

Sparse multiwall carbon nanotube electrodes arrays for liquid crystal photonic devices

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Introduction

We present a new class of hybrid devices[1] based on a hybrid combination of sparse nanotube arrays and liquid crystals to create a photonic micro-optical device. An array of electrodes are made from vertically aligned multiwall carbon nanotubes[2,3] which are used to address a liquid crystal cell.

The device is a reflective liquid crystal cell as outlined in Figure 1. The sparse CNT array forms the bottom electrode and a top electrode made from indium tin oxide (ITO) coated glass.

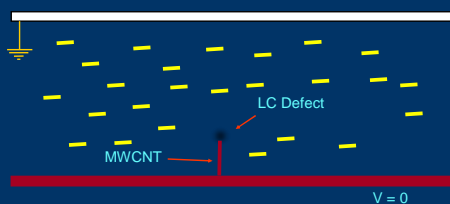


Figure 1

The electrodes create a Gaussian electric field profile (as in Figure 2) which is used to reorient a planar aligned nematic liquid crystal. The variation in refractive index within the liquid crystal layer acts like a graded index optical element which can be varied by changing the applied electric field to the carbon nanotube.

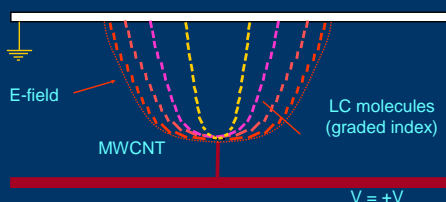


Figure 2

Device Simulation

A theoretical study on the electrical field effects of carbon nanotubes has been carried out using the finite element method (FEMLAB). A simulation of the electric field profile of the device structure in Figure 1 is shown in Figure 3a. The simulation assumes a conducting MWCNT in a vacuum and a good ohmic contact with the substrate underneath.

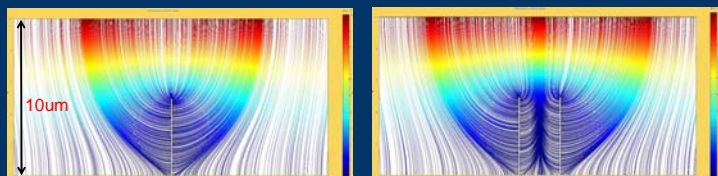


Figure 3 - Field = 1Vum⁻¹

Figure 4 - Field = 1Vum⁻¹

A theoretical 2D model of a single nanotube has also been extended into 3D to demonstrate that the field profile was circularly symmetric about the centre of the nanotube.

Further simulation showed that if small groups of 2,3 or 4 nanotubes were grown within a micron of each other, then the field profiles overlap making a larger optical aperture for each lenslet. Figure 4 shows how two closely spaced nanotubes can be used to create an effective single electrode with a wider field profile than the single nanotube.

Simulations were also done (see Figure 5) of multi-electrode devices to show how they can be used to form an array of micro-optical components such as lenslets.

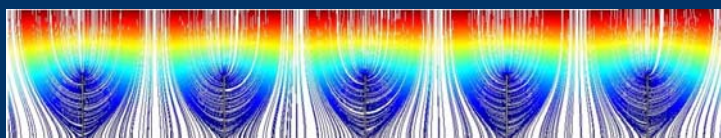


Figure 5 - Field = 1Vum⁻¹

Experimental Results

Three different kinds of MWCNT electrode structure were grown on silicon substrates. Each nanotube array was grown directly on a silicon wafer by PECVD after employing e-beam lithography to pattern a 5nm thick nickel catalyst layer into an array with each dot being 100nm in diameter, to allow the growth of a single MWCNT of 50nm diameter on each dot. The substrate was heated by DC current under vacuum of 10-2 mbar to 650°C at a ramping rate of 100°C per minute. Typical MWCNT arrays are shown in Figure 6.

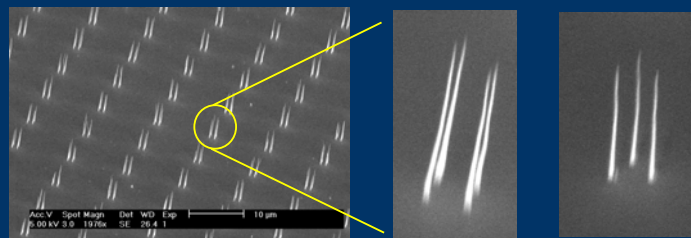


Figure 6 – 4-MWCNT group array and a 3-group cell

The array was finally coated with 40nm of aluminium to make it reflective and provide a common contact then assembled with a top electrode containing ITO on 0.5mm thick borosilicate glass into a liquid crystal cell with a 20um cell gap. No alignment layer was applied to the nanotube array, but the top glass electrode was coated with AM4276 liquid crystal alignment (low pretilt polyamide from Merck) and rubbed in the horizontal direction. The cell was then capillary filled with a positive dielectric anisotropy nematic, BLO48.

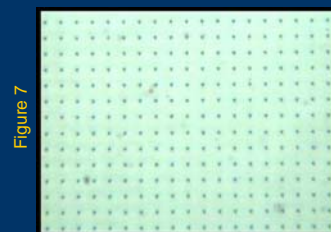


Figure 7



Figure 8

The device was then viewed under a horizontally polarised light microscope. The MWCNTs were clearly visible as black dots as each 50nm tip was a defect site. Figure 7 shows the sparse array at zero applied electric field. As the applied field was increased, the nanotube electrodes were seen to begin switching at 1.8Vum⁻¹, which corresponds to the equivalent of a Freedericksz transition. Figure 8 shows the nanotube array at 2.2Vum⁻¹ applied field and the nanotubes were all fully switched. The switch sequence is shown at x60 in Figure 9

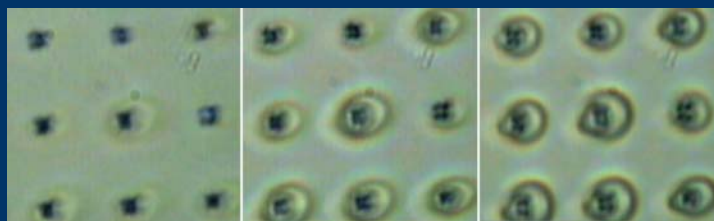


Figure 9 – 4-MWCNT group array 0 – 2.2Vum⁻¹

References

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