Electric switching of visible and infrared transmission using liquid crystals co-doped with plasmonic gold nanorods and dichroic dyes

GHADAH H. SHEETAH,[1,2] QINGKUN LIU,[1,2] BOHDAN SENYUK,[2] BLAISE FLEURY,[2] AND IVAN. I. SMALYUKH[1,2,3,4,*]

[1]*Materials Science and Engineering Program, University of Colorado, Boulder, Colorado 80309, USA*
[2]*Department of Physics and Soft Materials Research Center, University of Colorado, Boulder, Colorado 80309, USA*
[3]*Department of Electrical, Computer and Energy Engineering and Soft Materials Research Center, University of Colorado, Boulder, Colorado 80309, USA*
[4]*Renewable and Sustainable Energy Institute, National Renewable Energy Laboratory and University of Colorado, Boulder, Colorado 80309, USA*
**ivan.smalyukh@colorado.edu*

Abstract: Smart windows and many other applications require synchronous or alternating facile electric switching of transmitted light intensity in visible and near infrared spectral ranges, but most electrochromic devices suffer from slow, nonuniform switching, high power consumption and limited options for designing spectral characteristics. Here we develop a guest-host mesostructured composite with rod-like dye molecules and plasmonic nanorods spontaneously aligned either parallel or orthogonally to the director of the liquid crystal host. This composite material enables fast, low-voltage electric switching of electromagnetic radiation in visible and infrared ranges, which can be customized depending on the needs of applications, like climate-

Inc.); the cell gap thickness was confirmed by using an optical interference method. We used an Olympus BX-51 polarizing optical microscope (POM) equipped with 10 × , 20 × , and 50 × objectives with numerical aperture 0.3 0.9 along with a CCD camera (GS3-U3-28S5C, from Point Grey Research). The light source was a tungsten-halogen lamp. Extinction and transmittance spectra were recorded using a microscope-mounted spectrometer USB2000-FLG (Ocean Optics) with a broadband (400-1200 nm) polarizer inserted into the optical path after the sample. Electric switching properties, including the threshold voltage and response time, were measured utilizing a photodiode and data acquisition card SCC-68 (National Instruments Co.) controlled by a homemade software [6] written in LabVIEW and a Si amplified photodetector PDA100A (Thorlabs Inc.). The response times, including both the rise time upon applying the voltage and the decay time after removing the voltage, were measured as in our previous studies and are described elsewhere [6–10]. Wavelength-selective studies of switching of dye and GNR orientations utilized optical interference filters such as 700 nm long pass filter (Semrock Inc.) and an infrared filter (Olympus). TEM images were obtained using a FEI Tecnai T12 Spirit.

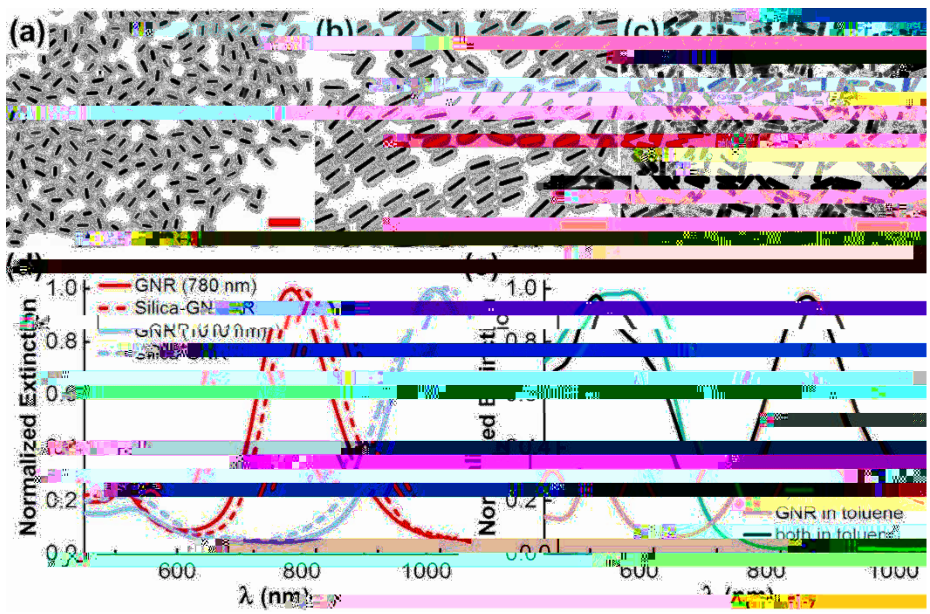

Fig. 1. TEM imaging of GNRs and extinction spectra of dye molecules and nanoparticles in isotropic solvents. (a-c) TEM images of GNRs with different longitudinal SPR peaks: (a) 780 nm, (b) 1010 nm and (c) 815 nm. GNRs shown in (a) and (b) are coated with a silica shell of average thickness of 21 nm and 25 nm, respectively. Scale bars are 200 nm. (d) Normalized by the maximum intensity extinction spectra of GNRs in water before (red and blue solid lines) and after silica capping (dashed corresponding lines). (e) Normalized by the maximum intensity extinction spectra of dye molecules and PEG-capped GNRs in toluene taken

dyes follow the LC molecules and **N** because of the induced dipole-dipole (anisotropic van der Waals) interactions [1], similar to that between LC molecules themselves [5,14]. Although the mechanisms of alignment of nanometer-sized rod-like dichroic dye molecules and much larger (20 to 100 nm) nanorods are rather different, the orientational self-ordering of both leads to anisotropic, polarization-dependent optical characteristics (Fig. 2(c),(d)). Orientational self-ordering of different types of GNRs and dye molecules can be quantified by determining the scalar order parameter commonly defined as $S = \langle 3\cos^2\theta - 1\rangle/2$, where the angled brackets denote sample average values and θ is the angle between the long axis of rod rubbing direction $\mathbf{N}_r$. (f) Normalized spectra of cholesteric LC with $\Delta\varepsilon<0$ (1:10 mixture of 5CB and AMLC-0010) co-doped with the dichroic dye and PEG-functionalized GNRs in a planar cell shown in (e); the spectra are obtained for $\mathbf{P}||\mathbf{N}_r$ and $\mathbf{P}$ $\mathbf{N}_r$.

Dye molecules and GNRs align with respect to the local director also in samples with spatially varying **N**, such as the uniformly   -twisted configuration shown in (Fig. 2(e)). In this sample, the dichroic dye molecules and PEG-functionalized GNRs fol .<u3 Tc u>Tc 0.001.5(N)   0 Tc 0 >w 0.330.al .<.5

dependences (Fig. 4(b)

4. Discussion and conclusions