Available online at www.sciencedirect.com
SCIENCE DIRECT®
Tetrahedron Letters 45 (2004) 4519–4523
Tetrahedron Letters

One-pot synthesis of new functionalized azacryptands from resorcinol derivatives for advanced photonic materials ☆

Jae-Won Ka and Hwan Kyu Kim*

Center for Smart Light-Harvesting Materials and Department of Polymer Science & Engineering, Hannam University, Daejeon 306-791, South Korea

Received 24 November 2003; revised 19 March 2004; accepted 9 April 2004

Abstract—Functionalized azacryptands containing resorcinol derivatives such as orcinol (5-methylresorcinol), 3,5-dihydroxybenzoic acid (5-carboxyresorcinol), and methyl 3,5-dihydroxybenzoate (5-methoxycarbonylresorcinol) were synthesized by one-pot synthesis in the presence of potassium carbonate with moderately good yields for advanced photonic materials, such as optical amplifying and light-emitting materials, for the first time to our knowledge.

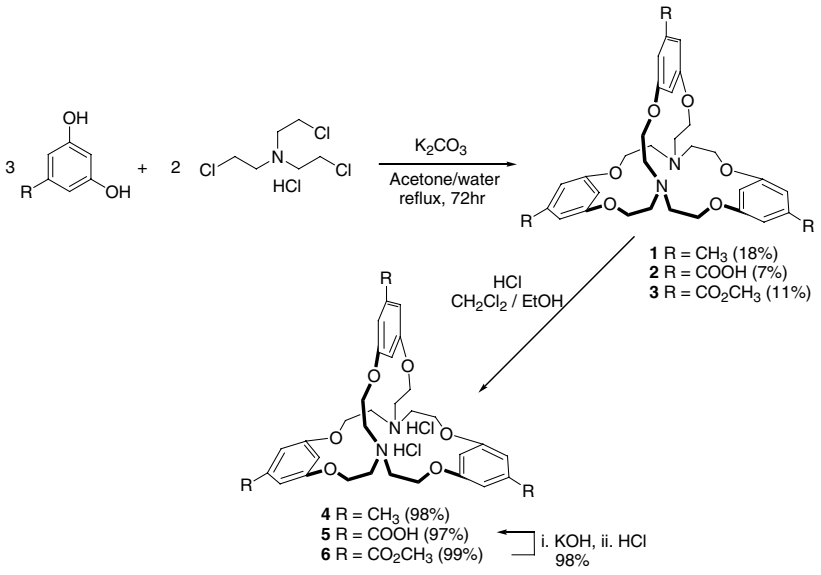
Very recently, the development of integrated planar waveguide optical amplifiers is extremely essential to realize the superhigh speed communication systems.[1] At present, erbium-doped silica amplifiers are widely used in telecommunication systems. But, the poor solubility of lanthanide cations (Ln^{3+}) in conventional inorganic/organic media leads to low amplification property. When the higher doping concentration of lanthanide cations was introduced, clustered Ln^{3+} species can be formed. It reduces the intensity of luminescence, due to the cooperative energy-transfer processes between the clustered Ln^{3+} species. In order to enhance the amplified luminescence intensity, the luminescent lanthanide complexes based on the energy transfer mechanisms have been extensively studied.[1–6] Luminescent lanthanide complexes consist of a lanthanide ion and its chelating luminescent ligand as an antenna chromophore, wherein luminescent ligands efficiently absorb and transfer lights to the central lanthanide ions through the energy transfer. So far, luminescent lanthanide complexes have not been developed in specific reference for advanced photonics materials.[1] They are simply supramolecular complexes containing well-known antenna chromophores to photoexcite the lanthanide ions via the energy transfer process. They were not satisfied with the quantum yield of energy transfer and the luminescence efficiency yet. Also, such efforts are just in the early stage and not only is the basic concept not established, but also the structure–property relationship is not yet clearly understood.[1]

