Luminescent lanthanide-containing chiral liquid crystalline polymers in the side chain

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(Received 13 June 2014; accepted 28 July 2014)

Luminescent lanthanide-containing chiral liquid crystalline polymers are graft-copolymerised using poly(methyl-hydrogen)siloxane (PMHS), crosslinking agent, liquid crystalline monomer and lanthanide complexes. The chemical structures of the monomers are characterised by FTIR, $^1$H NMR and elemental analyses. The mesomorphic properties and phase behaviour are investigated by differential scanning calorimetry, thermogravimetric analysis, polarising optical microscopy and X-ray diffraction. The polymers containing less than 9 mol% of the crosslinking units reveal reversible mesomorphic phase transition, wide mesophase temperature ranges and high thermal stability. With the introduction of lanthanide complex units, the polymers are enabled with the significant luminescent properties. The temperature dependence of fluorescence intensity was studied in the liquid crystalline phase. The IR imaging shows that the lanthanide complex units evenly distribute in polymers.

Keywords: graft copolymers; crosslinking; fluorescence; liquid-crystalline polymers; luminescence

1. Introduction

In recent years, luminescent lanthanide-containing materials have gained more and more attention as emitting centres due to their especially efficient strong narrow-width emission band in the visible region.[1,2] The lanthanide complexes with organic ligands hold large potential applications in many aspects such as fluorescent probes,[3] light-emitting diodes [4] and medical magnetic resonance imaging.[5] However, the unworkability, low thermal stability and low mechanical resistance are major drawbacks that hamper the practical applications of these materials.[6,7] Some methods have been put forward to overcome these problems such as by incorporating lanthanide complexes into inert host matrices such as polymers,[8–12] sol–gel glasses,[13–15] liquid crystal (LC) materials [16–21] or organic–inorganic hybrid materials.[22] Among these matrices, LC materials have great advantages.

Recently, LC materials with anisotropic properties have expanded rapidly [23–29] and LC materials with luminescent property are of considerable interest over recent years due to processing performance, thermal stability and their potential applications in the fields of photoconductor,[30] anisotropic light emitters,[31,32] LC display technology [33] and so forth. On the one hand, LC structure can tune the luminescence and polarisation due to the ordered arrays of luminescent groups; while on the other hand, the self-luminescence of LC materials can enrich the performance of LC display remarkably. Chiral liquid crystalline polymers (CLCP) are a kind of LC materials possessing unique properties and potential applications in nonlinear optical materials, fast optical switch, electro-optical materials and piezoelectricity.[34–38] However, luminescent lanthanide-containing CLCP have been little described so far, as regarding the compared studies on polymers with different lanthanide complexes which have been even more little described. So it is necessary and significant to synthesise various kinds of lanthanide-containing CLCP, to explore their properties and to be applied in effect. In this article, europium-containing CLCP and samarium-containing CLCP were synthesised by graft copolymerisation. The LC properties were characterised with differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), polarising optical microscopy (POM) and X-ray diffraction (XRD); the luminescent properties were measured by fluorescence spectrophotometer. The temperature dependence of fluorescence intensity was studied in the LC phase.

2. Experimental

2.1 Instrumentation

Fourier transform infrared (FTIR) spectra were measured on a Niccol 510 FTIR spectrometer (Nicollet Instrument, Madison, WI, USA); $^1$H NMR were measured by Varian WH-90PFT NMR Spectrometer (Varian Associates, Palo Alto, CA, USA); element analyses (EAs) were measured by Elemental Vario ELIII (Elementar, Donaustraße, Germany); DSC and TGA measurements were carried out with a NETZSCH TGA 209 C thermo gravimetric analyser and a NETZSCH instruments DSC 204 (Netzsch, Wittelsbacherstraße, Germany) at a scanning rate of 10°C min$^{-1}$ under a flow of dry nitrogen; POM study was performed using a Leica DMRX (Leica, Wetzlar, Germany) equipped

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with a Linkam THMSE-600 (Linkam, Surrey, England) heating stage; X-ray diffraction measurements were taken with a nickel-filtered Cu-Kα radiation with a DMAX-3A Rigaku powder diffractometer (Rigaku, Tokyo, Japan); luminescence measurements were taken on a HORIBA Jobin Yvon FL3-TCSPC fluorescence spectrophotometer (Horiba, Kyoto, Japan); scanning electron microscope (SEM) microphotographs were measured with a FEI QUANTA 600 (Hillsboro, OR, USA) instrument. Infrared (IR) imaging was performed using a Spotlight 300 infrared imaging system (PerkinElmer, Waltham, MA, USA).

