Novel Lanthanide Hybrid β-Diketone Polymers as Cu^{2+} Probe, Acid-Base Vapors Detector and MRI/Fluorescent Imaging Agent

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Introduction

Lanthanide β-diketone chelates are well known as probes based on their specific and intrinsic physical properties that can yield multi-modal signals including line-like emission, long-living fluorescence and magnetic resonance.[1)] In this work, we report the synthesis of a series of novel polymers with β-diketone pendants chelating lanthanide ions as Cu^{2+} probe, acid-base vapor detector and MRI/fluorescent agent. Eu^{3+} chelated polymers (Eu^{3+}-PDKMAs) and their strips have been synthesized for Cu^{2+} ion (as low as 2.0×10^{-8} mol L^{-1}) and acid-base vapors detection by naked eye.[2)] The amphiphilic block copolymers (PDKMA-*b*-POEGMAs) self-assemble into micelles and coordinate both Gd^{3+} and Eu^{3+} to realize bimodal imaging of MRI and fluorescence. [3)]

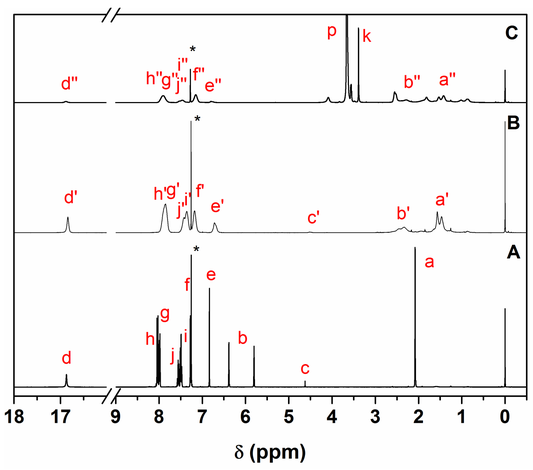
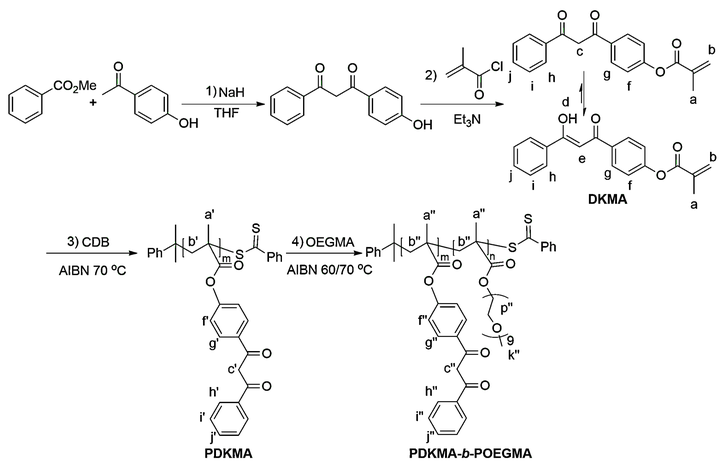


Fig. 1 ^{1}H NMR spectra of DKMA (A), PDKMA (B) and PDKMA-*b*-POEGMA (C) with the assignments in **Scheme 1**, *: residue $CHCl_3$ in solvent $CDCl_3$.



Scheme 1. Synthetic route for homo-polymer PDKMA and diblock copolymer PDKMA-*b*-POEGMA via sequential RAFT protocol

Table 1. RAFT homo- and block co-polymerization of DKMA with OEGMA.

Sample	Polymers	[M]/[CTA]/[I][a)]	Time (h)	Temp. (℃)	Con. (%)	$M_{n,thero}$ (kDa)[b)]	$M_{n,SEC}$ (kDa)[c)]	$Đ$[b)]
PD1	$PDKMA_{152}$[d)]	900/3/1	10.5	70	56	47.1	33.8	1.28
PD2	$PDKMA_{69}$[d)]	300/3/1	10.0	70	69.3	21.5	16.3	1.30
PD3	$PDKMA_{50}$[d)]	300/3/1	7.5	70	49.5	15.7	12.8	1.30
PDO1	$PDKMA_{152}$-b-$POEGMA_{310}$[e)]	900/3/1	3.7	70	77.4	202.1	79.8	1.33
PDO2	$PDKMA_{69}$-b-$POEGMA_{43}$[e)]	375/3/1	11.2	60	29	43.0	20.8	1.33
PDO3	$PDKMA_{50}$-b-$POEGMA_{50}$[e)]	300/3/1	6.0	60	30	40.7	18.2	1.36