Therefore, recently, we synthesized new functionalized azacryptands from resorcinol derivatives for luminescent lanthanide complexes (see Scheme 1). Functionalized azacryptands were chosen for ligands, because azacryptands are well known as macrobicyclics spherical and capable of encapsulating lanthanide ions in the cage-like cavities to form stable complex.[7,8] They can also provide the reaction sites for coupling with antenna systems or light-harvesting systems, in which the light is efficiently absorbed and transferred to the central lanthanide ions through the energy transfer process.[1]

A large number of macrobicyclic and macropolycyclic compounds have been synthesized,[9,10] since the synthesis of the first cryptand in 1968 by Lehn and co-workers.[11,12] And, the effect of benzo substituents on the complexation properties of cryptands have also been studied by several research groups.[13,14] Substituted benzene ring can manipulate functional group and fix rigid structure, although the introduction of benzene ring into cryptand usually decreases metal ion binding ability and selectivity. Here, instead of catechol derivatives, we used resorcinol derivatives bearing hydroxy groups at 1- and 3-positions of benzene ring in order to prepare new functionalized azacryptands. The new

Keywords: Resorcinol; Functionalized azacryptand; Lanthanide ions; Optical amplifier; Light-emitting materials.
☆ Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tetlet.2004.04.051
* Corresponding author. Tel.: +82-42-629-7865; fax: +82-42-629-8325; e-mail: hwankkim@mail.hannam.ac.kr

0040-4039/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2004.04.051



Scheme 1.

azacryptands could render a bigger cavity size to strongly bind with lager metal ions such as lanthanide ions or transition metal ions than from catechol derivatives.

Macrocyclization step in the synthesis of cryptand is competitive with undesirable linear polymerization (or oligomerization). The latter reaction is more favorable because of extremely reducing entropy in macrocyclization step. To circumvent this problem, high-dilution techniques and templates such as metal ions have been applied to increase yields seldom. Similarly, we synthesized azacryptands with moderately good yield in the presence of potassium carbonate as follows: Treatment of orcinol (5-methyl resorcinol) monohydrate with tris(2-chloroethyl)amine in the presence of potassium carbonate in the large amount of acetone/water (19/1, 0.007 M) afforded a 7,19,30-trimethyl-4,10,16,22,27,33-hexaoxa-1,13-diazapentacyclo[11.11.11.$1^{5,9}$.$1^{17,21}$.$1^{28,32}$] octatriconta-5,7,9(36),17,19,21(37),28,30,32(38)-nonaene (azacryptand) **1** with the yield of 18%. The chemical structure of azacryptand **1** was confirmed by elemental analysis, EI-MS, ^{1}H and ^{13}C NMR, COSY, HETCOR, and X-ray diffraction analysis.[16,17]

Instead of orcinol, we also used 3,5-dihydroxybenzoic acid and methyl 3,5-dihydroxybenozate under the same reaction condition of **1**, affording the corresponding azacryptands of **2** and **3** with the yield of 7% and 11%, respectively. As-prepared azacryptands of **1** and **3** possess almost the same solubility and NMR pattern. Azacryptands of **1** and **3** recrystallized from dichloromethane/ethyl acetate, as a white solid, were soluble in dichloromethane and chloroform, and slightly soluble in THF but insoluble in other solvents. So, there is a critical solubility problem for the further functionalization reactions such as radical bromination in CCl_4 for $-CH_2Br$ group and oxidation in water (or pyridine/water) for –COOH group. To solve this solubility problem, we synthesized azacryptand hydrochloride salts (**4**, **5**, and **6**) with quantitative yields by treatment of azacryptands **1**, **2**, and **3** with concd hydrochloric acid in the CH_2Cl_2/ethanol (1/1).[18] Azacryptand hydrochloride salts as prepared show good solubility in water, alcohols, DMF, and DMSO. In ^{1}H NMR spectra, all peaks assigned to NCH_2 peaks are broaden and downfield shift. Downfield shift of NCH_2 peak has also been observed in the formation of Zwitterion under neutral pH condition, since carboxyazacryptand **2** has both acidic and basic moieties in one molecule like amino acid. ^{1}H NMR and FT-IR spectra of **2** showed Zwitterionic characters. However, carboxyazacryptand **2** has poor solubility in common organic solvents and low reproducibility in its synthetic reaction (Fig. 1).

