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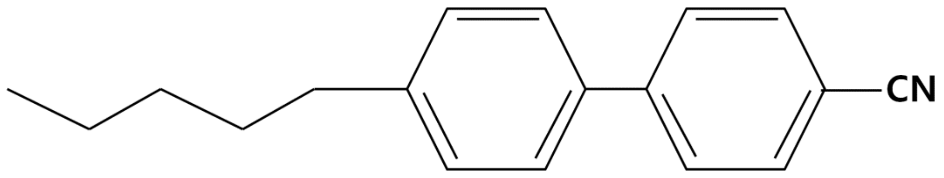
Supporting Information

CIS/ZnS Quantum Dots for Self-Aligned Liquid Crystal Molecules with Superior Electro-Optic Characteristics

*Won-Kyu Lee, Seung Jun Hwang, Min-Jae Cho, Hong-Gyu Park, Jin-Woo Han, Seogjeong Song, Jong Hyun Jang and Dae-Shik Seo**

S1. Chemical structure of commercial 5CB



S2. EDX composition analysis of synthesized QDs

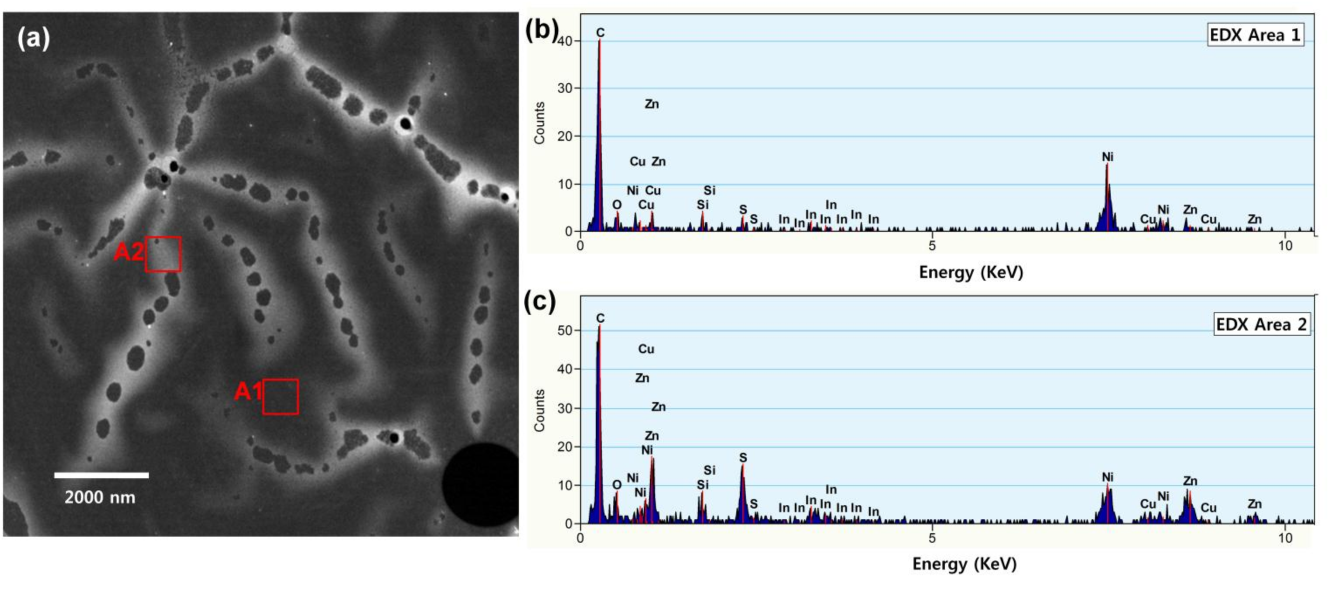


Fig. S2 For element analysis, FEI instrument with a field emission gun was operated at 300 kV, equipped with an EDAX spectrometer with Si (Li) detector. In dark-field STEM images of QDs (a), the bright area indicates the self-assembled QDs, and dark area exhibits nickel holey carbon support grid of the sample confirmed by EDX data (b) and (c). It clearly shows that 1D like self-assembled property of as-synthesized QDs.

