Low Driving Voltage of a Liquid Crystal Device Fabricated from 4′-Pentyl-4-biphenylcarbonitrile Doped with Environmentally Friendly ZnO Nanoparticles

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ZnO nanoparticles (NPs), prepared by an improved alco-sol method at relatively low temperature using oleic acid (OA) as a stabilizing agent, were added to a liquid crystal matrix of 4′-pentyl-4-biphenylcarbonitrile (5CB). Addition of ZnO NPs not only decreased the threshold voltage but also had a dramatic effect (about 30% reduction) on the driving voltage (V_d) of 5CB. The decrease of V_d of liquid crystal can reduce power consumption, which may meet the demands of future power-saving liquid crystal displays.

Liquid crystal displays (LCDs) are common electronic devices and are widely used any place and at any time. The display is an interface for information between man and machine. From this viewpoint, LCDs are useful for information technology (IT) at present.[1] The energy crisis is a global problem that people all over the world encounter. Recently, large (108 inches at maximum) LCDs with high brightness, high contrast, and high resolution consume huge amounts of energy (500 W to 2 kW), although a decade ago, mainstream CRT TVs only had a power consumption of less than 100 W. Since LCDs are widely used as TV sets, monitors for personal computers and so on, decreasing the energy consumption of LCD is an urgent research subject.[2–4]

Many reports have been published on nanostructured liquid crystals.[5–13] We have reported that a series of LCDs doped with metal nanoparticles (NPs) such as Ag, Pd, Au, Pt, or their alloys[7,10–13] may have much faster response than LCDs without dopants. However, the driving voltage (V_d) of LCDs usually increases by doping with metal nanoparticles. High V_d may provide high electronic power consumption which should be avoided. Furthermore, addition of those noble metals may increase the cost of LCDs.

Lately, ZnO NPs have attracted increasing attention owing to wide application in anti-ultraviolet-radiation cosmetics, highly efficient solar cells, light-emitting device, cancer detecting biosensors, gas sensors, and degradation of organic toxins.[14–17] Anyway, the traditional method to prepare ZnO NPs involves precipitation of $Zn(OH)_2$ by treatment of Zn^{2+} ions with weak alkali (e.g., NH_4OH) and heat treatment of $Zn(OH)_2$ at 400–700 °C for several hours.[18] This method has some disadvantages: 1) The method requires high temperature and long reaction time, which usually results in large particles sizes[19,20] (from several tens nm to several μm), loss of the quantum size effect, and huge power consumption during the annealing process. 2) ZnO NPs are obtained in powder state which is not easy to get good dispersion into liquid crystal matrix compared with a stable sol state in organic solvents. 3) Since most of the organics attached to the particle surface are removed by heat treatment, ZnO NPs have very poor compatibility with the liquid crystal matrix.

In this letter, we report an improved alco-sol method[21,22] for the preparation of nanosized ZnO capped by oleic acid, which can improve the compatibility of ZnO NPs with 4′-pentyl-4-biphenylcarbonitrile (5CB: a liquid crystal molecule) at relatively low temperature. Liquid crystal cells fabricated by 5CB doped with the prepared ZnO NPs show an obvious decrease in V_d. To the best of our knowledge, this is the first report of ZnO NPs applied to liquid crystal display devices resulting in an obvious decrease in V_d compared with pure 5CB without dopants. In addition, almost all solvents, by-products, and products can be easily recycled in our process, and almost all chemical reagents used in this process are nontoxic. Thus, this is an environmentally friendly chemical process.

The hydrophilic ZnO NPs were obtained as follows: 0.29 g (7 mmol) of $LiOH \cdot H_2O$ was dissolved in 50 mL of ethanol at room temperature in an ultrasonic bath (solution A). The mixture of 1.10 g (5 mmol) of $Zn(AcO)_2 \cdot 2H_2O$ and 1.41 g (5 mmol) oleic acid in 50 mL of ethanol were heated to boiling and kept boiling for 30 min until a transparent solution was formed (solution B). Solution A was added dropwise to solution B at 0 °C. The transparent solution was destabilized by addition of 200 mL of *n*-heptane. After keeping overnight, the upper transparent solution that may contain soluble impurities and the free oleic acid was removed from the product. After centrifugation and decantation, the resulting sediment was redispersed into absolute ethanol with the aid of ultrasonication. The above purification process was repeated 3 times until stable light-purple transparent ZnO sols were obtained at last.

Figure 1 shows the transmission electron micrograph (TEM) of ZnO NPs prepared by the above method. Due to high concentration of ZnO in sol, the particles are slightly aggregated with an average diameter of 3.6 nm. The as-prepared ZnO NPs sols were diluted 50 times (50×) with absolute ethanol, but the particle size and shape did not obviously change.