a) Molar ratio of monomer (M), CTA (CDB or PDKMAs) and AIBN (I) in feed. b) Trioxymethylene was taken as an initial sample to monitor the conversion by ^{1}H-NMR spectroscopy, and DP was measured by comparing the experimental conversion with desired conversion. c) $M_{n,\,calc} = M_{monomer} \times ([M]/[CTA]) \times Conversion + M_{CTA}$. d) Determined from SEC in THF calibrated by PS standards. e) M_n was determined by MALLS. f) PDKMA-*b*-POEGMAs composition determined by ^{1}H NMR according to [DKMA]/[OEGMEMA] = I(Ar*H*)/I(OCH_2CH_2O).

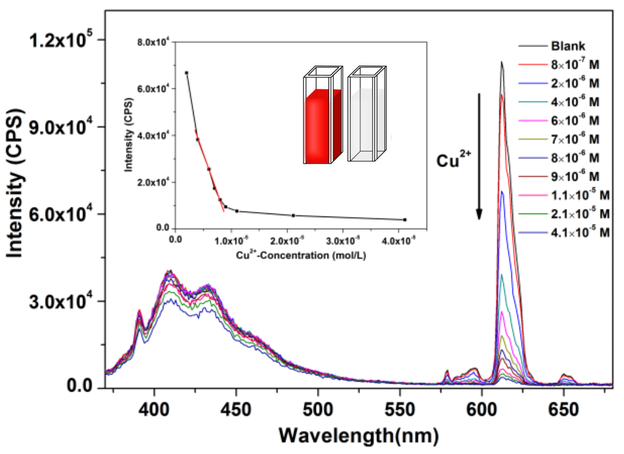


Fig. 2. Luminescence spectra of Eu^{3+}-$PDKMA_{67}$ in THF/water solution with different Cu^{2+} concentrations under excitation at 350 nm at 25 ° C. Inset: the photoluminescence intensity tendency at 612 nm as a function of various Cu^{2+} concentrations.

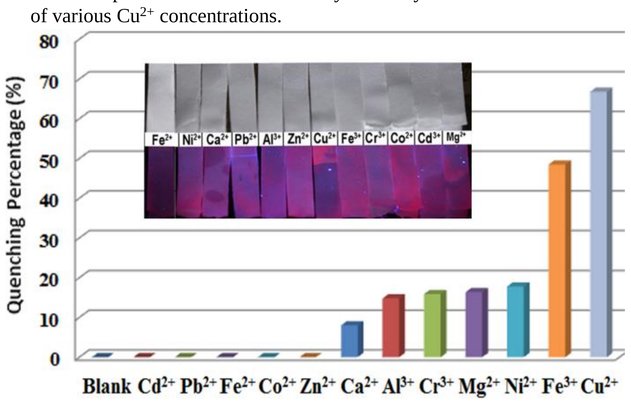


Fig. 3. Photoluminescence quenching intensity of the $^5D_0 \rightarrow {}^7F_2$ transition (612 nm) as a function of various cationic species in aqueous solution. Insets: photographs of PEP-strips with different cations under sunlight (top) and UV light of 365 nm (bottom).

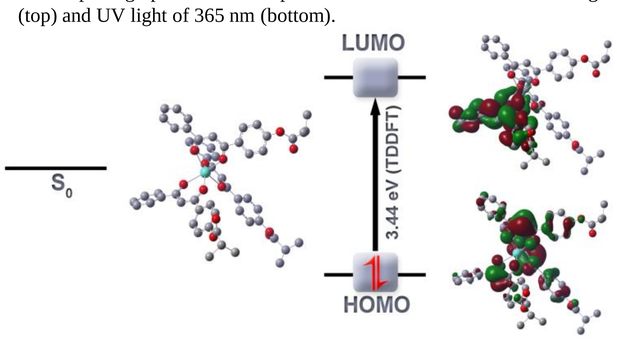


Fig. 4.. Optimized geometries of chelation of Eu^{3+} with three DKMA repeating units and the frontier molecular orbitals.

