Hyperbranched Poly(arylene oxindole)s with a Degree of Branching of 100% for the Construction of Nanocontainers by Orthogonal Modification

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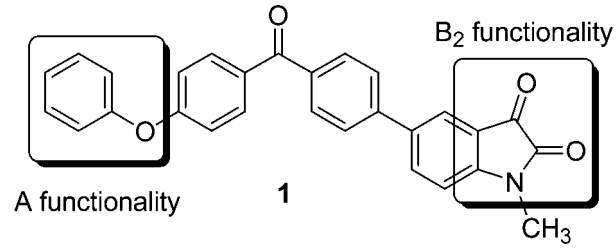
ABSTRACT: Hyperbranched polymers with a degree of branching of 100% have been prepared and converted into different types of unimolecular micelle-like structures. The polymers were obtained by acid catalyzed polycondensation of an isatin-based AB2 monomer, prepared without using toxic organometal reagents or extensive chromatographic purification. The molar masses as determined by SEC relative to linear PS standards were strongly underestimated as compared to absolute data determined by MALLS. This could be accounted for by the densely branched structure and the formation of intramolecular hydrogen bonds. The hyperbranched scaffolds were converted into unimolecular micelle-like structures in two ways. In a first approach, long alkyl chains were introduced at the terminal units and carboxyl groups at the dendritic units. The resulting macromolecules were soluble in apolar solvents and able to bind polar dyes. Alternatively, the terminal units could be converted into quaternary ammonium salts, leading to water-soluble macromolecules binding apolar BODIPY dyes.

Hyperbranched polymers have drawn much attention as an attractive alternative to dendrimers, because of their simple one-pot synthesis, for instance, by polycondensation of AB_2 monomers.[1] However, a branching degree (DB) of 100%, a characteristic feature of dendrimers, cannot be achieved unless postgrafting[2] is applied or when certain requirements are met.[3] Because the unreacted B groups are distributed over terminal and linear units, hyperbranched polymers cannot be functionalized as selectively as dendrimers, where, from a sufficiently high generation on, the end groups are mainly concentrated at the molecular surface.[4] However, a variety of applications of dendrimers arise from the possibility of discriminating upon functionalization between the focal, branched, or peripheral moieties.[5] In this respect, it could be helpful to develop a strategy toward modifiable hyperbranched polymers with a 100% branching degree as, due to the absence of linear units, the only B groups present are located at the terminal units. Although the structural and topological homogeneity of such hyperbranched polymers is still rather poor as compared to dendrimers and although the terminal units are not necessarily located at the periphery of the molecule, the feature of a DB of 100% could to some extent facilitate a more selective functionalization of the periphery and the interior.

In previous work, we designed an AB_2 monomer **1** (Chart 1) which was found to yield hyperbranched polymers with a DB of 100% in one step.[6] This can be attributed to the well-known fact that acid catalyzed condensation of isatin with aromatic compounds yields exclusively 3,3-diaryl oxindoles.[7]

The preparation of monomer **1**, however, was not attractive because of the use of organotin compounds and palladium catalysis and the low overall yield. Therefore, we have devised a new type of AB_2 monomer **2** (Scheme 1) which also combines the isatin and the phenoxy function as the B_2 and the A functionality, respectively, in order to ensure the formation of a hyperbranched polymer **8** with a DB of 1 (Scheme 2).

Chart 1. Our Initial Isatin-Based AB_2 Monomer Giving Rise to Fully Branched Hyperbranched Poly(arylene oxindole)s



Besides the high degree of branching that can be obtained in one step, the remarkable character of polymer **8** follows from the two kinds of modifiable groups present, i.e., 3-carbonyl groups in terminal units and lactam groups in all monomer units. Although the lactams are found in terminal units as well, these two functional groups allow functionalization independently from each other. Moreover, if these two kinds of groups were functionalized by hydrophobic and hydrophilic substituents, respectively, a unimolecular nanomicelle could be formed in a solvent that favorably interacts with the substituents introduced at the 3-carbonyl groups.[8] This indicates that the fully branched polymer **8** displays an interesting potential to be functionalized selectively at the periphery and in the interior, possibly allowing their use for the construction of nanoreactors or nanocapsules or even for protein mimicking.[9] Therefore, we have designed and prepared hyperbranched polymers bearing an apolar periphery and a polar interior or vice versa, through modification

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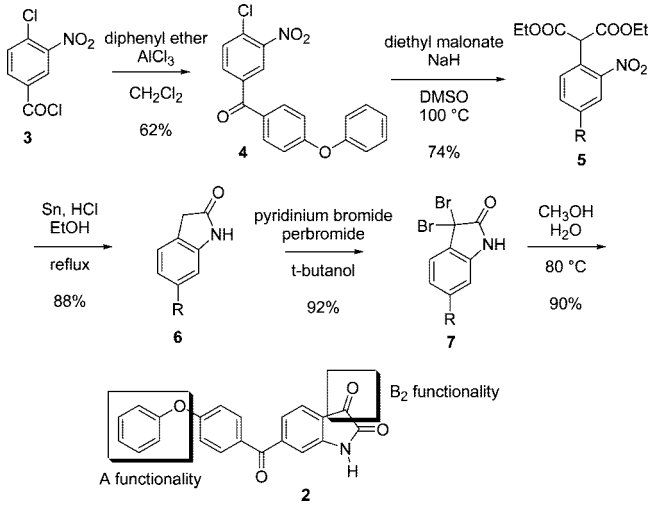
Scheme 1. Synthesis of Monomer 2