In order to solve the poor solubility problem, ester groups in **3** and **6** can be interconverted to various functional groups such as alcohol, carboxylic acid: Treatment of azacryptand methyl ester hydrochloride salt **6** with KOH in ethanol/water (1/1) and then acidify by HCl afforded an carboxy azacryptand hydrochloride

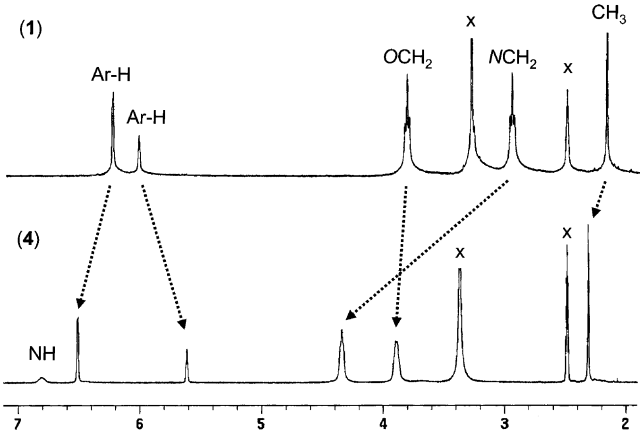


Figure 1. ^{1}H NMR spectra of **1** and **4** (DMSO-d_6, 300 MHz); x = solvents.

salt **5** with the yield of 98%. In ^{1}H NMR spectrum (300 MHz, DMSO-d_6) of **5**, methoxy peak (3.92 ppm) of **3** disappeared and new carboxylic acid peak appeared at 13.46 ppm. The functionalized derivative **5** was used for the further esterification reactions with phenol-containing compounds such as naphthalene and anthracene derivatives, or metallo-porphyrin derivatives.[1,15]

Furthermore, the single crystal structure of azacryptand **1**, obtained by slow evaporation of solution of **1** in a mixture of CH_2Cl_2 and hexanes, was confirmed by an X-ray diffraction analysis.[17] Its crystal structure, as shown in Figure 2, reveals four asymmetric molecules in unit without any strong interaction among them (see Supplementary information). And, the crystal structure shows the presence of 'cavity' consisted of two nitrogen and six oxygen atoms. The dimension of cavity can be described by distance of donor atoms as N1–N2 (8.19 Å), O1–O3 (4.11 Å), and O1–O5 (4.83 Å). The cavity size is big enough to encapsulate trivalent lanthanide(III) ions such as Sm^{3+} (1.13 Å), Eu^{3+} (1.12 Å), Er^{3+} (1.06 Å), and Yb^{3+} (1.04 Å).[19] So, it should provide enough encapsulating space for the formation of stable complexes with trivalent lanthanide(III) ions of Eu^{3+} and Er^{3+} ions.

For example, Eu(III)-encapsulated azacryptand complex **8** was prepared by refluxing **1** with Eu(III) nitrate pentahydrate in CH_2Cl_2/methanol (2/1) solution.[20] A resultant solid was filtered and washed with methanol and CH_2Cl_2. Eu(III) complex **8** shows the characteristic emission bands of Eu(III) ions at 593, 617, 692, and 696 nm, upon a photoexcitation of 395 nm with Xe-lamp (see Fig. 3). In a similar way, Er(III)-encapsulated azacryptand complex **9** was prepared by refluxing **1** with Er(III) nitrate pentahydrate in $CHCl_3$/methanol (2/1) solution.[20] Er(III) complex **9** exhibits the characteristic emission band of Er(III) ions around 1542 nm in the near infrared (near IR) region, upon a photoexcitation of 325 nm with He–Cd laser (see Fig. 3). The FT-IR spectra of **1**, **8**, and **9** showed the typical vibration mode for ν_s(C–O–CH=).[21] Its vibration mode at 1062 cm^{-1} in free host, **1**, is shifted about 14 and 10 cm^{-1} toward lower frequencies in the Eu(III) and Er(III) complexes, respectively. It indicates the formation of lanthanide(III)-encapsulated azacryptand complexes (Scheme 2).