2.2 Materials
Poly(methylhydrogenosiloxane (PMHS, Mn = 582) was purchased from Jilin Chemical Industry Company (Changchun, China); 2-thenoyltrifluoroacetone (TTA), 4ʹ-hydroxybiphenyl-4-carboxylic acid, 3,5-difluorophenol, 4-hydroxybenzoic acid, undecylenic acid, acrylic acid (AA), 2-propanol, N,N-dicyclohexyl carbodiimide (DCC), isopropanol and 4-(N,N-dimethylamino)pyridine (DMAP) were purchased from Shenyang Chemical Co. (Shenyang, China); isosorbide was purchased from Henan Xiayi Medical Co. (Zhengzhou, China); Eu₂O₃ and Sm₂O₃ were purchased from Beijing Fuxing Chemical Industry Co. (Beijing, China); toluene was used in the hydrosilylation reaction over sodium and distilled under nitrogen. All other solvents were purified by standard methods.

2.3 Monomers synthesis
The synthetic route to the olefinic monomers is shown in Figure 1.

**Isosorbide di-(10-undecyl-1-oxobenzoate) (M₁)**

M₁ was prepared according to previously reported synthetic method. Synthetic procedures have been provided as supplemental data. Yield: 77%. IR (KBr): 3077(=CH), 2977–2852(–CH₃, –CH₂–), 1783, 1758, 1717(C=O), 1641 (C=C), 1602, 1503(Ar–). Anal. Caled for C₄₂H₅₄O₁₀: C 70.17, H 7.57, O 22.26; Found: C 70.09, H 7.47, O 22.01. ¹H NMR

![Synthesis routes of the olefinic monomers.](Image)
(600 MHz, CDCl3, δ): 8.18–7.15 (m, 8 H, Ar–H), 5.86–5.78 (m, 2 H, CH2=CH–), 5.06–4.92 (t, 4 H, CH2=CH–), 4.67–4.04 (m, 8 H, isosorbide), 2.61–2.55 (m, 4 H, –CH2COO–), 2.07–2.02 (m, 4 H, CH2=CHCH2(CH2)2CH2COO–), 1.77–1.33 (m, 24 H, CH2=CHCH2(CH2)2CH2COO–). FT-IR and 1H NMR spectrograms have been provided as supplemental data.

4'-Hydroxybiphenyl-4-carboxylic acid (1)

4'-Hydroxybiphenyl-4-carboxylic acid (10.70 g, 0.05 mol) was dissolved in 120 mL of THF and 12 mL of pyridine to form a solution. Undecylenylacyl chloride (10.13 g, 0.05 mol) was added to the solution and reacted at 70°C for 12 h, cooled and poured into 1000 mL of cold water. The precipitated crude product was filtered and recrystallised in alcohol and acetic acid, isolated by filtration and dried overnight at 65°C under vacuum to obtain white crystals. Yield: 75%. IR (KBr): 3074 (=CH), 2926–2851 (–CH3, –CH2–), 2655–2557 (–COOH), 1745, 1685 (C=O), 1643 (C=C), 1603, 1496 (Ar–). Anal. Calcd for C55H36O4: C 73.15, H 6.14, O 13.92, Sm 16.55. FT-IR spectrogram has been provided as supplemental data. Yield: 67%. IR (KBr): 3099 (=CH), 1608 (C=O), 1540 (–COO–), 1356 (C–F). Anal. Calcd for C37H18F3O8S3Eu: C 36.45, H 2.02, O 14.40 Eu 17.10; Found: C 36.01, H 1.87, O 13.90 Eu 16.85. FT-IR spectrogram has been provided as supplemental data.

3, 5-Difluorophenyl 4'-(undec-10-enoyloxy) biphenyl-4-carboxylate (M2)

Compound 1 (7.6 g, 0.02 mol), DCC (4.12 g, 0.02 mol) and DMAP (0.21 g, 1.69 mmol) were dissolved in 150 mL of THF at 30°C. 3, 5-Difluorophenol (2.6 g, 0.02 mol) was dissolved in 50 mL of THF at 30°C and then added to the solution. The reaction mixture was stirred for 2 days at 30°C. The resulting solution was filtered and poured into 1000 mL of cold water. The precipitated crude product was filtered and recrystallised in alcohol, isolated by filtration and dried overnight at 65°C under vacuum to obtain white crystals in the yield of 70%. Mp: above 300°C. Yield: 68%. IR (KBr): 3079 (=CH), 2928, 2854 (–CH3, –CH2–), 1752, 1733 (C=O), 1641 (C=C), 1610, 1491 (Ar–). Anal. Calcd for C39H38F4O4: C 75.76, H 6.42, O 13.90, Sm 16.45; Found: C 75.69, H 7.47, O 13.92, Eu 16.72.