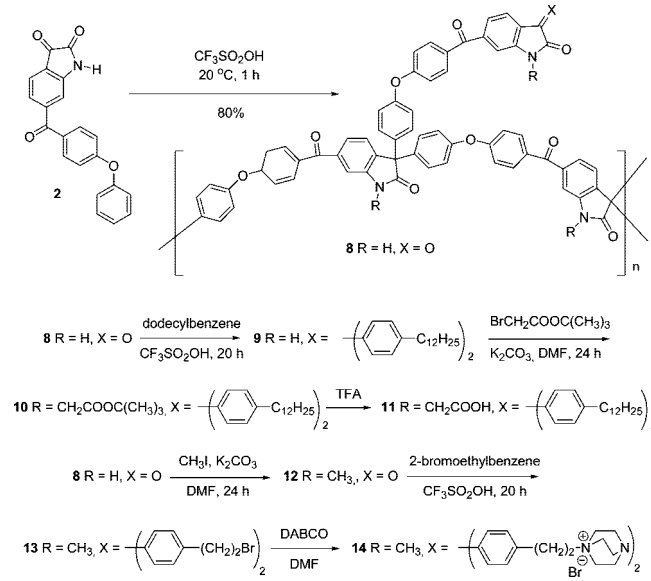


of polymer **8**. The encapsulation behavior of these compounds was explored by UV–vis probe molecules.

Monomer **2** was prepared based on a recently published approach to 6-substituted isatins.[10] The sequence starts with a Friedel–Crafts acylation of diphenyl ether with 4-chloro-3-nitrobenzoyl chloride (**3**) yielding benzophenone **4**. After substitution of the chlorine atom with the sodium salt of diethyl malonate, the obtained diester **5** was treated with metallic tin in a mixture of hydrochloric acid and ethanol, leading to oxindole **6** by reduction of the nitro group, ring closure by nucleophilic attack of the resulting amine on the ester function, and subsequent decarboxylation after hydrolysis of the second ester function. Oxindole **6** was then brominated, and the resulting dibromide **7** was subjected to hydrolysis, resulting in the desired AB_2 monomer **2**. Although this sequence requires more steps than the synthesis published for the original monomer **1**,[6] all of the reactions are high yielding and well reproducible without the need of chromatographic purification. Moreover, neither toxic nor costly reagents were necessary. The improvement in the monomer synthesis is of great importance for this strategy to fully hyperbranched polymers, because if the monomer synthesis could not be scaled up, the synthetic simplicity, the main advantage of hyperbranched polymers over dendrimers, would be lost. Another remarkable difference of monomer **2** is its unsubstituted lactam group, which could be used as an anchor point for further functionalization of the resulting polymer. In contrast, the unmethylated analogue of **1** could not be prepared as the Stille coupling, constituting the final step of the synthesis,[6] failed in the absence of an N-substituent on the isatin.

The hyperbranched polymer **8** with a DB of 1 was acquired by treatment of monomer **2** with trifluoromethanesulfonic acid (TFSA) in 80% yield (Scheme 2). The reaction was carried out at room temperature, and monomer concentrations of 100 mg/mL were applied. The polymer was isolated as published before.[6] Polymer **8** was found to be slightly soluble in tetrahydrofuran but insoluble in chloroform, in contrast to the polymer obtained from **1**, which was insoluble in tetrahydrofuran (THF) but freely soluble in chloroform. Standard GPC analysis of polymer **8** was performed in THF, and a molecular mass of $M_n = 4400$ g/mol and a polydispersity of 1.36 were found relative to linear PS standards. However, using MALLS detection in order to obtain absolute molecular masses, a much higher M_n value of 48 600 g/mol and a polydispersity of 2.14 were found. This remarkable underestimation of the molecular mass by standard GPC can partly be attributed, besides to the densely branched structure, to the formation of intramolecular hydrogen bonds between the free lactam NH groups and the

Scheme 2. Synthesis and Modification of Hyperbranched Poly(arylene oxindole)s



carbonyl groups of the oxindole and isatin moieties, resulting in additional compactness of the molecule. This reasoning was confirmed by two additional experiments. First, the lactam NH groups of **8** were methylated and the resulting polymer **12** was investigated by GPC, resulting in an apparent M_n value of 8400 g/mol and a polydispersity of 1.50 relative to linear PS standards. The observed difference cannot be accounted for by the real increase of the molecular mass, as this is hardly different from that of the unmethylated analog. Second, the presence of intramolecular hydrogen bonding was also confirmed by IR spectroscopy (in KBr). A significant shift of the absorption of the 2-carbonyl groups to higher wavenumber occurs upon methylation of the polymer (from 1708 cm^{-1} in polymer **8** to 1722 cm^{-1} in polymer **12**). This remarkable shift provides additional evidence for the presence of intramolecular hydrogen bonding as the 2-carbonyl groups of monomer **2** and its N-methylated analogue absorb at almost the same wavenumber (at 1737 and 1739 cm^{-1}, respectively).[11]

