Optofluidic Assembly of Red/Blue/Green Semiconductor Nanowires

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Abstract: A full-color pixel consisting of CdSe, ZnO, and CdS nanowires has been heterogeneously integrated on a substrate with lithographic accuracy using lateral optoelectronic tweezers (LOET). Red (CdSe, 685nm), blue (CdS, 496nm), and green (ZnO, 518nm) light emissions are obtained by selectively pumping the corresponding nanowires. Potentially the nanowires can be directly assembled on CMOS driver circuit for a low-power display.

OCIS codes: (350.4855) Optical tweezers or optical manipulation; (220.4241) Nanostructure fabrication

1. Introduction

Low power displays are important for many applications where it is desirable to have as large and bright a display as possible whilst conserving battery power. This field is dominated by the cell phone market where the current trend towards smart phones is increasing the demand for larger and better quality displays. Liquid crystal displays (LCDs), have poor efficiencies (5-10%) due to light losses in the polariser and colour filters [1]. The efficiency can be increased by replacing liquid crystals with MEMS shutters, however, it requires additional fabrication steps [2]. Organic light emitting diodes (OLED) do not require a backlight but still suffers from short lifetime [1]. Semiconductor nanowire LEDs are attractive alternative for low power display [3]. They have longer lifetime, and can be synthesized at low cost. For full color displays, however, nanowires with different materials need to be integrated heterogeneously with lithographic accuracy. This has been a persistent challenge. In this paper, we demonstrate a novel optofluidic assembly technique for combining CdSe/ZnO/CdS semiconductor nanowires on a substrate using lateral optoelectronic tweezers (LOET). A full-color pixel with red/blue/green light emission has been demonstrated.

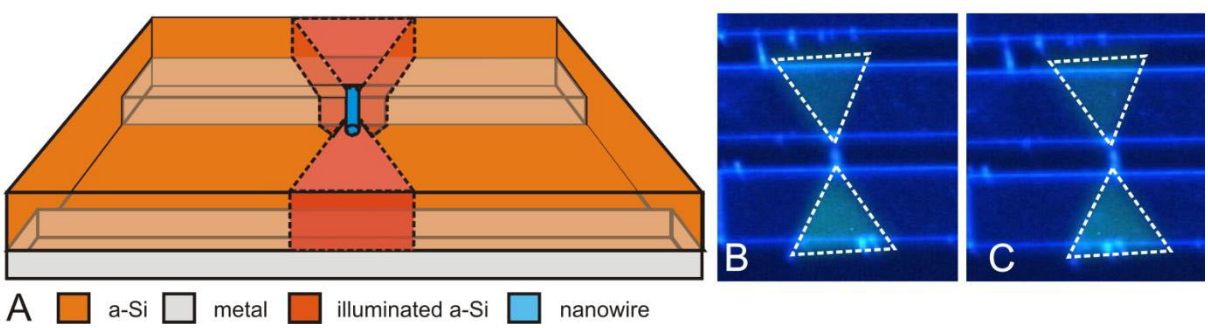

Figure 1. A) The LOET device consists of two metal electrodes covered in amorphous silicon (a-Si). Two triangular light patterns are illuminated on the a-Si attracting the nanowires to the gap between them. B) and C) show two stills from a movie of a ZnO nanowire being positioned. The gap between the electrodes here is 10µm.

Figure 1 shows the LOET device [4]. It consists of two aluminium electrodes which are patterned by photolithography before being covered by a 1µm layer of amorphous Si (a-Si) deposited by plasma-enhanced chemical vapour deposition (PECVD). An AC bias of 1Vpp at 500kHz is applied between the Al electrodes. A suspension of nanowires is then placed on the device. Two triangular light patterns are then projected onto the photoconductive a-Si layer, creating two virtual electrodes. This increases the electrical field in the gap between the two virtual electrodes, creating an electrical field gradient that attracts and aligns the nanowires between the triangular tips by dielectrophoresis. Figure 1 B and C show two frames from a video showing a ZnO nanowire being positioned. After alignment, the AC bias is increased to 20Vpp to permanently fix the nanowires on the substrate.