3 5-Difluorophenyl 4’-(undec-10-enoyloxy) biphenyl-4-carboxylate (M2)

The synthesis and purification were similar to the above procedures for Eu(TTA)3AA. Synthetic procedures have been provided as supplemental data. Yield: 63%. IR (KBr): 3093 (=CH), 1603 (C=O), 1541 (–COO–), 1355 (C–F). Anal. Calcd for C37H18F3O8S3Sm: C 36.53, H 2.03, O 14.43, Sm 16.91; Found: C 35.97, H 1.83, O 13.92, Sm 16.55. FT-IR spectrogram has been provided as supplemental data.

2.4 Synthesis of the liquid crystalline polymers

For synthesis of all the polymers, a standard method was adopted, as shown in Figure 2. The polymerisation experiments are summarised in Table 1. The synthesis

![Figure 2](https://example.com/figure2.png)
of Eu-P₁ was presented as an example. Monomers M₁ (0.038 g, 0.0525 mmol) and M₂ (0.809 g, 1.6450 mmol) were dissolved in 60 mL of dry, freshly distilled toluene. To the stirred solution, monomer Eu-M₃ (0.015 g, 0.0175 mmol), PMHS (0.145 g, 0.25 mmol) and 1.5 mL of H₂PtCl₆ in 20 mL THF were added; the mixture was heated under nitrogen and anhydrous conditions at 90°C for 48 h. Then, the solution was cooled and poured into 200 mL methanol; after filtration, the product was washed with hot ethanol (3 times) and dried at 60°C under vacuum for 12 h to obtain polymer Eu-P₁. Yield: 73%. IR (KBr, cm⁻¹): 2926–2855 (–CH₃, –CH₂–), 1743–1728 (C=O), 1603, 1511 (Ar), 1127–1007 (Si–O–Si). FT-IR spectrogram has been provided as supplemental data.

3. Results and discussion

3.1 Syntheses

The synthetic routes for the target monomers and polymers are shown in Figures 1 and 2; the chemical structures of monomers and polymers were characterised by FTIR and ¹H NMR spectroscopy. The FTIR spectra of M₁ and M₂, respectively, showed characteristic bands for ester C=O stretching (1785–1715 cm⁻¹), olefinic C=C stretching (1635–1645 cm⁻¹) and aromatic C=C stretching (1600–1490 cm⁻¹) in good agreement with the prediction. The FTIR spectra of Eu-M₃ and Sm-M₃ showed characteristic bands for β-diketone C=O stretching (1600–1610 cm⁻¹), the carboxylate stretching (1540–1541 cm⁻¹) and C–F stretching (1355 cm⁻¹) in good agreement with the prediction. The ¹H NMR spectra of M₁ and M₂, respectively, showed peaks at 8.24–6.74, 5.88–4.92 and 2.61–1.33 ppm corresponding to aromatic, olefinic protons, and methyl and methylene protons, respectively.

The polymers were synthesised by a one-step hydroisilylation reaction between Si–H groups of PMHS and olefinic C=C of monomers in toluene, using hexachloroplatinic acid as catalyst at 90°C. The reaction was monitored following the disappearance of the Si–H band at 2166 cm⁻¹ in the FTIR spectra. The complete disappearance of the Si–H band indicated successful incorporation of monomers into the polysiloxane chains. Yields and detailed polymerisation are summarised in Table 1. All the polymers were characterised by FTIR spectroscopy. Polymer Eu-P₁ contained the representative features for all of the polymers. The characteristic absorption bands were as follows: 2926–2855 cm⁻¹ (C–H stretching), 1743–1728 cm⁻¹ (C=O stretching), 1603, 1511 cm⁻¹ (C=C stretching of aromatic nucleus) and 1127–1007 (Si=O–Si).