^1H and ^{13}C NMR analysis provided clear evidence for the fully hyperbranched structure of polymer **8** (Figure 1). Extensive line broadening can be observed, indicating the presence of monomer units in different microenvironments. The intensity of the doublet for the 4-H of the isatin unit (7.61 ppm) is lowered with 50% in the spectrum of the polymer compared to the monomer spectrum, indicating that half of the 3-carbonyl groups of the isatin functions have been converted into 3,3′-diaryloxindole units. This is consistent with a branching degree of 100%, as only in this case the percentage of dendritic units could reach 50%. Moreover, two broad peaks with equal intensity can be observed for the lactam hydrogen. A first one is situated at 11.16 ppm, which is almost exactly the resonance value of the corresponding lactam hydrogen of the monomer (11.18 ppm). A second and even broader one can be found at 11.02 ppm. These signals are likely to correspond to the lactam hydrogen atoms of the terminal and the dendritic units, respectively. The ^{13}C NMR spectrum reveals the presence of a quaternary carbon signal around 62 ppm, corresponding to the 3-carbon atom of the dendritic oxindole residues. Moreover, a new carbonyl signal occurs at 178.6 ppm, corresponding to the dendritic oxindole lactam groups. No evidence for the presence of linear units can be obtained from NMR analysis.

Two kinds of orthogonal modification reactions, superelectrophilic condensation and alkylation, were employed to modify the terminal 3-carbonyl and interior lactam groups of polymer

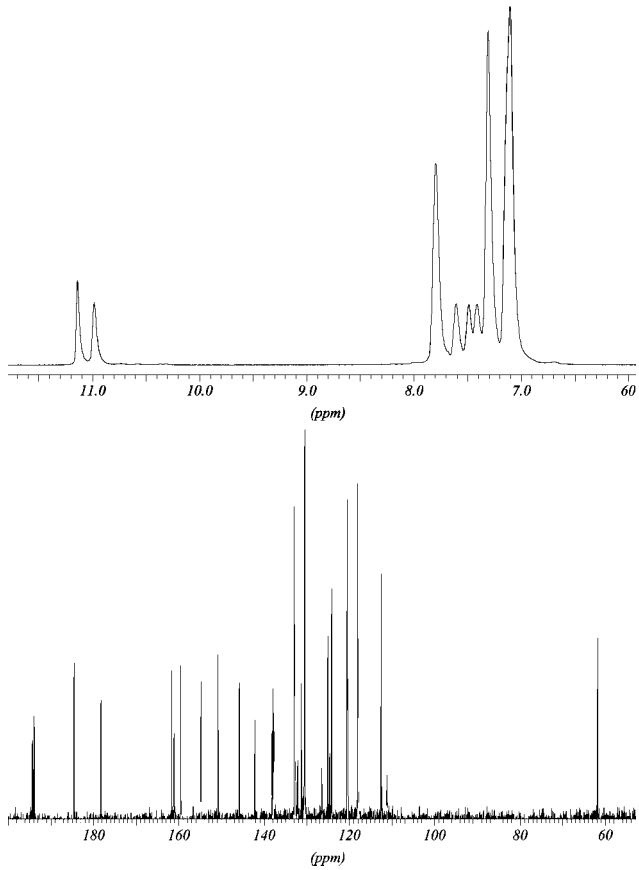


Figure 1. ^{1}H and ^{13}C NMR spectra of polymer **8**.

8, respectively. As shown in Scheme 2, polymer **11**, soluble in apolar solvents, and the water-soluble polymer **14** were obtained.

In the case of polymer **11**, the condensation was first performed by addition of an excess dodecylbenzene to a solution of polymer **8** obtained from **2** after the required polymerization time and leaving this reaction mixture at room temperature for 20 h yielding the polymers of type **9** with long alkyl chains attached to the terminal groups. Afterward, polymer **9** was alkylated with *t*-butyl bromoacetate in dimethylformamide (DMF) with K_2CO_3 as base at room temperature for 24 h. After isolation, the obtained polymer **10** was hydrolyzed in trifluoroacetic acid (TFA), producing polymer **11** with carboxylic acid residues as hydrophilic inner functionalities. All of these three polymers are soluble in chloroform and polymers **9** and **11** can be dissolved in THF as well. The ^{1}H NMR spectrum of the end-capped polymer **9** shows complete disappearance of the doublet of the 4-H on the isatin units, indicating that the terminal isatins were completely transformed into oxindoles. This was further confirmed by comparing the integration of the ^{1}H NMR signals of the alkyl chains and the aromatic protons of the oxindole groups. In the ^{1}H NMR spectrum of polymer **10**, the signal of the methylene on the lactam is split into two signals with equal intensity at 4.49 and 4.43 ppm, corresponding to the dendritic and terminal units, respectively. However, in the case of polymer **11**, a single broad peak at 4.55 ppm was observed. This may be attributed to the increased intramolecular interaction among the carboxyl groups in chloroform, a rather poor solvent for the carboxylic acid residues.

