Excitation of semiconductor nanowires using individually addressable micro-LED arrays

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***Abstract*—Optical pumping of nanowire emitters, embedded in polymeric waveguides is achieved using a micro-LED array at 410 nm. The micro-LED-on-CMOS chip allows for individual pixel control and therefore parallel pumping of multiple emitters simultaneously. The nanowires are integrated on-chip using high-accuracy transfer-printing and laser lithography.**

***Index Terms*—semiconductor nanowires, micro-LEDs, integrated photonics, polymeric waveguides**

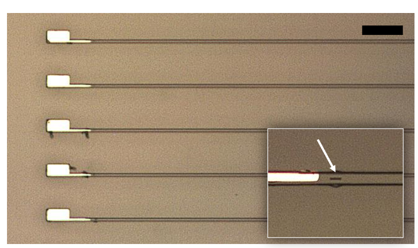
I. Introduction

Nanowire (NW) semiconductor light emitters have been attracting considerable attention in recent years due to their compact dimensions, high brightness and the ability to create complex optical layers through precise control of epitaxy [1]. By combining quantum dot (QD) epitaxy in NW growth or nanofabrication processes, single QD emitters can be embedded into single NWs for applications as single photon emitters or photon-spin interaction centres [2], [3]. Furthermore, the coupling of single NW devices with on-chip waveguides presents a route towards their integration in large scale quantum photonics [4]. Nevertheless, the statistical nature of characterising, selecting and deterministically integrating single nanowires remains a challenge, as does the optical addressing of multiple devices in a compact chip architecture where pulsed or continuous wave laser sources are typically employed through high-NA microscopy systems for pumping.

In this work, we present a new route for the scalable integration of NW devices with photonic waveguides on-chip and the multiplexing of direct electronically controlled optical excitation of arrays of emitters.

II. Fabrication of NWs embedded in photonic waveguides

The major challenge in working with NW technology is the inhomogeneity of device performance across populations [5]. Selection of devices with pre-defined characteristics can be achieved through a process of characterisation, selection and deterministic transfer [6]. By coupling automated device characterisation and transfer-printing systems, NWs can be selected from their native substrate and accurately pick-and-placed onto a receiver chip [7]. As a proof-of-concept in this work we use InP semiconductor NW emitters with an absorption spectrum through the visible range of the spectrum and emission in the near-IR. The NWs are in the order of 5 μm in length and 500 nm diameter, for information see ref. [8]. The NWs are first selected from their native substrate and using a high-accuracy transfer-printing process, transferred to a host chip with positions well-defined relative to on-chip overlay marker features. To embed the devices in polymeric waveguides, a layer of SU-8 photoresist polymer is spin-coated onto the sample and then waveguide patters directly aligned to the printed NWs using a direct-write laser lithography system with automated overlay marker recognition. The developed SU-8 waveguides then fully encompass the printed NWs, as shown in Fig.1. This ensures efficient mode coupling from the NW to the polymeric guide [9]. In total, 20 nanowire-waveguide devices were fabricated with all NWs were confirmed to be located inside the SU-8 waveguides. The dimensions of the waveguides are approx. 4.7 μm in height, 4 μm in width and approx. 1 cm in length with a cleaved end facet to allow imaging of the guided optical mode.



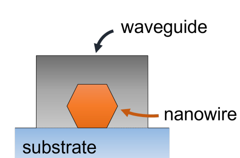


Fig. 1. (left) Plan view image of the developed nanowire-in-waveguide arrays. Inset shows enlarged image with (arrow) an embedded-into-waveguide nanowire. Scale bar: 100 μm. (right) Schematic cross section of the fabricated nanowire-waveguide structure, not to scale.