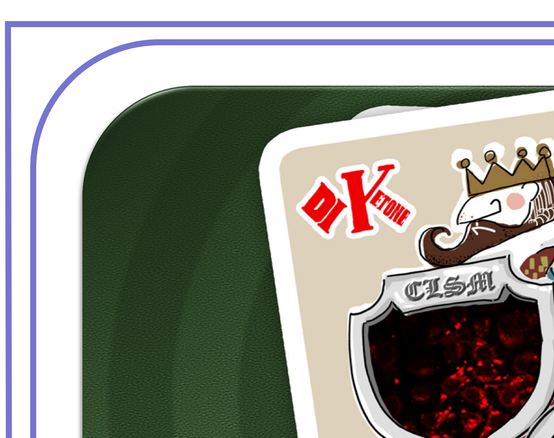


Fig 5. Responses of luminescence intensities at 612 nm of Eu^{3+}-PDKMA film coated quartz substrate (excitation: 350 nm) during several alternate acid and base vapors exposure cycles. Inset: photo of the Eu^{3+}-$PDKMA_{67}$ film upon short exposure with NH_3 (On) and HCl (Off).

Fig. 7. Relative cell viability of NPDO1 for MCF-7 cells after 48 h incubation at a concentration between 0 to 800 μg/mL.

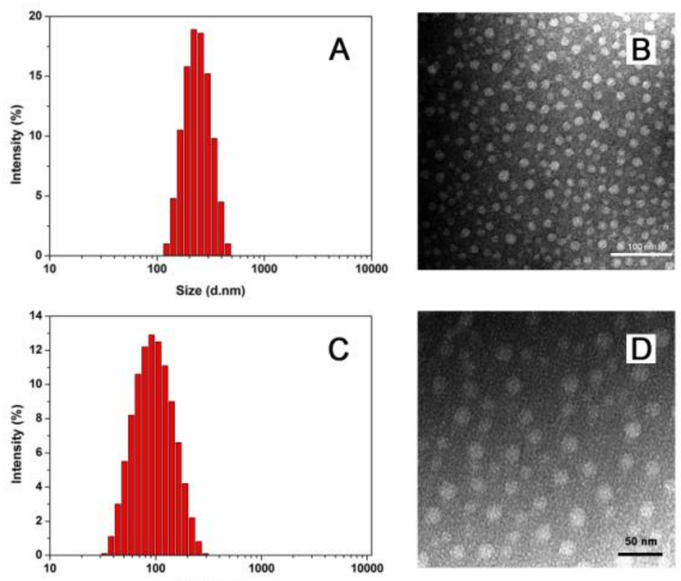


Fig 6. Size distributions histograms (A and C) and TEM images (B and D) of NPDO1 (A and B) and NPDO3 (C and D) nanoparticles in aqueous media at 25 ° C. The scale bars in B and D are 100 and 50 nm, respectively.