To confirm the alleged uptake of guest molecules inside the polymer, encapsulation tests of water-soluble dyes in the chloroform solutions of the polymers were carried out. We used Rose Bengal as a water-soluble dye, of which λ_{max} decreases with the dielectric constant (λ_{max} of 549 nm in water and λ_{max} of 559 nm in methanol). For comparison, polymers **9**, **10**, and

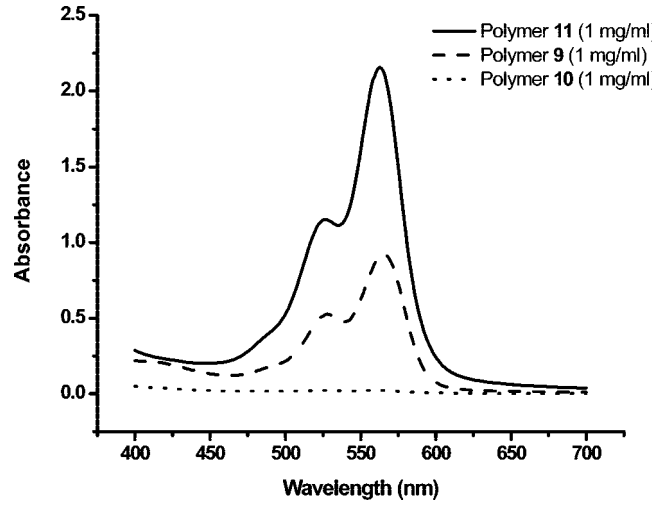


Figure 2. UV−vis spectra of Rose Bengal encapsulated in chloroform solutions of polymers **9**, **10**, and **11**.

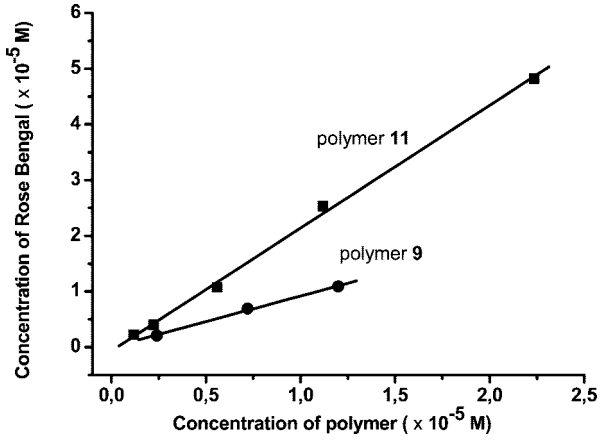


Figure 3. Concentration of encapsulated Rose Bengal as a function of the concentration of polymer **9** (circles) and polymer **11** (squares) solutions.

11 were studied. The chloroform solutions of the above polymers were stirred with an excess amount of Rose Bengal (2 mg/mL) for 24 h after which residual solid was removed by filtration and centrifugation (3600 r min^{-1}, 5 min). The resulting polymer solutions were studied by UV–vis spectroscopy. As shown in Figure 2, the dye molecule could be solubilized in the polymer **9** and **11** solutions, showing a λ_{max} at 562 nm in the case of polymer **11** and 565 nm in case of polymer **9**, suggesting that the microenvironments of the encapsulated dye molecules are similar and close to that in methanol. This indicates that both polymer **9** and **11** can encapsulate polar guests in chloroform solutions. The polar interior cavity consists of either lactam or acetic acid groups which could host polar guest molecules, accounting for the observed encapsulation. Meanwhile, no absorption of Rose Bengal was observed in the solution containing polymer **10**, confirming the crucial role played by the interior polar residues for the encapsulation.

To gain further insight into the encapsulation behavior, the solubility of Rose Bengal in solutions of polymers **9** and **11** at different concentrations was explored. Figure 3 shows the concentrations of encapsulated Rose Bengal as a function of the polymer concentration ranging from 0.12×10^{-5} to 2.24×10^{-5} M for polymer **11** and from 0.24×10^{-5} to 1.2×10^{-5} M for polymer **9**. The linear increase in these low concentration ranges indicates that the polymers **9** and **11** behave as unimolecular micelles in chloroform.[12] Using the extinction coefficient of Rose Bengal in methanol, the average number of

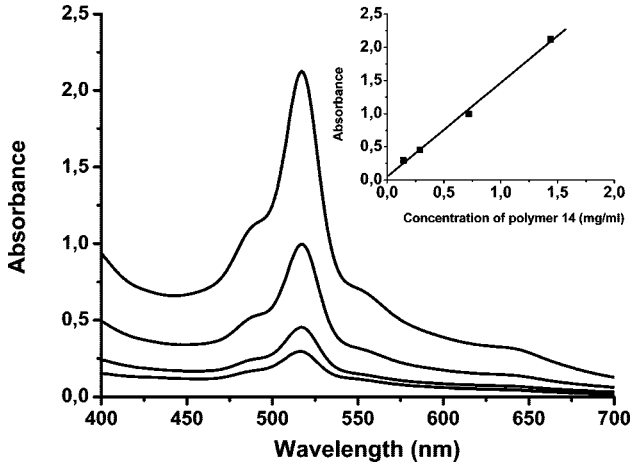


Figure 4. UV−vis spectra of diCl-BODIPY encapsulated in aqueous solutions of polymer **14** at different concentrations (0.14, 0.28, 0.72, and 1.44 mg/mL from bottom to top). The inset graph is the absorbance as a function of the concentration of polymer **14**.

encapsulated dye molecules per hyperbranched polymer molecule was estimated. The values obtained were 2.2 for polymer **11** (28 mg/g of polymer) and 0.9 for polymer **9** (13 mg/g of polymer), on the basis of the molecular mass data from MALLS, which is comparable to results of hyperbranched polymers reported earlier.[13] The different encapsulation ability of the two polymers can be interpreted as a consequence of the more polar microenvironment of the carboxyl groups of polymer **11** compared to the lactam groups of polymer **9**. In addition, the enhancement also indicates that the encapsulation ability of the polymer can be adjusted by modification of the interior residues.