S3. Elemental line profiles of concentrated QDs in LC matrix

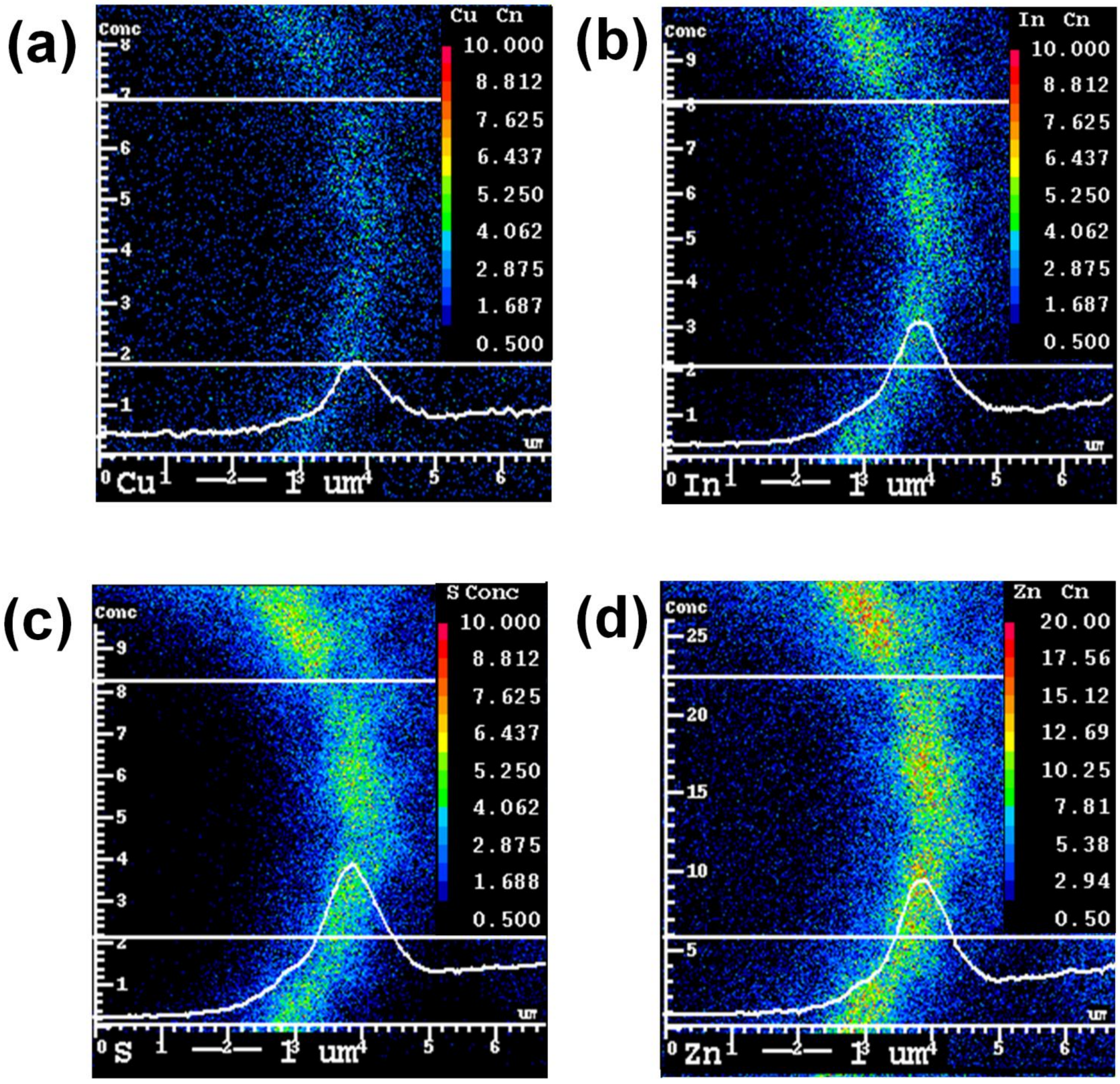


Fig. S3 Line profiles of concentrated QDs embedded in LC media. The width of the each elemental core is 700-900nm which value is well coincide with the size of QD clusters shown in STEM image in Figure 1a.