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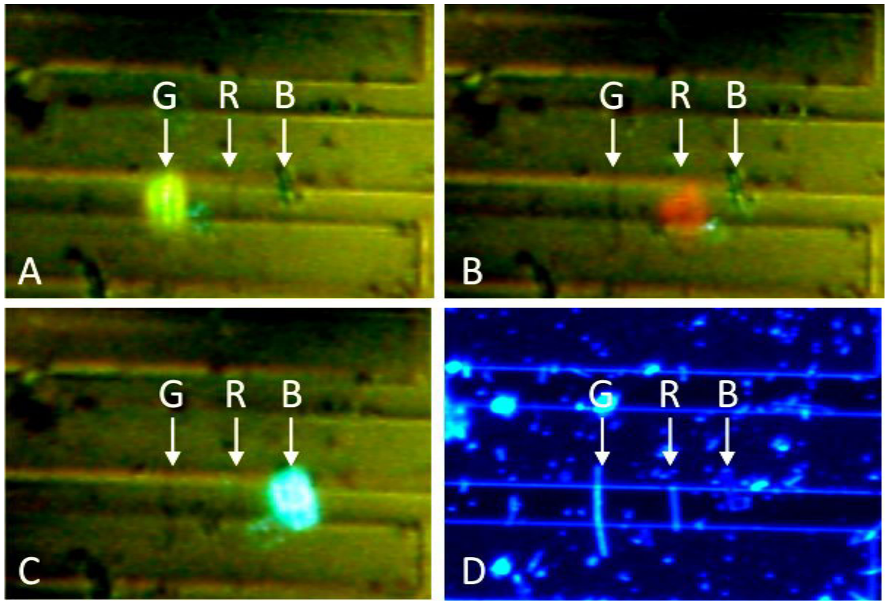

Figure 2. A) to C) show the ZnO, CdSe and CdS nanowires being illuminated successively by the UV laser. These images show that the photoluminescence from these nanowires is of different wavelength and can hence be used as a RGB pixel. D) shows a dark field image of the nanowire array.

2. Experiment

CdSe, ZnO, and CdS nanowires are used for red, green, and blue pixels, respectively. These nanowires were grown by vapour-liquid-solid (VLS) method. Their diameters range from 60 to 200nm. The nanowires were suspended in ethanol by agitation in an ultrasonic bath. The optical setup for nanowire manipulation resembles that of a microscope and is built with Thorlabs 30mm rail system. The virtual electrodes are generated by imaging the light patterns from a data projector (Dell 2400MP) using a 20x objective. A dichroic filter is placed between the projector and the objective, allowing viewing of the manipulation process. A second filter was used to remove most of the projected light. The images of trapped ZnO nanowires are shown in Fig. 1B and C. The assembled nanowires were optically pumped using a He-Cd laser (8mW of power at 325nm, IK series from Kimmon). The pump beam is focused by a reflective 15x objective. A hot mirror is used as a dichroic and a 500nm long pass filter is used to reduce the appearance of the UV laser. This filter also blocks some of the short wavelength light from the ZnO nanowires, making them appear more green (they emit in blue and green due to varied levels of stoichiometry) whilst the CdS nanowires still appear blue as they emit much more strongly at shorter wavelengths.

3. Results and Conclusion

Figure 2 shows photoluminescence images of the color pixel consisting of ZnO, CdSe, and CdS nanowires. Green emission is obtained when pump light is focused on the ZnO nanowire (λ=518nm, Fig. 2A). Red and blue emissions are obtained by focusing the pump light on CdSe (λ=685nm, Fig. 2B) and CdS (λ=496nm, Fig. 2C). Figure 2D shows the dark field image of the nanowire array. These results show that LOET can be used as a tool to manipulate nanowires and heterogeneously integrate them into an array. Potentially, the nanowire array can be directly assembled on CMOS circuit drivers for a full color display.

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