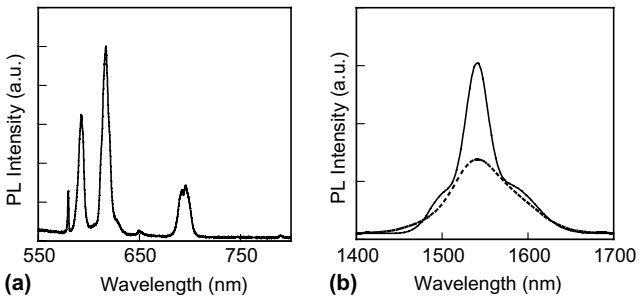


Figure 3. Emission spectra of (a) Eu(III)-encapsulated azacryptate complex **8** excited at 395 nm (powder, 25 °C) and (b) Er(III)-encapsulated azacryptate complexes of **9** (dashed line) and **10** (line) excited at 325 nm (powder, 25 °C).

In addition, in order to incorporate antenna chromophores into the Er(III)-encapsulated azacryptand complexes for enhancing the near IR emission, the room temperature esterification reaction[22] of carboxyazacryptand hydrochloride salt **5** with Pt(II)-5,10,15-trimesityl-20-(4-hydroxyphenyl)porphyrin[23] was achieved. It afforded a metalloporphyrin-attached cryptand ligand **7** with the yield of 22%.[15,22,24] And, its Er(III) complex **10** was obtained by the similar synthetic reaction condition of Er(III) complex **9**. The Er(III)-encapsulated azacryptand complex with Pt(II)-metalloporphyrin derivative, as shown in Figure 3, exhibits stronger near IR emission band than Er(III) complex **9** by two times. It might be due to the effective energy transfer from metalloporphyrin ligands to Er(III) ions.[1] Very recently, we reported that similar results were observed from lanthanide(III)-cored supramolecular complexes based on metalloporphyrin derivatives.[25] In progress, azacryptand complexation mechanistics with various lanthanide salts as well as the energy transfer mechanism between metalloporphyrin ligands and lanthanide ions are being studied in more details.

In conclusion, we have synthesized novel azacryptands from resorcinol derivatives by one-pot synthesis in the presence of potassium carbonate with moderately good

