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Effect of insulating-nanoparticles addition on ion current and voltage-holding ratio in nematic liquid crystal cells

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The transient currents induced by an applied direct voltage (dc) electric field have been measured liquid-crystal cells in nematic phase. The experimental results show that the addition of insulating nanoparticles, such as diamond powders, leads to a reduction of the ion concentration in cells so as to drastically reduce the transient currents and threshold voltage. Simultaneously, a high voltage-holding ratio (VHR) in doped cells is observed. Such a high VHR, in comparison with nematic liquid crystals doped by carbon nanotubes, is a superior feature for future liquid crystal display applications. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2740581]

Liquid crystals (LCs) are anisotropic fluids. The nematic is the most common phase of LCs. Nematic LC displays (LCDs) have become a mature technology affording a wide range of applications from simple black and white pocket calculators to full color televisions nowadays. In order to obtain high quality performance in LCDs, it is an important issue to lower the concentration of charged impurities and maintain high resistivity.[1] Many experiments on the transient behavior of impure ions in nematic liquid crystals (NLCs) have been done,[2] such as measurement of electro-optical properties,[3] study on the behavior of transient currents,[2] and the voltage-holding ratio (VHR) depending on the ion concentration.[4] By investigating the switching behavior of electric capacitance and optical transmittance hystereses, earlier studies have shown that the doping of nanosolids into NLCs suppresses the unwanted ion effect and reduces the dc driving voltage.[5] These results are likely to be of considerable interest for both nanotechnology and LC photonics.

Carbon nanotubes (CNTs) have been doped in NLCs in the past.[5,6] CNTs are primarily conductive along the tubes and hardly conductive across them.[6] Due to elastic interactions between the CNTs and the LCs, the CNTs follow the reorientation of the LC, and *electrically* controlled on-off switches were realized on the basis of LC-CNT dispersions.[6] The electric field reorients the LC from planar to homeotropic; elastic interactions exert a torque on the dispersed CNTs reorienting them from a nonconducting state to a conducting state above the electric threshold voltage V_{th}.[6,7] In the conducting state, the CNTs were not able to maintain the voltage across the LC cells.[6,7]

In LCDs, VHR is defined as the fraction of voltage remaining over the cells after a certain length of open circuit time. LC cells with high resistivity can lead a high VHR for better contrast and avoid image flickering in thin film transistor (TFT)-addressed LCDs.[8] Therefore, it is important to understand how the ion-adsorption process and ion-charge density are affected by insulating nanoparticles[9] such as diamond powders to suppress the ion effect and still maintain a high VHR. In this letter, we report that the addition of diamond powder nanoparticles not only leads to a drastic reduction of the ion concentration in LC cells but also simultaneously maintains a high VHR. Such a high VHR value, in comparison with NLCs doped by many nanosolids and CNTs, is a superior feature for future liquid crystal display applications.

The empty cells with indium tin oxide electrodes and polyimide alignment layers for planar orientation were manufactured in a 90° twisted-nematic (TN) configuration, where a cell gap of 4 μm was ensured by spacers. A mixture of the nematic LC MJ9915 (from Chung-Hwa Picture Tube Company) with a small amount of diamond powders of 4 nm in diameter (from Nanostructured & Amorphous Materials, Inc.) was ultrasonicated to promote dispersion. Following ultrasonication, the suspension was then introduced into empty cells by capillary action in the isotropic phase. We applied square waveform bias voltage to the cells and measured the voltage of resistor cascaded with the cells to get the transient current in the cell. The detailed experiments and procedures for the transient-current measurements can be found in Ref. 4.

In fact, the conduction in the LC layer is due to ionic transport. Depending on the concentration of the ions, the uniformity of the field inside the LC layer can be disturbed.[2] It is necessary to use voltages below the Freedericksz threshold to avoid switching of the LC.[2] The transient-current