3.2 Thermal properties

The thermal properties of monomers and polymers were determined by DSC, POM and TGA (Tables 2 and 3). Thermal properties determined by DSC were consistent with PO-M observation results. Typical DSC curves of monomers and polymers

| Table 1. Polymerisation and yield. |
|-----------------------------------|
| Polymer | Feed | PMHS (mmol) | M₁ (mmol) | M₂ (mmol) | Ln-M₁ (mmol) | M₁ (Mol %) | Ln³⁺ (Mol %) | Yield (%) |
| Sm-P₁   | 0.25 | 0.0525      | 1.6450    | 0.0175    | 3            | 1           | 75         |
| Sm-P₂   | 0.25 | 0.1050      | 1.5400    | 0.0175    | 6            | 1           | 77         |
| Sm-P₃   | 0.25 | 0.1575      | 1.4350    | 0.0175    | 9            | 1           | 81         |
| Eu-P₁   | 0.25 | 0.0525      | 1.6450    | 0.0175    | 3            | 1           | 73         |
| Eu-P₂   | 0.25 | 0.1050      | 1.5400    | 0.0175    | 6            | 1           | 69         |
| Eu-P₃   | 0.25 | 0.1575      | 1.4350    | 0.0175    | 9            | 1           | 73         |

| Table 2. Thermal properties of monomers. |
|-----------------------------------------|
| Monomer | Phase transition temperature (°C) | Yield (%) | ΔT¹ | ΔT² |
|          | (corresponding enthalpy changes/J g⁻¹) |           | (°C) | (°C) |
| M₁       | Heating: K 74.6 (48.75) I         | 71        | –   | –   |
|          | Cooling: I 70.1 (14.69) K        |           |     |     |
| M₂       | Heating: K 75.4 (72.01) N 137.1 (9.55) I | 73    | 61.3 | 70.5 |
|          | Cooling: I 135.1 (11.08) N 64.6 (36.47) K₄ | | |

Notes: K = solid, N = nematic, I = isotropic.

*Peak temperatures obtained by DSC were taken as the phase transition temperature.

*Mesophase temperature ranges on heating cycle.

*Mesophase temperature ranges on cooling cycle.
are shown in Figures 3 and 4, respectively. DSC curves of M₁ only showed a melting transition at 74.6°C and a crystallisation transition at 70.1°C on heating and cooling cycles. DSC heating thermograms of M₂ showed a melting transition at 75.4°C and a nematic to isotropic phase transition at 137.1°C; the cooling thermogram of M₂ showed an isotropic to nematic phase transition at 135.1°C and crystallisation temperature at 64.6°C and 59.3°C.

All the polymers synthesised showed a glass transition at low temperatures and an LC phase to isotropic transition at high temperature. For all the polymers, reversible mesomorphic phase transitions were observed due to sufficient liquid crystalline molecular motion and orientation, suggesting that complex units did not disturb the liquid crystalline order of the polymer system. As seen from the data of Table 3, the general tendency of polymers was basically accordant. The glass transition temperature ($T_g$) values of polymers Sm-P₁–Sm-P₃ and Eu-P₁–Eu-P₃ decreased with the increase of the content of crosslinking agent. The crosslinking agent has two opposite actions: crosslinking and plasticisation. Crosslinking imposes additional constraints on the segment motion of polymer chains and might be expected to raise the glass transition temperature. Plasticisation inclines to reduce the glass transition temperature. When the content of crosslinking agent is less than certain critical, the plasticisation effect is predominant; otherwise the crosslinking effect is a main factor. It can be seen from Table 3 that the $T_g$ values of Sm-P₁–Sm-P₃ and Eu-P₁–Eu-P₃ were decreased from 57.1°C to 46.7°C and 50.9°C to 44.1°C, respectively, which is the influence of plasticisation.