S4. PL spectra and absorbance of QDs in different media

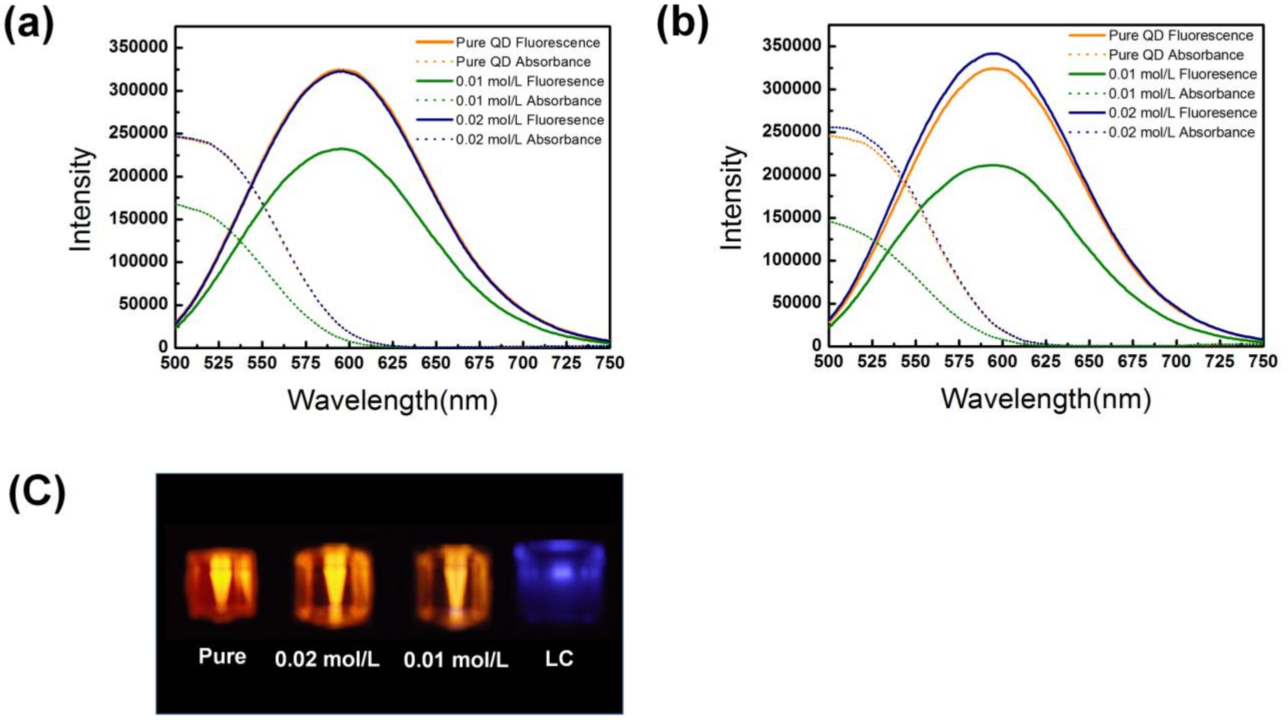


Fig. S4 PL spectrum and absorbance (dotted line) of QDs in positive anisotropic LCs (a) and negative anisotropic LCs (b) with different concentration. Pure QDs dispersed in chloroform was used for comparison. There were no significant red or blue shift in Figure (a and b), meaning that the inter-particle distance or the degree of agglomeration is almost same irrespective of LC hosts. The images of the fluorescing QD-LCs composites were also shown in Figure (c).

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S5. POM images of pure LCs on ITO surfaces