Instead of unimolecular micelles soluble in apolar solvents, water-soluble analogues could be acquired while starting from the same polymer **8**. Thus, polymer **14** was synthesized by N-alkylation of the isatin and indolone moieties with iodomethane yielding **12** followed by condensation of the peripheral isatin groups with (2-bromoethyl)benzene resulting in **13** and subsequent nucleophilic substitution with 1,4-diazabicyclo[2.2.2]octane (DABCO) in DMF. An aqueous solution of polymer **14** was prepared by dropping 1 mL of this reaction mixture (containing 20 mg of polymer **14**) into 10 mL of water, followed by 2 days of dialysis (cutoff of $M_w = 3500$ g/mol) to remove the excess of reagents and DMF. The removal of DMF was confirmed by the absence of typical resonances in the ^{1}H NMR spectrum of the resulting solution. The polymer concentration of the water solution was estimated by the absorbance at 300 nm, using its extinction coefficient in DMF. For the encapsulation study, 3,5-dichloro-BODIPY (4,4-difluoro-4-bora-3a,4a-diaza-s-indacene) was used as the probe dye,[14] which is not soluble in water but can be dissolved in apolar solvents, such as chloroform ($\lambda_{max} = 508$ nm) and toluene ($\lambda_{max} = 516$ nm). In a way similar to what was described above, encapsulated diCl-BODIPY containing aqueous solutions with different concentrations of polymer **14** were prepared and investigated by UV–vis spectroscopy. As shown in Figure 4, diCl-BODIPY could be stabilized in the polymer solutions displaying an absorption maximum at 517 nm. This indicates that the probe molecules were captured in the apolar interior of the polymer molecules, where the polarity is comparable to that of toluene. Meanwhile, the absorbance increases linearly with the polymer concentration, as the inset shows. From the extinction coefficient, the average number of encapsulated dye molecules per polymer molecule was estimated as 1.5 (5.7 mg/g of polymer). This suggests that polymer **14** could form a unimolecular nanomicelle in water, analogously to polymer **11** in chloroform.

In conclusion, a fully branched hyperbranched polymer was used for the construction of nanocontainers. The polymer was obtained by one-pot polymerization of an AB_2 monomer, the synthesis of which could be accomplished without either the use of toxic organometallics nor chromatographic purification. The modifications could be performed independently at the molecular periphery and in the interior cavity. Water-soluble structures able to encapsulate a hydrophobic dye and polymers soluble in apolar solvents able to encapsulate a hydrophilic dye were prepared from the same starting polymer. At present, more work on the modification with functional or receptor groups is being carried out, aiming at the construction of nanomaterials or at biomimicking.

Experimental Section

NMR spectra were recorded on a Bruker Avance 300 or Bruker AMX 400 spectrometer with tetramethylsilane as internal reference. UV−vis spectra were recorded on a Perkin-Elmer Lambda 20 spectrometer. The GPC measurements with linear PS standard calibration were performed on a Shimadzu apparatus using PLgel mixed-D columns (Polymer Laboratories) at 1 mL/min at 30 °C. SEC-MALLS measurements were carried out on the following column system: guard (Polymer Laboratories) + 2 × Mixed-C (Polymer Laboratories) with refractive index detector Δn-2010 RI WGE Dr. Bures and a multiangle light scattering detector DAWN HELEOS of Wyatt Technologies ($\lambda = 658$ nm). Measurements were performed at 45 °C in DMF with a nominal flow rate of 1 mL/min. The results were collected and evaluated by ASTRA 5.1.9 software from Wyatt Technologies using the known constant of refractive index detector and 100% mass recovery method. IR spectra were recorded on a Perkin-Elmer 1600 infrared fourier transform spectrometer in KBr pellets. Melting points were measured on a Reichert-thermovar or electrothermal 9200 and are uncorrected. Mass spectra were recorded on a Hewlett-Packard MS-engine 5989 A. All reagents were purchased from Acros Organics or Aldrich and used without further purification. DMF, dimethyl sulfoxide (DMSO), and CH_2Cl_2 were dried over molecular sieves (4 Å).

Synthesis of 4-Chloro-3-nitro-4′-phenoxybenzophenone (4). 4-Chloro-3-nitrobenzoyl chloride (**3**) (21 g, 95 mmol) was added in a portionwise manner to an ice-cooled suspension of diphenyl ether (35 g, 206 mmol) and $AlCl_3$ (20 g, 150 mmol) in CH_2Cl_2 (40 mL) for approximately 30 min under an argon atmosphere. The mixture was stirred for 2 h at room temperature and poured onto a mixture of crushed ice (400 g) and aqueous HCl (0.5 M, 400 mL). The product was extracted with CH_2Cl_2 (2 × 200 mL) and the organic layer was washed with a saturated $NaHCO_3$ solution (2 × 200 mL). After drying over $MgSO_4$ and evaporation under reduced pressure, **4** was obtained as a white crystalline solid (21 g, 62%) after crystallization from heptane (approximately 300 mL). mp 146–147 °C. ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 8.25$ (d, ^4J(H−H) = 1.5 Hz, 1H; *o*-H to NO_2), 7.93 (dd, ^3J(H−H) = 8.4 Hz, ^4J(H−H) = 1.8 Hz, 1H; *p*-H to NO_2), 7.78 (d, ^3J(H−H) = 8.8 Hz, 2H; *m*-H to OPh), 7.68 (d, ^3J(H−H) = 8.0 Hz, 1H; *m*-H to NO_2), 7.43 (t, ^3J(H−H) = 8.1 Hz, 2H; *m*-H to COPhO), 7.22 (m, 1H; *p*-H to COPhO), 7.11 (m, 2H; *o*-H to COPhO), 7.05 (d, ^3J(H−H) = 6.6 Hz, 2H; *o*-H to OPh). ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 191.7, 162.7, 155.0, 137.5, 134.0, 133.6, 132.4, 132.1, 130.7, 130.2, 130.1, 126.6, 125.0, 120.4, 117.3$. MS (CI) $m/z = 354$ (MH^+).