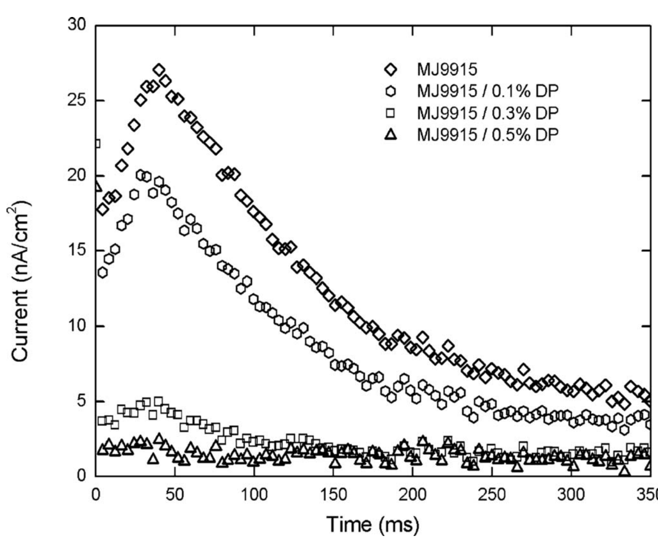

FIG. 1. Transient currents induced by a dc voltage of 1.2 V applied to an MJ9915 cell and three MJ9915/DP cells at room temperature.

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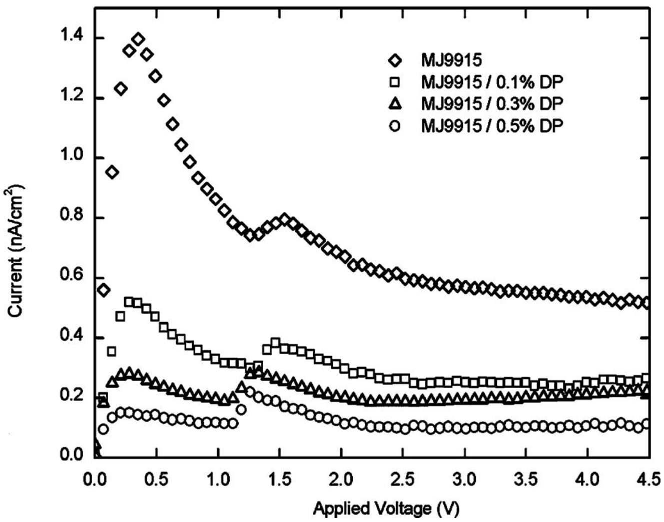

FIG. 2. Transient currents through the TN MJ9915 and MJ9915/DP cells under the applied dc voltage.

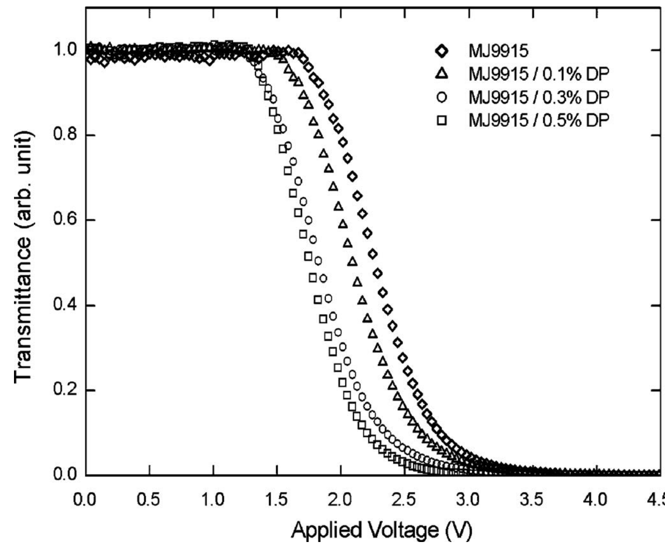

FIG. 4. Power transmitted through the TN MJ9915 and MJ9915/DP cells under the applied dc voltage.

curves induced by the applied voltage V are displayed in Fig. 1. We can see that current bump I_p appears at about 50 ms. The I_p of MJ9915 neat is higher than MJ9915 doped with diamond powders. We also find that the NLCs doped with larger than 0.3 wt % diamond powders can drastically suppress the transient current so as to decrease I_p. In Fig. 2, we found that when the bias voltage is increased, the transient current will increase before 0.3 V. The transient current will decrease until the second current peak appears when the bias voltage is larger than 0.3 V. We know that the second current peak is produced by LC switching because the voltage of the second current peak is the same as the threshold voltage (V_{th}).