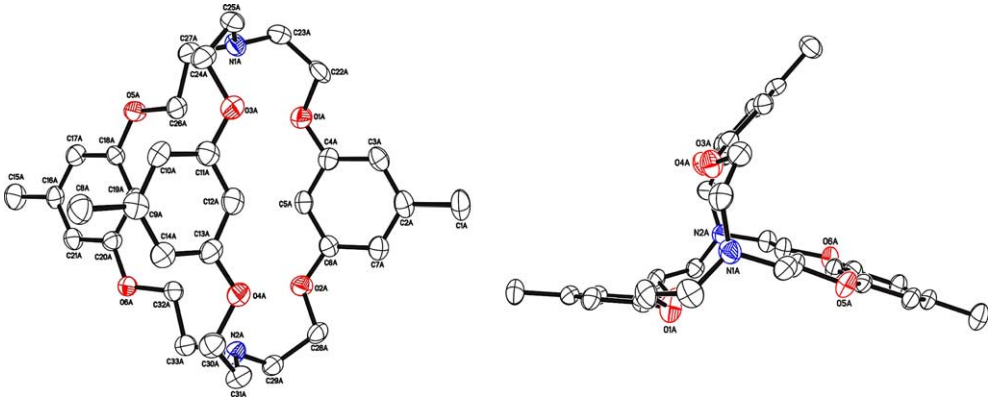
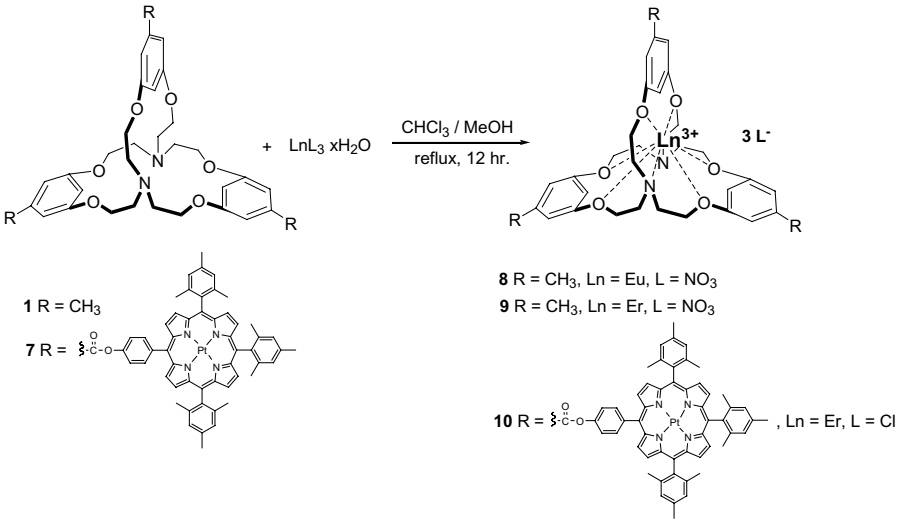


Figure 2. Crystal structure of **1** deduced from X-ray diffraction analysis. Hydrogen atoms have been omitted for clarity.



Scheme 2.

yields. These compounds represent an interesting large cavity azacryptand bearing functionalized substituents at phenyl group. It has provided the encapsulating sites enough for the formation of stable complexes with lanthanide(III) ions of Eu(III) and Er(III) ions. We also synthesized the Er(III)-encapsulated azacryptand complex bearing metalloporphyrin as photon antennas for advanced photonic materials such as optical amplifying and light-emitting materials.

Acknowledgements

The authors acknowledge that this research was financially supported from the National Creative Research Initiatives Program of the Ministry of Science and Technology of Korea.