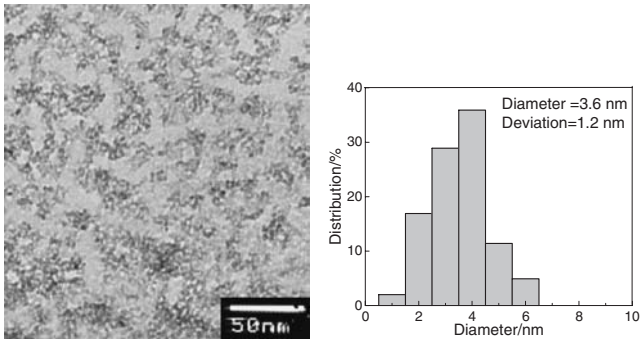

Figure 1. Transmission electron micrograph and particles size distribution histogram of the as-prepared ZnO nanoparticles.

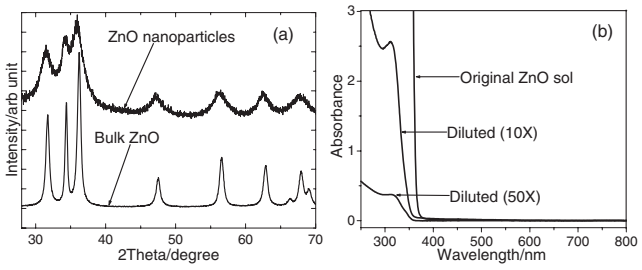

Figure 2. (a) The XRD patterns of the as-prepared ZnO nanoparticles (top) and bulk ZnO powder (bottom). (b) UV–vis absorbance spectra of original ZnO sol (right), 10 times diluted (middle) and 50 times diluted (left).

XRD patterns of oleic acid-protected ZnO NPs and commercially available bulk ZnO are presented in Figure 2a. ZnO NPs capped with oleic acid have all the same diffraction peaks as the bulk although the peaks are wider than bulk owing to the size effect. This is in good agreement with the JCPDS Card No. 36-1415. The particle size calculated from XRD patterns according to the Scherer equation is 3.8 nm, which is in good agreement with the TEM observation.

UV–vis spectra of ZnO sols are shown in Figure 2b. Usually the absorbance edge of bulk ZnO is located at 381.5 nm,[23] while an aqueous sol of the prepared ZnO NPs shows an absorbance edge of about 365 nm. The obvious blue shift is due to a quantum size effect.[19] Due to the high concentration of ZnO NPs in the original sol, the absorbance plasma cannot be observed. Diluted solutions of the original sol of ZnO NPs by the addition of absolute ethanol give the absorbance plasma at about 330 nm.

Electrooptic properties were measured at 25 °C in a twisted nematic mode with a cell gap of 5 μm using a LCD evaluation system (Photal, model LC-5200). Voltage–transmittance (V–T) curves of 5CB doped with ZnO NPs having a frequency dependence (Figure 3) indicates that the threshold voltage (V_{th}) and the driving voltage (V_d) of doped 5CB decrease with increasing weight percent of ZnO less than 0.5 wt %. Table 1 summarizes the threshold and driving voltages for pure 5CB and those doped with ZnO NPs at various wt %. The V_d of pure 5CB and 5CB doped with 0.5 wt % of ZnO are 1.7 and 1.2 V, respectively. The doped material has a 30% lower V_d than that of the pure 5CB. The lower V_d may lead to lower power consumption. This is a very interesting phenomenon, because the V_d of 5CB doped with metal nanoparticles (Au, Ag, and Pd) usually increase.[24] Thus, semiconductor NPs may have a unique behavior in the liquid crystal matrix. The elimination of internal electric field is believed to have contributed to the decrease of V_d of 5CB cells

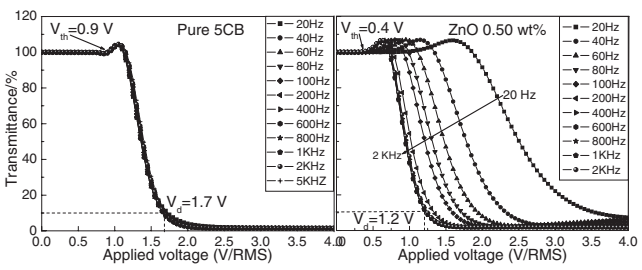

Figure 3. V–T curves of pure 5CB cells and the cells doped with 0.5 wt % of ZnO nanoparticles.

Table 1. The threshold voltages (V_{th}) and the driving voltages (V_d) of pure 5CB cells and the cells doped with ZnO nanoparticles (wt %)

Samples	5CB	ZnO nanoparticles/wt %				
		0.01	0.05	0.10	0.20	0.50
V_{th}/V	0.9	0.75	0.7	0.6	0.55	0.4
V_d/V	1.7	1.37	1.34	1.34	1.32	1.2

by doping with the prepared ZnO NPs. Further studies will be described in detail elsewhere.

In summary, ZnO NPs were successfully prepared by an improved alco-sol method at low temperature with low power consumption via a green chemistry process. The effect of ZnO NPs on the electrooptic properties of 5CB has been studied in detail. It is clear that the addition of ZnO NPs to 5CB liquid crystal can decrease the V_d and V_{th} dramatically. Lower V_d may lead to lower electronic power consumption, which may meet the demands of future power-saving liquid crystal displays.

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