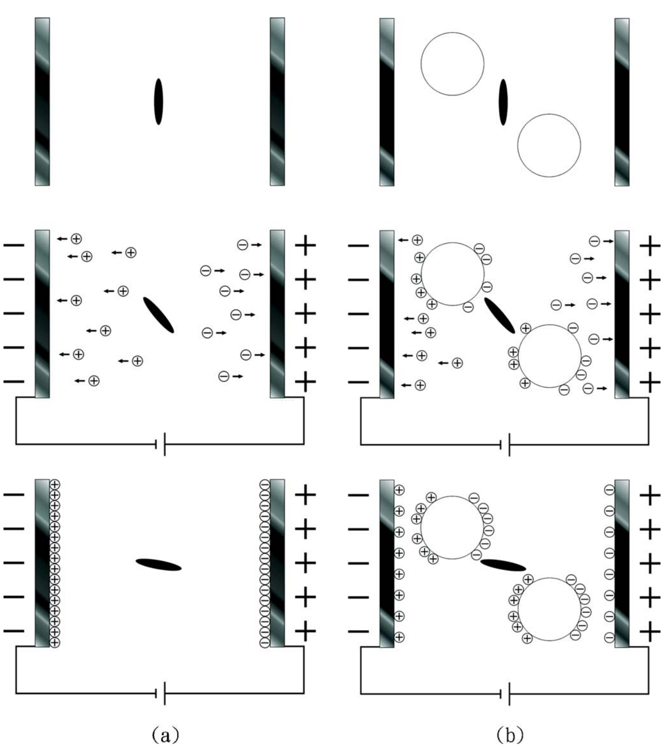

FIG. 3. Conceptual depiction variation of internal ions in a TN cell. (a) Without doping of diamond powders and (b) with doping of diamond powders.

The screening effect arising from the increased population of absorbed ion charges on the interface under the applied dc voltage V and causes a decrease of the effective voltage for the LC layers, as such it increases the V_{th} required for display. Figure 3(a) is the conceptual depiction of NLCs without diamond powder doping and Fig. 3(b) is the conceptual depiction of NLCs with diamond powder doping. Figure 3(b) shows that the insulating diamond powders can trap the ions in the NLCs to avoid ions flowing to the two sides of cells and thus decrease the screening effect. Figure 4 shows that the diamond powders can reduce the threshold voltage of NLCs because of the lessened screening effect. Doping diamond powders into NLCs can suppress the field screening effect, and therefore less switching voltage is needed. This agrees with the result that doping nanosolids into twisted NLCs (Ref. 5) suppresses the unwanted screening effect and reduces the dc driving voltage, as shown in Fig. 4.

Table I is the VHR of NLCs doped by diamond powders and CNTs. There are two types of CNTs used here: multiwalled carbon nanotubes 0.5 μm long, 8–15 nm thick, and multiwalled carbon nanotubes 1.5 μm long, 10–30 nm thick. We use a 5 V dc pulse to measure VHR and the results are illustrated in Table I. The detailed experiments for measuring VHR can be found in Ref. 4. The VHR of the NLCs MJ9915 doped by diamond powders is almost the same as undoped NLCs. Because the diamond powders are insulating nanoparticles, they cannot increase the conductance of NLCs. However, if carbon nanotubes are doped into the NLCs, the conductance increases when the carbon nanotubes

TABLE I. Voltage-holding ratio of the TN MJ9915, MJ9915/DP, and MJ9915/CNT cells under the applied dc voltage of 5 V.

	VHR (%)
MJ9915	97.22
MJ9915/0.3% DP	96.17
MJ9915/0.5% DP	97.54
MJ9915/0.5% CNT (0.5 μm)	33.06
MJ9915/0.5% CNT (1.5 μm)	36.88

drastically orient from the planar state to the homeotropic state,[7] resulting in lowering of VHR.

In summary, the observed much lower transient current in the doped cells indicates that doping diamond powders into the LC cells facilitates the decrease of the moving-ion density, thus suppressing the unwanted field screening effect and contributing to a reduction of the driving voltage. Moreover, the insulating diamond nanoparticles also maintain a very high VHR in the cells better than CNTs do. These experimental results enable the development of an electro-optical application of a LC device by the incorporation of insulating nanoscale materials.

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