References and notes

1. (a) Kim, H. K.; Roh, S. G.; Hong, K.-S.; Ka, J.-W.; Baek, N. S.; Oh, J. B.; Nah, M. K.; Cha, Y. H.; Ko, J. *Macromol. Res.* **2003**, *11*(3), 133; (b) Oh, J. B.; Piak, K. L.; Ka, J.-W.; Roh, S.-G.; Nah, M. K.; Kim, H. K. *Mater. Sci. Eng. C* **2004**, *24*, 257.
2. Steemers, F. J.; Verboom, W.; Reinhoudt, D. N.; van der Tol, E. B.; Verhoeven, K. W. *J. Am. Chem. Soc.* **1995**, *117*, 9408.
3. Klink, S. I.; Hebbink, G. A.; Grave, L.; van Veggel, F. C. J. M.; Reinhoudt, D. N.; Slooff, L. H. *J. Appl. Phys.* **1999**, *86*, 1181.
4. Pitois, C.; Vestberg, R.; Rodlert, M.; Malmström, E.; Hult, A.; Lindgren, M. *Opt. Mater.* **2002**, *21*, 499.
5. Kido, J.; Okamoto, Y. *Chem. Rev.* **2002**, *102*, 2357.
6. Kang, T.-S.; Harrison, B. S.; Foley, T. J.; Knefely, A. S.; Boncella, J. M.; Reynolds, J. R.; Schanze, K. S. *Adv. Mater.* **2003**, *15*, 1093.
7. Dietrich, B. *Comprehen. Supramol. Chem.* **1996**, *1*, 153.
8. Shestakova, A. K.; Chertkov, V. A.; Schneider, H.-J. *Tetrahedron Lett.* **2000**, *41*, 6753.
9. Izatt, R. M.; Pawlak, K.; Bradshaw, J. S.; Bruening, R. L. *Chem. Rev.* **1995**, *95*, 2529.
10. Lehn, J.-M. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 89.
11. Dietrich, B.; Lehn, J.-M.; Sauvage, J.-P. *Tetrahedron Lett.* **1969**, *34*, 2885.
12. Dietrich, B.; Lehn, J.-M.; Sauvage, J.-P. *Tetrahedron Lett.* **1969**, *34*, 2889.
13. Dietrich, B. *Inclusion Compd.* **1984**, *2*, 337.
14. Cox, B. G.; Firman, P.; Schneider, I.; Schneider, H. *Inorg. Chim. Acta* **1981**, *49*, 153.
15. (a) Baek, N. S.; Nah, M. K.; Kim, Y. H.; Roh, S.-G.; Kim, H. K. *Bull. Korean Chem. Soc.* **2004**, *25*(4), 443; (b) Ka, J.-W.; Kim, H. K. Unpublished data.
16. Preparation of azacryptand **1**: Orcinol monohydrate (2.0 g, 14.07 mmol) was dissolved in acetone (1.5 L). Potassium carbonate (20.0 g, 144.7 mmol) was added to the solution and the reaction mixture was refluxed for 1 h. And then, tris(2-chloroethyl)amine hydrochloride (4.5 g, 18.7 mmol) was dissolved in acetone/water (500 mL, 4/1) and added to reaction flask, drop by drop, and refluxed for 48 h. Methylene chloride was then added. The organic phase was washed with water, and solvent removed under vacuum to afford a pink solid that was recrystallized from ethyl acetate to give pure **1** (480 mg, 18%) as a white solid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.22 (s, 9H, CH_3), 3.01 (t, 12H, NCH_2), 3.90 (t, 12H, OCH_2), 6.21 (m, 3H, Ar-H), 6.24 (m, 6H, Ar-H); ^{13}C NMR (75.46 MHz, $CDCl_3$) δ 22.17, 55.81, 68.14, 100.14, 108.31, 139.97, 160.50; FT-IR (KBr, cm^{-1}) 1062, 1172, 1258, 1322, 1374, 1466, 1600, 2734, 2808, 2868, 2914, 2942, 3060. Anal. Calcd for $C_{33}H_{42}N_2O_6$: C, 70.44; H, 7.52; N, 4.98. Found: C, 69.57; H, 7.48; N, 5.03; MS (EI) Calcd: 562. Found: 562.
17. Crystallographic data (excluding structure factors) of **1** have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication numbers CCDC 224977. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK (Fax: +44(0)-1223-336033 or e-mail: deposit@ccdc.cam.ac.uk).
18. Synthesis of azacryptand hydrochloride salt **4**: A solution of compound **1** (500 mg, 0.89 mmol), concd HCl (5 mL), CH_2Cl_2/EtOH (50 mL, 2/1) was stirred for 1 h at room temperature. Solvent was evaporated under reduced pressure. The remaining white solid was dissolved in methanol, and then insoluble salt was filtered off. Methanol was evaporated under reduced pressure to give pure

azacryptand HCl salt **4** (552 mg, 98%) as a white solid. ^{1}H NMR (300 MHz, DMSO-d_6) δ 2.33 (s, 9H, CH_3), 3.91 (m, 12H, OCH_2), 4.36 (br s, 12H, NCH_2), 5.63 (m, 3H, Ar-H), 6.53 (m, 6H, Ar-H), 6.83 (br s, 2H, NH); ^{13}C NMR (75.46 MHz, DMSO-d_6) δ 22.66, 54.32, 61.19, 102.85, 106.59, 141.58, 158.00.