Synthesis of Diethyl-2-[2-nitro-4-(4′-phenoxybenzoyl)-phenyl]malonate (5). NaH dispersed in mineral oil (80%, 1.90 g, 63 mmol) was washed with petroleum ether (approximately 40 mL) and suspended in dry DMSO (140 mL) at 80 °C under an argon atmosphere. A solution of diethyl malonate (10.0 g, 63 mmol) in dry DMSO (14 mL) was added, and the mixture was stirred for 10 min until a clear solution had formed. A suspension of **4** (10.5 g, 30 mmol) in dry DMSO (80 mL) was added slowly, and the red reaction mixture was kept at 80 °C for 1 h. The solution was poured into a saturated aqueous NaCl solution (1 L) and extracted with

diethyl ether (3 × 300 mL). After drying over $MgSO_4$, the solution was concentrated to approximately 200 mL under reduced pressure, and **5** was obtained as white crystals (10.5 g, 74%) after storing of the solution in the refrigerator overnight. mp 95–96 °C. ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 8.43 (d, ^4J(H−H) = 1.5 Hz, 1H; *o*-H to NO_2), 8.04 (dd, ^3J(H−H) = 8.1 Hz, ^4J(H−H) = 1.5 Hz, 1H; *p*-H to NO_2), 7.82 (d, ^3J(H−H) = 8.1 Hz, 2H; *m*-H to OPh), 7.68 (d, ^3J(H−H) = 8.1 Hz, 1H; *m*-H to NO_2), 7.42 (t, ^3J(H−H) = 8.1 Hz, 2H; *m*-H to COPhO), 7.23 (t, ^3J(H−H) = 7.3 Hz, 1H; *p*-H to COPhO), 7.11(d, ^3J(H−H) = 7.3 Hz, 2H; *o*-H to COPhO), 7.05 (m, 2H; *o*-H to OPh), 5.36 (s, 1H; $CH(COOCH_2CH_3)_2$), 4.30 (q, ^3J (H−H) = 7.0 Hz, 4H; $COOCH_2CH_3$), 1.30 (t, ^3J(H−H) = 7.0 Hz, 6H; $COOCH_2CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C, TMS): δ = 192.1, 166.7, 162.5, 155.0, 148.7, 138.9, 133.8, 132.5, 131.7, 131.4, 130.1, 126.1, 124.9, 120.4, 117.3, 62.5, 54.4, 14.0. MS (CI) *m*/*z* = 478 (MH^+).

Synthesis of 6-(4-Phenoxybenzoyl)-2-oxindole (6). A suspension of **5** (10.0 g, 22.0 mmol) and tin powder (7.5 g, 63.2 mmol) in a mixture of ethanol (75 mL) and aqueous HCl (10 M, 38 mL) was heated at 90 °C for 2 h. The mixture was filtered while hot, and **6** was collected by filtration as a crystalline solid (6.0 g, 88%) after cooling to room temperature. mp 200–201 °C. ^{1}H NMR (300 MHz, DMSO, 25 °C, TMS): δ = 10.53 (s br, 1H; NH), 7.78 (d, ^3J(H−H) = 8.8 Hz, 2H; *m*-H to OPh), 7.48 (t, ^3J(H−H) = 7.7 Hz, 2H; *m*-H to COPhO), 7.37 (d, ^3J(H−H) = 7.3 Hz, 1H; 4-H oxindole), 7.28 (m, 2H; 5-H oxindole + *p*-H to COPhO), 7.18 (s, 1H; 7-H oxindole), 7.14 (d, 2H; *o*-H to COPhO), 7.09 (d, ^3J(H−H) = 8.8 Hz, 2H; *o*-H to OPh), 3.60 (s, 2H; CH_2). ^{13}C NMR (75 MHz, DMSO, 25 °C, TMS): δ = 194.9, 177.0, 161.8, 155.4, 142.7, 138.0, 132.4, 131.7, 130.0, 129.8, 124.6, 124.3, 124.2, 120.2, 117.1, 110.5, 36.2. MS (CI) *m*/*z* = 330 (MH^+).