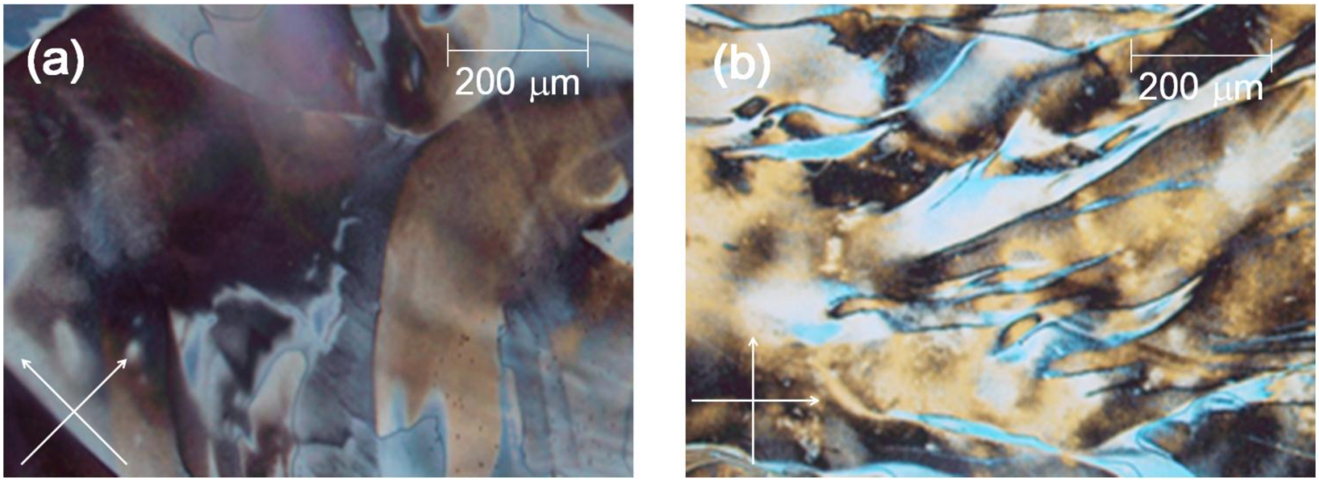

Fig. S5 Schlieren textures were shown in both negative (a) and positive (b) dielectric anisotropic LCs on ITO surfaces without alignment layers

S6. Equations for LC response times in VA and ECB mode LCDs

Response times of ECB mode LCD are represented by (Equation (1 and 2)) and those of VA mode LCD are expressed by (Equation (3 and 4)) where K_{11} and K_{33} are splay, bend elastic constants respectively. Also, d and γ are cell gap and rotational viscosity of LCs.

$$\tau_{on} = \frac{\gamma}{K_{11}}\left(\frac{d}{\pi}\right)^2\left[\frac{1}{(V/V_{th})^2-1}\right] \quad (1)$$

$$\tau_{OFF} = \left(\frac{d}{\pi}\right)^2\frac{\gamma}{K_{11}} \quad (2)$$

$$\tau_{on} = \frac{\gamma}{K_{33}}\left(\frac{d}{\pi}\right)^2\left[\frac{1}{(V/V_{th})^2-1}\right] \quad (3)$$

$$\tau_{OFF} = \left(\frac{d}{\pi}\right)^2\frac{\gamma}{K_{33}} \quad (4)$$

We believe that further investigation using various material combinations is necessary, to determine which property-either the elastic constant, the viscosity or focused electric field-pays a more crucial role in the electro-optic properties of the resultant suspension. Nonetheless, Figure 4 in main text provides strong evidence that improved electro-optic properties can be expected in LC devices with QDs dispersed composites in various LCD modes.

S7. Switching performances in VA and ECB mode LCDs containing LC-QDs composites

		Response time [ms]	Total response time [ms]	V_{th} [V]	
ECB mode	**0.01 mol/L**	3.7 (fall)	8.0	**T10%**	3.35
		4.3 (rise)		**T90%**	1.44
	0.02 mol/L	2.3 (fall)	5.9	**T10%**	3.2
		3.6 (rise)		**T90%**	1.26
	PI	4.6 (fall)	9.3	**T10%**	4.03
		4.7 (rise)		**T90%**	2.01
VA mode	**0.01 mol/L**	7.1 (rise)	23.7	**T10%**	1.67
		16.6 (fall)		**T90%**	3.59
	0.02 mol/L	3.4 (rise)	18.4	**T10%**	1.10
		15.0 (fall)		**T90%**	3.46
	PI	10.0 (rise)	29.8	**T10%**	2.07
		19.8 (fall)		**T90%**	4.02

