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Sub-micron-accuracy automated position and rotation registration method for transferred devices

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***Abstract*— We demonstrate a high accuracy and throughput automated method for the spatial registration of micron-scale devices on planar chips. The system is used to assess the yield, spatial pitch and rotation of mass transfer-printed membrane devices (here micro-LEDs for illustration) using simple optical microscopy tools.**

Keywords—Mass transfer, yield, accuracy, inspection method, integrated devices

I. Introduction

The integration of opto-electronic devices from multiple different material platforms allows the production of advanced systems, such as high-speed micro-displays, with improved operating characteristics, low power consumption, and scalable manufacture [1]. Mass transfer is one of the main stages in the manufacturing of these hybrid optoelectronic devices and has many technological challenges, including the transfer yield and the realization of a precise inspection method [2], [3]. A key issue in this process is to rapidly assess the relative position of thousands of devices with accuracy in the 100nm range [4]. Furthermore, this measurement must be done rapidly, and with relatively simple imaging equipment, to allow it to be integrated into the manufacturing process. To address this challenge, we have developed a computational image processing method which can be used to analyze a large area of printed devices using relatively low magnification optics. Using an image processing analysis technique, based on a cross correlation method, individual device central coordinates and rotational orientation can be calculated with sub-micron accuracy, even where the minimum optical resolution of the microscopy system is in the micron range.

II. MATERIALS AND METHODOLOGY

A. *High-throughput optical microscopy*

A large effective field of view is obtained using a simple optical microscope (50x objective) with an automated nano-scale accurate translation stage. High resolution, small field of view sub-images are captured and stitched together to form a complete image of the sample, typically covering cm^2 areas. Low stage drift and rapid automated acquisition allows for stitching errors in the 10's nanometer range. An example full effective field of view image of a micro-LED Quarter Video Graphics Array (QVGA) is shown in Fig. 1 along with a zoomed in view of a small number of stitched sub-fields. The resultant calibrated image can then be input for the imaging processing method that we have developed for analysis, in order to characterize the entire chip.

B. *Image processing method*

The image processing method is based on the cross correlation technique for the detection of the center location and rotation of devices, and requires a template of the device geometries to predefined. This was achieved with an adequately sized matrix (correlator), that has the same dimensions as the devices to be detected. The cross-correlation method is similar to that presented in our previous work on spatial registration for high accuracy transfer printing [4] and is carried out with respect to x,y and θ_z variations. Figure 2 shows a schematic of the figures of merit being targeted on a uniform array. For this work, the spatial center position of devices, their local rotation and yield (i.e. device present or not) was assessed for sets of thousands of devices, as detailed below. Figure 3 shows an example of a cross-correlation map of a single device in an array, with the bright central point corresponding to the measured device position. By fitting the correlation map to a smoothly varying function, the central position can be estimated with a resolution, below the imaged pixel dimensions.

C. *Devices*

The method detailed above was implemented for the analysis of an as-fabricated array of GaN/Si micro-LED pixels with individual elements of 30x30 μm^2 on a 50 µm center-to-center spacing, prior to any printing process. Moreover, we consider the example of a transferred array with limited yield, designed for demonstration. These devices were picked from the growth substrate (donor) and printed to a silica substrate (receiver) coated with a fully-cured thin layer of optical polymer (Norland NOA 65).

III. RESULTS AND DISCUSSION

For the as-fabricated chip, the measured results can be directly compared to the photolithography mask file used for this microfabrication. Figure 4 shows the resulting image, including the centers detection and the pitch values. By adjusting our correlator matrix with the dimensions of the devices, we were able to find the centers and the pitch values for all the devices appearing in the image. A single pixel in our camera corresponds to dimensions 0.094 x 0.094 μm^2. In this case, no evident rotation of devices was detected and the corresponding matrix returned only zero values. The results are compared with the pitch values known from the GDS file of the corresponding mask used for the photolithography process. The distance between the centers of the devices in both x and y directions is 30 µm as per design. The average error value is 0.06 µm and the standard deviation is 0.26 µm. The same analysis is carried out for a roll-transfer printed chip using the micrograph presented in Fig. 5. The chip imaged here comprises of 4000 suspended micro-LEDs transfer printed onto a polymer coated flexible receiver substrate by roll printing. The results after the correlation, highlighting the centers, the pitch values and the effective assessment of missing devices are shown in Fig. 6.

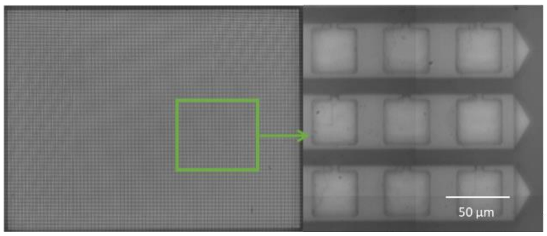

Fig. 1. QVGA micro-LED device (320x240 elements) with a close up snapshot of the stitched elements

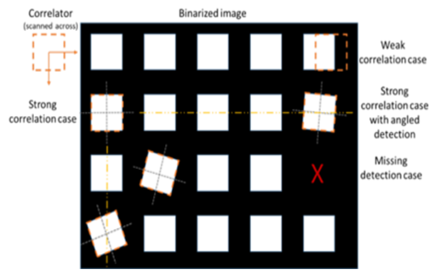

Fig. 2. Schematic representation of the cross correlation.

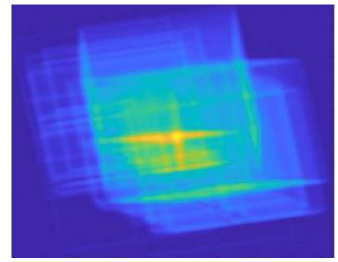

Fig. 3. Reconstructed device after the correlation for multiple angles

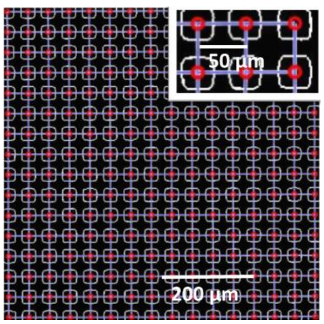

Fig. 4. Center detection and pitch values of the QVGA device,

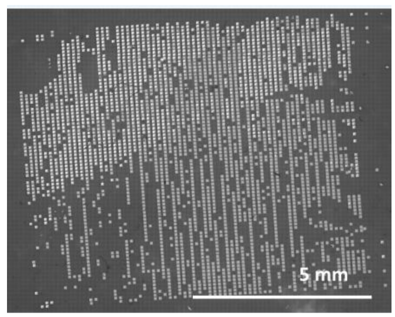

Fig. 5. Full array of the printed devices (order of cm).

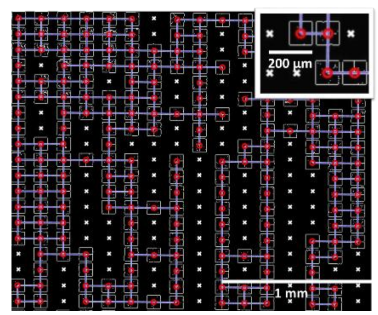

Fig. 6. Snapshot of the printed devices after processing, highlighting the centers of each device (red dots), the missing devices (white cross) and the pitch values (blue lines).

IV. CONCLUSIONS

We have presented a tool, using standard optical microscopy elements and computer vision, designed to measure the accuracy of mass printing processes with a sub-micron precision. We have illustrated this capability using the important example of micro-LEDs but the technique is broadly applicable in high throughput manufacturing process flows for heterogeneous integration and semiconductor devices.

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