Response to "Comment on Electrical-field effect on carbon nanotubes in a twisted nematic liquid crystal cell [Appl. Phys. Lett. 87, 263110 (2005)]"

Sang Youn Jeon and Seung Hee Lee[a)]
Research Center of Industrial Technology, BK-21 Polymer BIN Fusion Research Team, Chonbuk National University, Chonju, Chonbuk 561-756, Korea

Young Hee Lee[b)]
Department of Physics, Center for Nanotubes and Nanostructured Composites, Sungkyunkwan Advanced Institute of Nanotechnology, Sungkyunkwan University, Suwon 440-746, Korea

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First of all, we would like to thank Huang and Pan[1] for their comments on our recently paper[2] published with the title "Electrical-field effect on carbon nanotubes in a twisted nematic liquid crystal (TNLC) cell." They commented on the origin of hysteresis reduction in a TNLC cell. They fabricated a particular cell with massive ions and found that the hysteresis was still reduced, although the threshold voltage was increased, due to the ion trapping that occurred at the interface between the alignment and the LC layers. On the basis of this result alone, they claimed that the hysteresis reduction did not completely contribute to the ion trapping effect by carbon nanotubes (CNTs).

We agree that the reduction of the hysteresis may not have been completely due to the ion trapping by the CNTs in the TNLC cell with massive ions. Nevertheless, we question whether their experimental data prove their assertion.

In their experiment, LC E7 was used with a dielectric anisotropy of 14.1 and a cell gap of 6.25 μm. With this condition, the operation voltage which shows a dark state should be less than 4 V, as observed in Fig. 2(a). Nevertheless, the voltage-dependent transmittance (*V-T*) curves under ac voltage driving were shifted to the right in the cells with minute doping of multiwall CNT of 5×10^{-3} and 5×10^{-4} wt %. Furthermore, the dark state was not obtained even at a high applied voltage of 6 V for a cell with CNT of 5×10^{-4} wt %. These effects were never observed in our cells, as has been previously reported.[1] The authors claimed that the shift of threshold voltage (at which the transmittance starts to change) was attributed to the increase of effective elastic constant. We also agree that the CNTs affect the elastic constants of the LC but not by such an extent as to increase the threshold voltage by more than 0.5 V. One of the problems in their measurements was the large voltage ramping rate of 1 V/s compared with our data measured with a ramping rate of 0.1 V/s. In addition, the light leakage even at 6 V indicates that the LC orientation was disturbed by the existence of the CNTs at a microsize level from the beginning, confirming that a dark state cannot be achieved at such a voltage. Therefore, when the LC orientation of the twisted nematic was disturbed by the CNTs, the *V-T* measurements could not yield repeatable characteristics, which render unreasonable any attempt to judge the CNT effects on the LC by investigating *V-T* curves. Now, according to Fig. 2(b), they claimed that the threshold voltage under dc driving was shifted due to ion trapping at the interface between the alignment layer and the LC layer. Nevertheless, the hysteresis was reduced in the CNT-doped cell. In general, the hysteresis is caused by the ion trapping between two layers so that such hysteresis in the *V-T* curve increases with increasing ion trapping, as already commented in a previous report.[3] The shift of threshold voltage under dc driving occurred for all cells, irrespective of the presence or absence of CNT doping. Therefore, all cells should exhibit the hysteresis in the *V-T* curves, whereas only the CNT-doped cell with 0.01 wt % (C-1) showed hysteresis suppression while the hysteresis was maintained in the CNT-doped cell with 0.005 wt %. Even in the C-1 cell, the threshold voltage was shifted by more than 1 V according to Fig. 2. If one assumes that the screening voltage is +1 V by the trapped ions, then the effective voltage when a dc current of +5 and −5 V is applied during the positive and negative cycles becomes +6 and −4 V, respectively, resulting in a maximum hysteresis of 2 V. However, no such hysteresis was observed in Fig. 2(b). The data showed some inconsistent results which seriously contradicted the conventional concepts.

In summary, experiments were performed to investigate whether or not the reduction of the hysteresis in the *V-T* curves was completely due to the ion trapping by the CNTs when the LC cell is assumed to have massive ions. However, as noted above, we found some inconsistencies in the presented explanation for the reduced hysteresis in the CNT-doped cell even with massive ions. We believe that these inconsistencies may have arisen from the high ramping rate of 1 V/s and/or the disturbance of the LC orientation by the CNTs in their measurements. Although we agree with the authors' stated explanation for the origin of the hysteresis reduction, we believe that the data they have presented are incapable of perfectly proving their assertion.

[a)]Electronic mail: lsh1@chonbuk.ac.kr
[b)]Electronic mail: leeyoung@skku.edu

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