Similar to $T_g$, crosslinking may influence the clearing point ($T_i$). Crosslinking units act as a non-mesogenic diluent and lead to a downward shift in the clearing point as increasing contents were added to an LC polymer. For a crosslinked sample, chemical crosslinking could prevent the motion and orientation of the mesogenic molecule and was not in favour of the mesogenic orientation in the polymers with increasing the content of crosslinking agent. It can be seen that the $T_i$ value was reduced with the increasing content of crosslinking agent. When the concentration of crosslinking units increased from 3% to 9%, the $T_i$ values of Sm-P₁–Sm-P₃ and Eu-P₁–Eu-P₃ were decreased from 208.8°C to 171.9°C and 200.5°C to 172.7°C, respectively. At the same time, it can be seen from Table 3 that Sm-P₁–Sm-P₃ and Eu-P₁–Eu-P₃ displayed wide mesophase temperature ranges ($\Delta T$). $\Delta T$ values of Sm-P₁–Sm-P₃ and Eu-P₁–Eu-P₃ decreased with increasing the content of crosslinking agent.
The TGA curves of polymers are illustrated in Figures 5 and 6. For noncoordinated polymers, the decomposition temperature was in the order of Sm-P\(_3\) > Sm-P\(_2\) > Sm-P\(_1\) and Eu-P\(_3\) > Eu-P\(_2\) > Eu-P\(_1\), indicating that there was an increase with the introduction of crosslinking agent. Temperature for 5 wt% loss has often been used as a degradation temperature (\(T_d\)) to estimate thermal stability of a synthetic polymer. The 5% weight loss of all the polymers took place at the temperatures above 270°C, showing good thermal stability.

3.3 Optical texture

Optical textures of the samples were studied by POM with hot stage. POM results showed that M\(_2\) displayed typical nematic threaded texture and droplet texture on heating and cooling cycles. The droplet texture of M\(_2\) is shown in Figure 7(a). All of the polymers showed similar cholesteric phase textures in the heating and cooling cycles. When Eu-P\(_1\) here used as example was heated to 55°C, the cholesteric Grandjean texture gradually

Figure 5. TGA curves of Sm-P\(_1\)–Sm-P\(_3\).

Figure 6. TGA curves of Eu-P\(_1\)–Eu-P\(_3\).

Figure 7. (colour online) Optical texture of M\(_2\) and polymers (200×): (a) droplet texture of M\(_2\) on cooling to 170.3°C; (b) Grandjean texture of Sm-P\(_1\) at heating to 120.1°C; (c) Grandjean texture of Eu-P\(_1\) at heating to 145°C; (d) Grandjean texture of Eu-P\(_2\) at cooling to 176°C.
appeared; the texture disappeared at 210°C. Similarly when the isotropic state was cooled to 203°C, the similar Grandjean texture gradually appeared. Photomicrographs of Sm-P$_1$, Eu-P$_1$ and Eu-P$_2$ are shown in Figure 7 (b)–(d).

The cholesteric mesophase of polymers was also confirmed by XRD. XRD studies were carried out to obtain more detailed information on LC phase structure. All the polymers displayed broad peaks at wide angles around $2\theta = 18$–$20^\circ$ in the wide-angle region of XRD measurement, and a sharp peak associated with the smectic layers did not appear in the small-angle region of XRD measurement. Therefore, cholesteric phase structure of polymers was confirmed by XRD, which was consistent with DSC and POM results. Figure 8 shows the XRD diagrams of polymers at 125°C.

3.4 Luminescent properties

By quick freezing the obtained polymers in the LC phases in liquid nitrogen, vitrified mesophase solids were obtained and the luminescent properties of the LC states were examined. The excitation and luminescence spectra of Eu-P$_1$ are shown in Figure 9. The excitation spectrum of Eu-P$_1$ was monitored at 612 nm. The observed transitions were due to light absorption by the β-diketonate and the acrylic acid ligands. The luminescence spectra were measured with 380 nm as the excitation wavelength. In the emission spectra, the red $^5\text{D}_0\rightarrow^7\text{F}_j (J = 0, 1, 2, 3)$ transitions were clearly observed. The band near 579 nm was assigned to the $^5\text{D}_0\rightarrow^7\text{F}_0$ transition; the band near 592 nm was assigned to the $^5\text{D}_0\rightarrow^7\text{F}_1$ transitions; the band near 612 nm was assigned to the $^5\text{D}_0\rightarrow^7\text{F}_2$ transitions; and the band near 653 nm was assigned to the $^5\text{D}_0\rightarrow^7\text{F}_3$ transition. The maxima of these bands were all the Eu$^{3+}$ ions were strictly prohibited in a symmetric field, so the existence of this band indicates that Eu$^{3+}$ in polymers was in low symmetry and did not have an inversion centre. The $^5\text{D}_0\rightarrow^7\text{F}_1$ transition was a magnetic dipolar transition; its intensity hardly changes with the local structure environment. On the other hand, the $^5\text{D}_0\rightarrow^7\text{F}_2$ transition was an electric dipole transition and was sensitive to the coordination environment of the Eu$^{3+}$. The europium (III) ion can be replaced in this system by samarium (III) ions that show luminescence in the visible regions. In Figure 10, the excitation and luminescence spectra of Sm-P$_1$ are shown. The excitation spectrum of the europium (III)-containing resin was monitored at 647 nm. The observed transitions were due to light absorption by the β-diketonate and the acrylic acid ligands. The luminescence spectra were measured with 397 nm as the excitation wavelength. The narrow peaks observed in the emission spectra were transitions between the excited $^4\text{G}_{5/2}$ level and the different $J$-levels of the $^6\text{H}$ term. The band near 564 nm was assigned to the $^4\text{G}_{5/2}\rightarrow^6\text{H}_{5/2}$ transitions; the band near 600 nm was assigned to the $^4\text{G}_{5/2}\rightarrow^6\text{H}_{7/2}$ transitions; the band near 647 nm was assigned to the $^4\text{G}_{5/2}\rightarrow^6\text{H}_{9/2}$ transitions.