III. Micro-LED array pumping of NW emitters

The optical pumping of the semiconductor NWs was carried out using a micro-LED-on-CMOS chip with an emission wavelength of 410 nm, 16 x 16 active pixel array and individual pixel dimensions of 100 x 100 μm^2 [10] and optical power of $\sim$ 1 mW. Fig.2 shows a schematic of the optical pumping and imaging setup. A micro-LED array, along with CMOS board is mounted on a XYZ-stage. An infinity-corrected 10x objective is used for collecting light from a single pixel or an array of pixels. Then, a set of lenses is used for the projected pixel's demagnification and also to cover the back-aperture of 60x optical objective, which is used for the light projection onto a sample. The emission from nanowire is then collected by the objective and, after filtering micro-LED light, is projected onto a high-sensitivity CCD camera. A second 10X microscope objective and camera are used to image the light emitted from the waveguide end-facet to characterise the optically coupled NW emission into the waveguide [7].

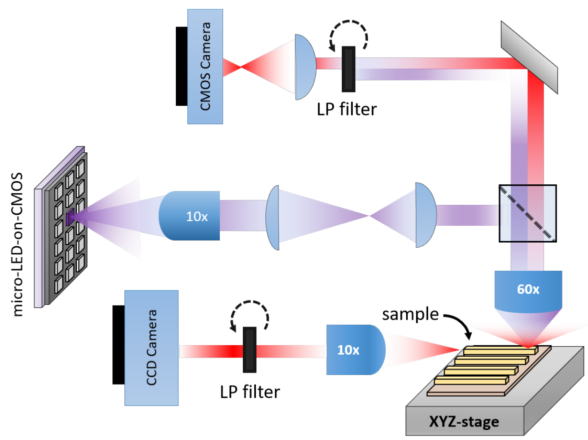


Fig. 2. Schematic diagram showing the micro-PL setup used for the optical pumping of nanowire emitters.

IV. Results

The array of NWs in polymer waveguides were optically pumped using individual micro-LED pixels. Fig.3 show images of the micro-LED pump aligned to a NW containing waveguide, the vertical emission from the NW through a long pass filter, and the facet coupled light from the waveguide end, respectively. The clear mode confinement of the output waveguide facet demonstrates the effective mode coupling between NW and waveguide and that micro-LED pixels have sufficient optical power for the excitation of NW semiconductor devices.

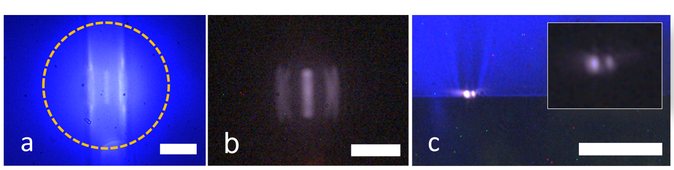


Fig. 3. (a) Brightfield micrograph showing nanowire inside waveguide with projected micro-LED (dashed circle). Scale bar: 4 μm. (b) Darkfield micrograph of the excited inside waveguide nanowire. Scale bar: 5 μm. (c) Side view of the edge of a waveguide sample showing output light from the excited nanowire inside waveguide from (a-b). Inset shows enlarged and long pass filtered darkfield image of (c). Scale bar: 100 μm.

V. Conclusion

Semiconductor NW devices promise to be important building blocks for future on-chip quantum photonic systems. Transfer-printing integration and direct write laser lithography have been shown to be an accurate and scalable method for the integration of NW devices into regular arrays of waveguide devices. Micro-LED-on-CMOS systems have shown modulation bandwidths into the 100's of MHz range and individual control of each pixel in an array making them an attractive option for optical pumping of on-chip light emitter arrays. Here we show direct optical excitation of NW light emitters into on-chip waveguide devices using these LED arrays.

Acknowledgment

The authors acknowledge the Australian Research Council for its financial support and Australian National Fabrication Facility, ACT node for providing NW samples. The authors also wish to thank A. Blanchard and R. Henderson's Group at the University of Edinburgh. This work was supported by the Royal Academy of Engineering (Research Chairs and Senior Research Fellowships), Engineering and Physical Sciences Research Council (EP/R03480X/1, EP/V004859/1, EP/W017067/1, EP/T00097X/1) and Innovate UK (50414). Z. Xia acknowledges PhD studentship support from Fraunhofer UK.

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