1.4851875.

[6] E. Margariti, B. Guilhabert, D. Jevtics, M. D. Dawson, and M. J. Strain, “Sub-micron-accuracy automated position and rotation registration method for transferred devices,” *2021 IEEE Photonics Conf. IPC 2021 - Proc.*, pp. 2021–2022, 2021, doi: 10.1109/IPC48725.2021.9592935.