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Photoinduced change of dielectric permittivity in molecular doped polymer layer

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We demonstrate a large photoinduced change of dielectric permittivity due to the charge separated (CS) state of an electron donor-acceptor linked molecule, 6-[4’-(N,N-diphenylamino)phenyl]-3-ethoxycarbonylcoumarin (DPA–CM), doped in a polymethylmethacrylate (PMMA) matrix. Dielectric permittivity of DPA–CM in PMMA film increases from 4.1 to 7.5 under photoirradiation. Electron spin resonance spectra of the films measured under photoirradiation clearly show the formation of the CS state of DPA–CM in PMMA matrix. The origin of the photoinduced change of the dielectric permittivity is ascribed to the realignment of dipole of the CS state of DPA–CM. © 2009 American Institute of Physics. [doi:10.1063/1.3275800]

Organic field-effect transistors (OFETs) using organic semiconductors have attracted much research interests due to their unique advantages, including a variety of molecular designs, light weight, low-cost fabrication, and mechanical flexibility. In particular, research interest in the gate dielectrics is recently increasing since the choice of the gate dielectrics directly affects the electric properties of the OFETs.1 For example, high-k gate dielectrics or very thin gate dielectrics can reduce the operation voltage of the OFETs.2,3 The threshold voltage (Vth) of the OFETs can be tuned by using polar self-assembled monolayers inserted at the surface of the gate dielectrics,4,5 and also by using ferroelectric gate dielectrics, where the origin of the shift is due to remnant polarization of the gate dielectrics.6,7 Controlling Vth was also realized by using the polarized gate dielectrics with charged electrets.8 We have reported that the polarization of gate dielectrics can be achieved by the alignment of poly segments (carbonyl groups) of polyurea chains9 and a space charge polarization in ion-dispersed gate dielectrics.10 The polarization of the gate dielectrics induced charged carriers in an organic semiconductor at the semiconductor/dielectric interface and Vth shifted toward a lower voltage. These reports indicate that device characteristics of OFETs are significantly affected by the surface or bulk polarization of gate dielectrics. When the gate dielectrics in OFETs reveal a photoinduced polarization due to photoinduced changes of dielectric permittivity and/or a space charge polarization, one can realize organic photoswitches, phototransistors, and photomemories which are key components in optoelectronic circuits.

Photoinduced change of dielectric permittivity was reported in a liquid crystal doped with photosensitive compound.11 A large change of dielectric permittivity up to 60% was achieved by the photoinduced change of the alignment of a liquid crystal. However, it may be difficult to incorporate a liquid crystal layer as a gate dielectric in OFET, since the liquid crystals require a rubbing treatment on the electrodes in order to obtain homogeneous alignment. Photoinduced change of dielectric permittivity has been realized by the photoinduced isomerization and reorientation of azo dye molecules in a polymer matrix.12 Although no rubbing treatment is necessary in the case of azo dye doped in a polymer matrix, the photoinduced change of the dielectric permittivity was limited to 15%.

Recently, we have reported that an electron donor-acceptor linked compound, 6-[4’-(N,N-diphenylamino)phenyl]-3-ethoxycarbonylcoumarin (DPA–CM), forms a long-lived charge-separated (CS) state (DPA**−–CM**) up to milliseconds by intramolecular photoinduced electron transfer from the DPA moiety to the photosexcited state of CM moiety (Fig. 1).13 Since the CS state exhibits the large dipole moment, the dielectric permittivity may change by the alignment of the CS state molecules under external electric field. Thus, DPA–CM can be a promising material for photosensitive gate dielectric material. Up to now, there has been no report on the change of dielectric characteristics utilizing a long-lived CS state under photoradiation. Here, we demonstrate that DPA–CM in polymer matrix film exhibits a large photoinduced dielectric permittivity originated from the CS state of DPA–CM.

![Diagram](http://example.com/diagram.png)

**FIG. 1.** (Color online) Capacitor structure using DPA–CM in PMMA film and chemical structures of DPA–CM at ground state and CS state after photoirradiation.
After fabricating the first layer of Cytop™ on glass substrates coated with a 150 nm thick ITO layer, prepared all the polymer layers by a spin-coating technique. DPA–CM in polymethylmethacrylate of glass substrate/indium-tin-oxide the gate dielectrics were measured using a capacitor structure/electrode

The second Cytop™ layer solvent of the DPA–CM:PMMA solution was acetonitrile. The repeating unit of PMMA to DPA–CM was 2:1 and the molar ratio of the constitutional repeating unit of PMMA to DPA–CM was 2:1 and the constitutional repeating unit of PMMA to DPA–CM was 2:1. Capacitance was measured with an Agilent 4284A LCR meter and an Omron ZUV UV irradiator. The ESR measurements were performed on a JEOL X-band ESR spectrometer (JES-ME-LX) at 298 K. A film of DPA–CM in PMMA spin-coated on quartz substrate was irradiated in the cavity of the ESR spectrometer with the focused light from a 1000-W high-pressure Hg lamp (Ushio-USH100SD) through an aqueous filter.

The photoirradiation of DPA–CM/PMMA film results in the formation of the CS state of DPA–CM (Fig. 1), which is clearly detected by ESR as shown in Fig. 4(a). In sharp contrast, no ESR signal was observed without the photoirradiation. Based on the ESR signal observation, we confirmed the formation of CS state of DPA–CM (DPA+−−CM−) in PMMA matrix at 298 K. When photoirradiation was performed at 77 K, a typical triplet ESR signal with zero-field splitting due to intramolecular triplet radical ion pair was observed at g = 2.0044 and 4.02 as shown in Fig. 4(b). Reversible change of ESR signal was observed for the DPA–CM in PMMA film on periodic photoirradiation at 298 K [Fig. 4(c)]. Thus, the plausible mechanism of the change of dielectric permittivity under photoirradiation is realignment of the large dipole of CS state of DPA–CM molecule.

In summary, we have investigated the influence of doping of DPA–CM on the dielectric property of PMMA matrices. The dielectric permittivity measurements show that the DPA–CM molecule significantly enhances the dielectric permittivity of DPA–CM in PMMA film upon photoirradiation. The CS state of DPA–CM is responsible for the change in the dielectric permittivity, we measured electron spin resonance (ESR) spectra of DPA–CM in PMMA films under photoirradiation. We fabricated a thin film of DPA–CM in PMMA where the molar ratio of the constitutional repeating unit of PMMA to DPA–CM was 2:1. The dielectric permittivity measurements show that the formation of the CS state of DPA–CM differs from PMMA matrix upon photoirradiation. The dielectric permittivity of DPA–CM in PMMA upon photoirradiation. The dielectric permittivity under photoirradiation is realignment of the large dipole of CS state of DPA–CM molecule.

In summary, we have investigated the influence of doping of DPA–CM on the dielectric property of PMMA matrices. The dielectric permittivity measurements show that the DPA–CM molecule significantly enhances the dielectric permittivity of DPA–CM in PMMA film upon photoirradiation. The CS state of DPA–CM is responsible for the photoinduced change of the dielectric permittivity. Unique photosensitive characteristics of DPA–CM make it a promising candidate for the applications to the optoelectronic devices.
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FIG. 4. ESR spectra of DPA–CM (2.5 × 10^{-11} mol g^{-1}) in PMMA (5.0 wt%) film observed (a) under dark conditions (broken line) and with photoirradiation (solid line) at 298 K and (b) after cutting off the photoirradiation at 77 K. Asterisks denote the signals due to zero-field splitting. (c) Time profile of ESR signal intensity at 3218 G observed at 298 K.