Synthesis of 3,3-Dibromo-6-(4-phenoxybenzoyl)-2-oxindole (7). Oxindole **6** (6.0 g, 18 mmol) and water (0.8 mL) were dissolved in *t*-BuOH (170 mL) at 30 °C. Pyridinium bromide perbromide (23 g, 76 mmol) was added in portions for approximately 5 min, and the mixture was stirred for 16 h at 30 °C. The solution was poured into water (250 mL) and extracted with ethyl acetate (3 × 100 mL). The organic layer was washed with an aqueous saturated NaCl solution (1 × 100 mL). After drying over $MgSO_4$ and evaporation under reduced pressure, **7** was obtained as a solid (8.2 g, 92%) which was directly used in the next step without further purification. ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 9.72 (s br, 1H; NH), 7.82 (d, ^3J(H−H) = 8.8 Hz, 2H; *m*-H to OPh), 7.68 (d, ^3J(H−H) = 8.0 Hz, 1H; 4-H oxindole), 7.52 (d, ^3J(H−H) = 8.0 Hz, 1H; 5-H oxindole), 7.42 (m, 3H; 7-H oxindole + *m*-H to COPhO), 7.22 (t, ^3J(H−H) = 7.3 Hz, 1H; *p*-H to COPhO), 7.11 (m, 2H; *o*-H to COPhO), 7.03 (d, ^3J(H−H) = 8.8 Hz, 2H; *o*-H to OPh). ^{13}C NMR (75 MHz, $CDCl_3$, 25 °C, TMS): δ = 194.0, 171.5, 162.3, 155.2, 141.0, 137.4, 134.7, 132.6, 130.8, 130.1, 125.9, 125.8, 124.8, 120.3, 117.2, 112.1, 44.3. MS (CI) *m*/*z* = 486 (MH^+).

Synthesis of 6-(4-Phenoxybenzoyl)-isatin (2). Oxindole **7** (9.6 g, 20 mmol) was suspended in a mixture of methanol (100 mL) and water (25 mL) and heated at 85 °C for 24 h. The reaction mixture was cooled in the refrigerator overnight and filtered. The precipitate was washed with cold methanol (2 × 20 mL) and water until the filtrate was neutral, affording **2** as a crystalline yellow solid (6.1 g, 90%). mp 218–219 °C. ^{1}H NMR (300 MHz, DMSO, 25 °C, TMS): δ = 11.19 (s br, 1H; NH), 7.82 (d, ^3J(H−H) = 8.8 Hz, 2H; *m*-H to OPh), 7.65 (d, ^3J(H−H) = 8.0 Hz, 1H; 4-H isatin), 7.49 (t, ^3J(H−H) = 8.1 Hz, 2H; *m*-H to COPhO), 7.29 (m, 2H; 5-H isatin + *p*-H to COPhO), 7.17 (d, ^3J(H−H) = 8.0 Hz, 2H; *o*-H to COPhO), 7.11 (m, 3H; 7-H isatin + *o*-H to OPh). ^{13}C NMR (75 MHz, DMSO, 25 °C, TMS): δ = 193.9, 184.6, 162.1, 159.6, 155.3, 150.8, 145.9, 133.0, 130.9, 130.8, 125.5, 125.0, 124.1, 120.6, 120.5, 117.6, 112.5. MS (CI) *m*/*z* = 344 (MH^+).

Polymerization of Monomer 2 to Polymer 8. Monomer **2** (100 mg, 0.29 mmol) was dissolved in trifluoromethanesulfonic acid (1 mL), and the solution was stirred under an argon atmosphere at room temperature for 1 h. The solution was added in a dropwise manner to water (15 mL), and the precipitate was separated by centrifugation (3600 r min^{-1}, 5 min). Water was added to the centrifugation tube and the polymer suspended again by vigorous shaking after which the polymer was precipitated and separated again by centrifugation (3600 r min^{-1}, 5 min). This procedure was repeated once more with water and two times with acetone. Polymer **8** was obtained after drying in a vacuum at 60 °C as a brownish solid in a yield of 85%. ^{1}H NMR (400 MHz, DMSO, 25 °C, TMS): δ = 11.16 and 11.02 (br, 2H), 7.79 (br, 4H), 7.61 (br, 1H), 7.47–7.41 (br d, 2H), 7.29 (br, 5H), 7.13–7.09 (m br, 10H). ^{13}C NMR (100 MHz, DMSO, 25 °C, TMS): δ = 194.7, 194.3, 184.9, 178.6, 162.1, 161.5, 160.0, 155.2, 155.1, 151.1, 146.1, 142.5, 138.5, 138.3, 138.2, 138.1, 134.0, 133.4, 132.4, 131.6, 130.9, 128.9, 126.9, 125.9, 125.3, 125.1, 124.5, 123.0, 121.0, 118.3, 112.9, 111.5, 62.2. M_n = 4400, M_w/M_n = 1.36 (GPC in THF).