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S8. Thermal stability test

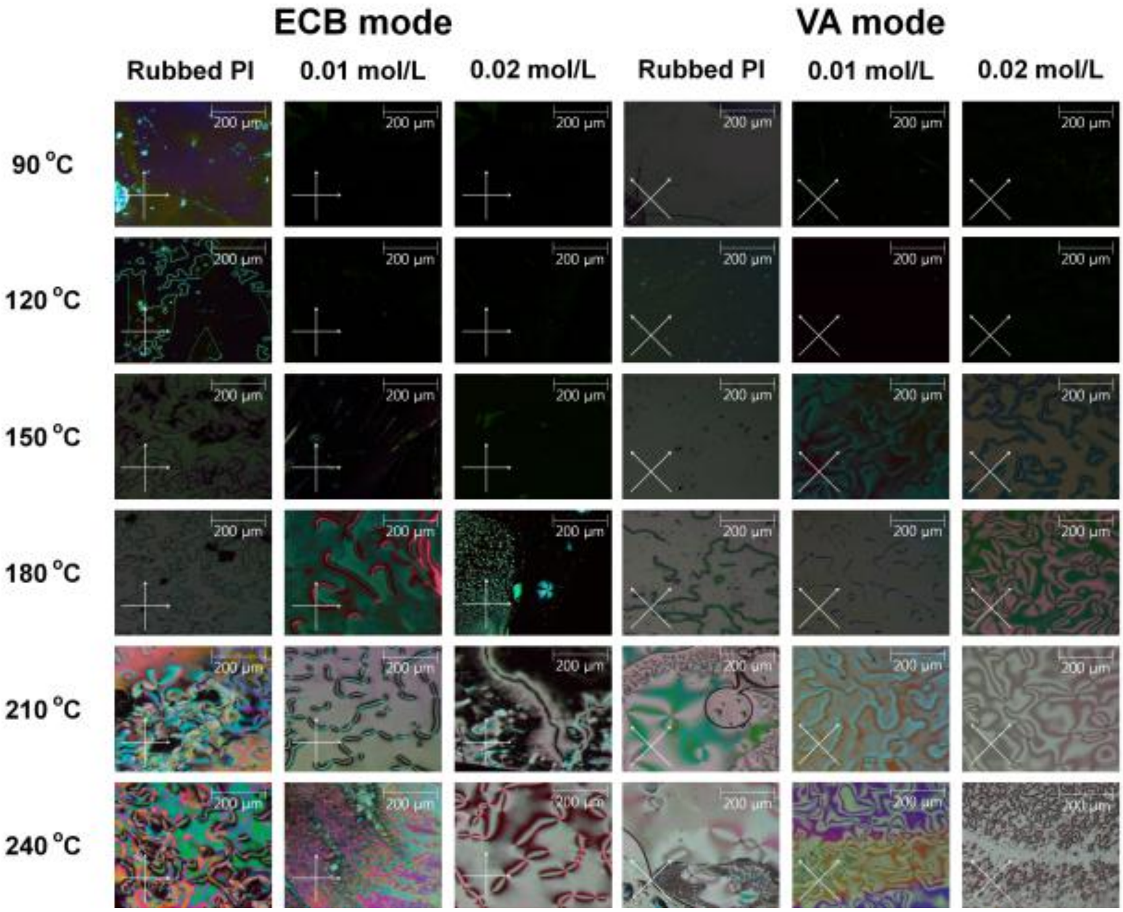

Fig S8. We conducted thermal stability test as shown upper image. From this experiment we found that the LC-QD composite have the higher thermal stability than that of pure LCs on conventional PI alignment layers. The LC-QD composite has stable thermal stability up to 120 ^{o}C in both ECB and VA mode, while pure LC on PI showed good alignment states only under 90^{o}C. Our LC-QD composites are beneficial for high temperature operation due to their higher thermal stability suitable for microdisplays and high-brightness displays which require increased thermal budgets in LCDs.