To study the thermal stability of photoluminescence in the LC phase, the temperature dependence of fluorescence intensity was measured. Figure 11 displays the emission spectra of the Eu-P$_1$ at different temperatures. It is obvious that the fluorescence intensity of the Eu-P$_1$ decreased monotonically with the increasing temperature in the studied range. The
intensity as a function of temperature can be well fitted by the well-known thermal activation function [41]:

$$I(T) = I_0/\left[1 + \alpha \exp \left(-E_A/k_B T\right)\right]$$

where $I_0$ is the emission intensity at 0 K, $\alpha$ is the proportional coefficient, $E_A$ is the thermal activation energy, $k_B$ is Boltzmann’s constant and $T$ is the absolute temperature. In the same polymer, the value of $E_A$ is the same. Temperature-dependent emission spectra of Sm-P$_1$ has been provided as supplemental data.

The observed luminescence lifetime was determined from measurement of the luminescence decay curve. For Eu-P$_1$, the luminescence lifetime of the $^5D_0$ level was measured as a function of the temperature upon heating from 51°C (vitrified mesophase) to 201°C (isotropic). The luminescence lifetime decreased from 0.53 to 0.19 ms (Figure 12). This decrease can be attributed to a higher efficient quenching of the excited states in the mesophase due to an increase of the molecular mobility. For Sm-P$_1$, the luminescence lifetime of the $^4G_{5/2}$ level was measured as a function of the temperature upon heating from 58°F (vitrified mesophase) to 210°C (isotropic). The luminescence lifetime decreased from 34 to 29 µs (Figure 13). Notice that the luminescence lifetime of samarium-(III) polymers was much shorter than that of the corresponding europium-(III) polymers.

The surface morphology of the polymers was observed by SEM. Figure 14 displays SEM photographs of sample Eu-P$_1$ and Eu-P$_3$. The fracture surfaces showed a laminar and a considerably ordered
state in Figure 14(a) for Eu-P1. On the other hand, Eu-P3 that contains more crosslinking units displayed a relatively unordered and a trace of tangle as displayed in Figure 14(b). These results demonstrated that the order in these LC polymers was disturbed by the crosslinking agents.

The distribution of complexes in the polymers was observed by IR imaging system. The IR imaging of Eu-P2 and Sm-P2 is shown in Figure 15(a)–(b). The yellow zone represents the europium complex units and corresponds to the carboxylate characteristic peak at 1540 cm\(^{-1}\) in Figure 15(a) for Eu-P2. On the other hand, in Figure 15(b), the yellow zone for Sm-P2 represents the samarium complex units and corresponds to the carboxylate characteristic peak at 1541 cm\(^{-1}\). Experimental results showed that the lanthanide complex units evenly distributed in polymers, rather than gather together to form clusters.

4. Conclusions
In this article, the polymers containing less than 9 mol% of crosslinking units showed reversible mesomorphic phase transition, wide mesophase temperature ranges and high thermal stability. All of the polymers showed similar cholesteric Grandjean texture in the heating and cooling cycles, which were confirmed by X-ray diffraction. With the introduction of lanthanide complex units, the polymers were enabled with the significant luminescent properties. The IR imaging showed that the lanthanide complex units evenly distributed in polymers, rather than gather together to form clusters. The fluorescence intensity and luminescence lifetime of polymers decreased monotonically with the increasing temperature in the LC phase.

Funding
The authors acknowledge financial support from the National Key Technology Support Program of China [contract grant number 2008BAL55B03].

Supplemental data
Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/02678292.2014.950354.

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