Synthesis of Polymer 9. Polymer **8** (40 mg) and dodecylbenzene (1 mL, 3.5 mmol) were dissolved in trifluoromethanesulfonic acid (2 mL), and the mixture was stirred under an argon atmosphere at 60 °C for 20 h. The solution was added dropwise to water, and the mixture was extracted with CH_2Cl_2. After drying over $MgSO_4$ and evaporation under reduced pressure, the liquid was added in a dropwise manner to petroleum ether (20 mL) and the precipitate was separated by centrifugation (3600 r min^{-1}, 5 min). After washing with petroleum ether and acetone, polymer **9** was obtained as a white solid (41 mg, 62%). ^{1}H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.73 (br, 2H), 7.38–7.24 (br m, 5H), 7.12 (br, 2H), 7.03 (br, 2H), 6.93 (br, 4H), 2.5 (br, 2H), 1.5 (br, 2H), 1.2 (br, 18H), 0.87 (br, 3H). ^{13}C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): δ = 194.7, 179.7, 161.0, 155.4, 142.3, 141.5, 138.5, 138.1, 137.8, 133.1, 132.5, 130.0, 128.5, 128.2, 126.0, 124.7, 121.7, 119.9, 117.7, 111.1, 62.3, 35.5, 31.8, 31.2, 29.4, 29.3, 22.6, 14.0. M_n = 10 700, M_w/M_n = 1.97 (GPC in THF); M_n = 8400, M_w/M_n = 1.58 (GPC in chloroform).

Synthesis of Polymer 10. To the solution of polymer **9** (55 mg) in 3 mL of dry DMF were added *tert*-butyl bromoacetate (41 mg, 0.21 mmol) and K_2CO_3 (30 mg, 0.21 mmol). After stirring at room temperature for 24 h, the mixture was poured into water, followed by extraction with ethyl acetate. After drying with $MgSO_4$ and evaporating under reduced pressure, the liquid was added in a dropwise manner to methanol (40 mL) and the precipitate was separated by centrifugation (3600 r min^{-1}, 5 min). After washing with methanol (2 × 10 mL), polymer **10** (50 mg, 76%) was obtained. ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.80 (br m, 2H), 7.28–7.50 (br m, 5H), 7.18–7.23 (br m, 2H), 7.01–7.11 (br, 6H), 4.49 and 4.43 (br, 2H), 2.55 (br, 2H), 1.54 (br, 2H), 1.46 and 1.43 (br, 9H), 1.24 (br, 18H), 0.87 (br, 3H). M_n = 14 200, M_w/M_n = 1.63 (GPC in chloroform).

Hydrolysis of Polymer 10. The solution of polymer **10** (50 mg) in 3 mL of trifluoroacetic acid was stirred at room temperature for 17 h. After evaporation under reduced pressure, the solid was dissolved in acetone and precipitated in water. Polymer **11** (42 mg, 92%) was obtained after washing with methanol (2 × 10 mL). ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.76 (br, 2H), 6.85–7.42 (br m, 13H), 4.56 (br, 2H), 2.71 (br, 2H), 1.54 (br, 2H), 1.24 (br, 18H), 0.84 (br, 3H). M_n = 11 100, M_w/M_n = 3.60 (GPC in THF).

Methylation of Polymer 8. To the solution of polymer **8** (30 mg) in dry DMF (3 mL) were added iodomethane (0.10 mL, 1.6 mmol) and K_2CO_3 (20 mg, 0.14 mmol). After stirring at room temperature for 24 h, the mixture was dropped into water and the precipitate was separated by centrifugation (3600 r min^{-1}, 5 min). After being washed by water and acetone twice, polymer **12** (30 mg, 96%) was obtained. ^{1}H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.81 (br, 4H), 7.63 (br, 1H), 7.49–7.26 (m br, 7H), 7.04 (br, 10H), 3.36 and 3.27 (br, 2H). ^{13}C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): δ = 194.4, 193.5, 182.9, 177.2, 162.0, 161.4, 157.8, 155.2, 155.0, 151.4, 146.8, 143.6, 138.8, 137.4 137.2, 136.8, 132.5, 132.4, 131.9, 130.9, 130.2, 130.1, 125.5, 125.3, 125.0, 124.7, 121.8, 120.2, 120.1, 119.4, 117.7, 110.3, 109.5, 61.6, 27.0, 26.4. M_n = 8,400, M_w/M_n = 1.50 (GPC in chloroform).

End Capping of 12. To the solution of polymer **12** (100 mg) in 5 mL of trifluoromethanesulfonic acid was added 2-bromoethylbenzene (2 mL, 15 mmol). After stirring under an argon

atmosphere at room temperature for 20 h, the solution was added in a dropwise manner to water (60 mL), followed by extraction with CH_2Cl_2. After drying over $MgSO_4$ and evaporation under reduced pressure, the liquid was added dropwise to petroleum ether (20 mL) and the precipitate was separated by centrifugation (3600 r min^{-1}, 5 min). After washing with petroleum ether twice, polymer **13** (110 mg, 73%) was obtained. ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ = 7.83 (br, 2H), 7.28–7.50 (br m, 5H), 7.14–7.17 (br m, 4H), 7.03 (br, 4H), 3.51 (br, 2H), 3.35 and 3.31 (br, 2H), 3.11 (br, 2H).

Synthesis of Polymer 14. To a solution of polymer **13** (110 mg) in 5 mL of DMF was added an excess amount of 1,4-diazabicyclo[2.2.2]octane (150 mg, 1.3 mmol). The solution was refluxed for 20 h, followed by addition in a dropwise manner to diethyl ether (150 mL). The precipitate was separated by centrifugation (3600 r min^{-1}, 5 min). Polymer **14** (80 mg, 68%) was obtained after washing with diethyl ether (2 × 10 mL). ^{1}H NMR (300 MHz, DMSO, 25 °C, TMS): δ = 7.83 (br, 2H), 7.44 (br, 3H), 7.30 (br, 2H), 7.13 (br, 8H), 3.21 (t, 6H), 3.84 (t, 6H).

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