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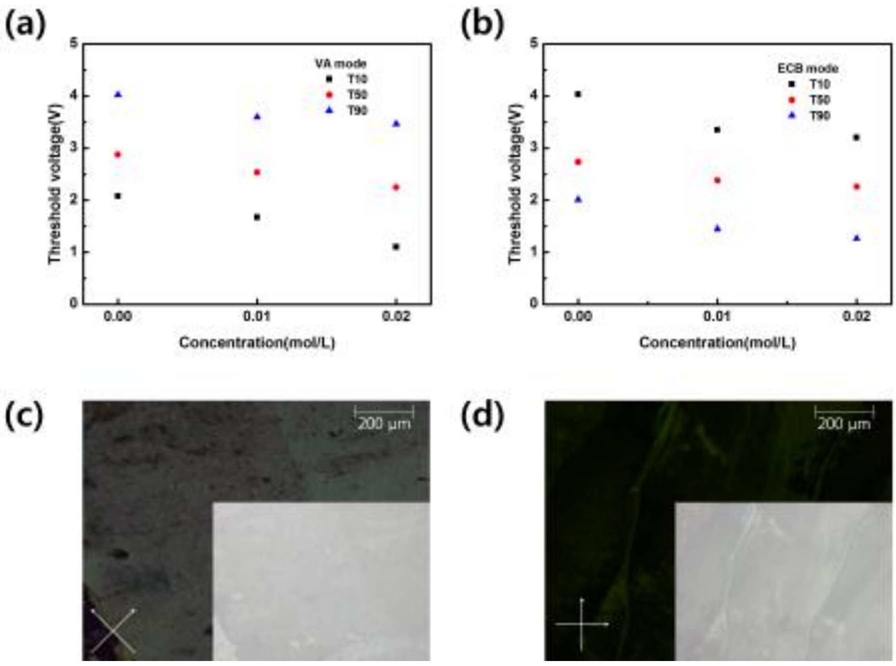
S9. QD concentration vs. V_{th} trend



We demonstrated the QD concentration vs. V_{th} (10, 50, 90 % transmittance) for more clear trend as shown in figure (a) and (b). We also checked that LCs doped with QD concentration above 0.02 mol/L (i.e. 0.03 mol/L) showed poor alignment states as shown in figure (c) and (d) (The figure (a) and (c) are about VA mode LCDs and, (b) and (d) are about ECB mode LCDs, respectively). We believe that this result might because the aggregation of QD particles (not self assembled within LC matrix) with higher concentration. In sum, the QD concentration around 0.02mol/L is the optimal condition for LC alignment and switching.

SUPPORTING REFERENCES

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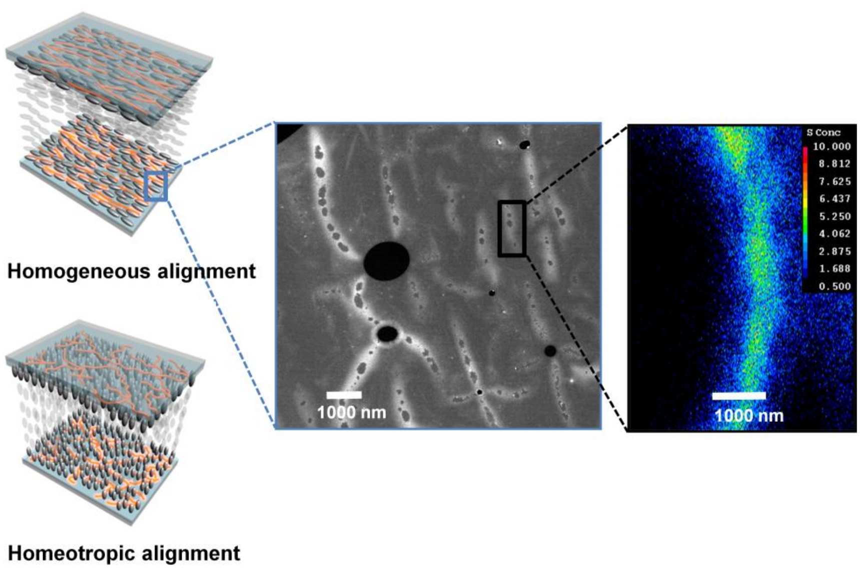

The $CuInS_2$ (CIS)/ZnS quantum dot (QD) doped liquid crystals (LCs) with both positive and negative dielectric anisotropies were successfully self-aligned with homeotropic or homogeneous states using different LC cell fabrication methods. The QD-LCs composites show the superior electro-optic (EO) characteristics of a reduced threshold voltage and the fast response times for both vertical alignment (VA)- and electrically compensated bend (ECB)-mode LC cells with controllable device switching.