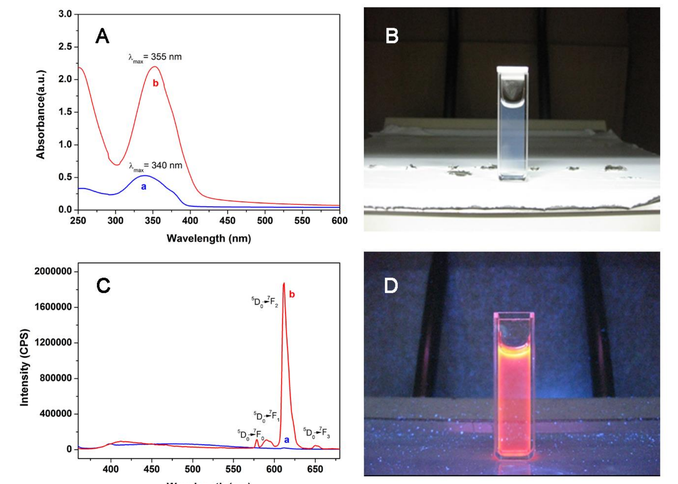


Fig. 8. (A):UV-vis of 0.04 mg/mL PDO1(a) and 0.073 mg/mL PDO1 with Ln^{3+}(b) in aqueous media, (B): Photographs of solution NPDO1 under sunlight, (C): PL spectra of a (PDO1, 0.0004 mg/mL mg/mL) and b (NPDO1, 0.00066 mg/mL) in aqueous media under excitation at 350 nm at 25 °C, (D) Photographs of solution NPDO1 under UV lamp at 365 nm.

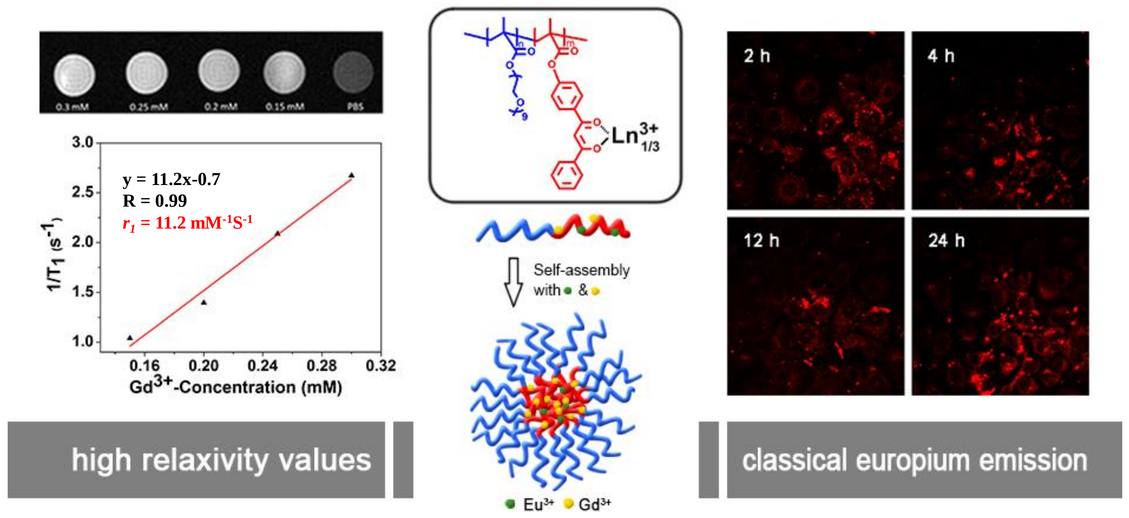


Fig. 9. Plots of longitudinal ($1/T_1$) for aqueous solutions of Gd^{3+}-chelated polymer micelle (NPDO1) at various concentrations, inset: T_1-weighted spin-echo MR images recorded in versus Gd^{3+}-concentrations of NPDO1 and PBS was measured as references. CLSM images of MCF-7 cells incubated with NPDO1 for 2~24 h at 37 °C.

Conclusion

- We have synthesized a novel dual-responsible material (Eu^{3+}-PDKMA) for simple and reliable monitor of Cu^{2+} as well as quickly responsive and reusable detector for acid-base vapors.
- Biocompatible Gd^{3+}/Eu^{3+} hybrid nanoparticles which combine favorable properties for both simultaneous MRI as well as fluorescence imaging in one single sensor have been demonstrated through CLSM and in vitro relaxivity studies. The dual-modal probe has promising potential in biological imaging applications.

Acknowledgement

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Reference:

1) Elke Debroye, Tatjana N. Parac-Vogt. *Chem. Soc. Rev.* **2014**, 8178-8192. 2) Fangyi Cao, Zheng Yuan, Junhua Liu, Jun Ling *RSC Advances* **2015**, 102535-102541.

3）Fangyi Cao, Tongcun Huang, Yifei Wang, Fei Liu, Lumin Chen, Jun Ling, Jihong Sun, *Polymer Chemistry*, **2015**, 7949-7957.