19. Shanon, R. D. *Acta Cryst.* **1976**, *A32*, 751.
20. Preparation of Ln(III) complexes: To a solution of ligand and $CHCl_3$/MeOH (2/1) was added lanthanide(III) salts (erbium (III) nitrate pentahydrate or europium(III) nitrate pentahydrate). The resulting solution was refluxed for 12 h. Precipitation was filtered and washed with CH_2Cl_2 and MeOH, and then dried to give pure Ln(III) complexes. Eu(III)-azacryptate, **8** (69%). FT-IR (KBr, cm^{-1}) 1048, 1170, 1266, 1316, 1386, 1470, 1606, 2948, 3122; ICP-AES Calcd for Eu: 16.8%. Found: 13.7%; λ_{em}: 593, 617, 692, and 696 nm (λ_{ex} = 395 nm, powder, 25 °C). Er(III)-azacryptate, **9** (66%). FT-IR (KBr, cm^{-1}) 1052, 1174, 1262, 1314, 1384, 1474, 1608, 2890, 2970, 3122; ICP-AES Calcd for Er: 18.3%. Found: 21.0%; λ_{em}: 1542 nm (λ_{ex} = 325 nm, powder, 25 °C). Pt(II)-porphyrin Er(III)-azacryptate **10** (22%). FT-IR (KBr, cm^{-1}) 1017, 1070, 1165, 1198, 1314, 1354, 1449, 1560, 1740, 2852, 2918; ICP-AES Calcd for Er: 4.5%. Found: 3.2%; λ_{em}: 1542 nm (λ_{ex} = 325 nm, powder, 25 °C).
21. Ramirez, F. de M.; Solache-Rios, M.; Campero, A. *Inorg. Chem.* **1991**, *30*, 321.
22. Moore, J. S.; Stupp, S. I. *Macromolecules* **1990**, *23*, 65.
23. Pt(II)-5,10,15-trimesityl-20-(4-hydroxyphenyl)porphyrin was prepared by condensation of mesitaldehyde, 4-hydroxybenzaldehyde, and pyrrole in the presence of $BF_3{\cdot}OEt_2$, and then platinum(II) insertion reaction followed by $PtCl_2$.
24. Spectroscopic data for **7**: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.85 (m, 54H, CH_3), 2.61 (m, 27H, CH_3), 3.14 (br s, 12H, NCH_2), 4.20 (br s, 12H, OCH_2), 6.29 (t, J = 2.4 Hz, 3H, Ar-H), 7.26 (m, 18H, Ar-H), 7.61 (d, J = 2.4 Hz, 6H, Ar-H), 7.64 (d, J = 8.4 Hz, 6H, Ar-H), 8.21 (d, J = 8.4 Hz, 6H, Ar-H), 8.55 (s, 12H, β-pyrrole), 8.61 (d, J = 4.8 Hz, 6H, β-pyrrole), 8.76 (d, J = 4.8 Hz, 6H, β-pyrrole); MS (MALDI-TOF) Calcd for $C_{192}H_{168}N_{14}O_{12}Pt_3$: 3446.19. Found: 3447.98; λ_{abs}: 401, 510, and 538 nm; λ_{em}: 670 and 740 nm (λ_{ex} = 401 nm, 1.0×10^{-6} M in $CHCl_3$, 25 °C).
25. Kim, H. K.; Oh, J. B.; Baek, N. S.; Ka, J.-W.; Roh, S. G.; Kim, Y. H.; Nah, M. K.; Hong, K.-S.; Song, B. J.; Zhou, G. *J. Nonlinear Opt. Phys. Mater.* **2004**, in press.