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The Synthesis and Physical Properties of Novel Polyaromatic Profluorescent Isoindoline Nitroxide Probes

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New profluorescent mono- and di-isoindoline nitroxides (**5**, **11**, **16** and **19**) containing 9,10-diphenylanthracene and 9,10-bis(phenylethynyl)anthracene structural cores were synthesised by palladium-catalysed Suzuki and Sonogashira couplings. These nitroxide-fluorophore probes possess strongly suppressed fluorescence, even in the presence of only one nitroxide radical. Upon reduction, or reaction with other radicals, normal fluorescence emission is returned. The significant difference in fluorescence output between the nitroxides and their corresponding diamagnetic analogues makes these probes ideal tools for imaging polymer degradation using fluorescence microscopy.

Introduction

Nitroxides (aminoxyls) are stable free-radical species which are finding increased use in a wide range of applications. Isoindoline nitroxides possess some advantages over the more common nitroxide-containing piperidine or pyrrolidine units. The fused aromatic moiety imparts rigidity on the ring system, making it less susceptible to ring-opening reactions and providing greater chemical and thermal stability in polymers.[1,2] Electron paramagnetic resonance (EPR) linewidths for isoindoline nitroxides are also often narrower,[3] leading to increased accuracy in EPR oximetry. In addition, substitution onto the aromatic ring of the isoindoline system facilitates the synthesis of more complex structures for a variety of applications with little impact on the reactivity or stability of the nitroxide moiety.[4]

One common use for nitroxides is as sensitive probes for the study of processes involving reactive free radical species. Profluorescent nitroxides, which consist of a fluorophore joined to a nitroxide moiety by a short covalent link, are efficient quenchers of excited electronic states. As many intermolecular quenching mechanisms rely on chance collisions between an excited molecule and the nitroxide radical, the linking together of these moieties increases the rate of interaction which subsequently enhances the efficacy of fluorescence quenching. Work by Blough[5–10] and Scaiano[11–13] has shown that fluorescence is significantly reduced in the presence of a nitroxide radical. Following radical trapping or redox activity, a diamagnetic species is formed and normal fluorescence emission is restored. Thus, nitroxide-fluorophore species have been utilized as very sensitive probes for the detection of free-radical species.

Most of the nitroxide-fluorophore adducts synthesized to date possess potentially labile linkages such as esters,[5–7,11,14–18] amides[19–21] or sulfonamides.[22–25] Cleavage of the nitroxide moiety from the fluorophore restores fluorescence independently from the radical reactions of the nitroxide. Our group has focused on the synthesis of profluorescent nitroxides based on low reactivity, carbon atom-only, extended aromatic frameworks. We have reported the formation of an isoindoline nitroxide bearing a stilbene fluorophore[26] and have also prepared an azaphenalene-based profluorescent nitroxide.[27] Both of these fluorophore-nitroxide adducts exhibit increased fluorescence following free-radical trapping to form an alkoxyamine. Furthermore, we have reported the use of the novel profluorescent nitroxide 1,1,3,3-tetramethyldibenzo[*e*,*g*]isoindolin-2-yloxyl (TMDBIO) as a probe for monitoring the thermo-oxidative degradation of polypropylene.[28–30] This probe, which contains a phenanthrene fluorophore covalently fused to a five-membered nitroxide-containing ring, allows the detection by spectrofluorimetry of free radicals formed during the "induction period" of polypropylene degradation.

In order to further expand the potential of the profluorescent nitroxide technique to image polymer degradation using fluorescence microscopy, we desired access to nitroxide-fluorophore probes possessing very high (masked) quantum yields for maximum sensitivity for radical detection as well as excitation and emission profiles at longer wavelengths outside the absorption bands of typical organic chromophores.[31] Herein, we describe the synthesis and

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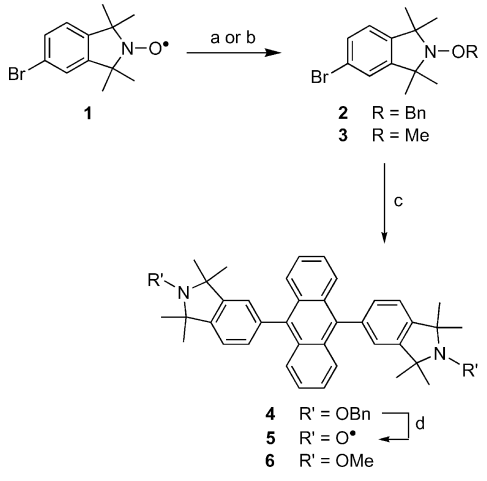
physical properties of new profluorescent mono- and di-isoindoline nitroxides bearing the highly fluorescent cores of 9,10-diphenylanthracene and 9,10-bis(phenylethynyl)anthracene. In addition, we examine the influence of either one or two nitroxide radicals on fluorescence suppression.

Results and Discussion

Synthesis

It was initally envisaged that the diphenylanthracene-based di-nitroxide target molecule, 9,10-bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (BTMIOA) (**5**), could be prepared by reaction of anthraquinone with a lithiated, protected nitroxide, followed by in situ reduction of the resulting diol.[32] Thus, 5-bromo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**1**) was protected by reduction with phenylhydrazine in the presence of benzyl chloride and potassium *tert*-butoxide to give the corresponding benzyloxyamine **2** in reasonable yield (60%) (Scheme 1). Lithiation of **2**, reaction with anthraquinone and reduction by tin(II) chloride gave the desired 9,10-bis(2-benzyloxy-1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (**4**) in modest yield (36%). The methoxyamine analogue **6** could also be prepared using this methodology in 38% yield from 5-bromo-2-methoxy-1,1,3,3-tetramethylisoindoline (**3**) and anthraquinone. Subsequent debenzylation of **4** proved problematic on a preparative scale, due to a lack of solubility. A saturated solution of **4** in acetic acid (≈ 0.14 mM) underwent catalytic hydrogenation to furnish BTMIOA **5** in moderate yield (52%). Other methods for the preparative debenzylation of **4**, such as oxidative cleavage with DDQ,[33] exposure to boron tribromide[34] or acidic cleavage with methanesulfonic acid,[35] did not provide the required deprotected product. In an attempt to improve the yield, the Suzuki–Miyaura cross-coupling reaction[36–38] was explored as an alternative synthetic route for the synthesis of BTMIOA **5**.

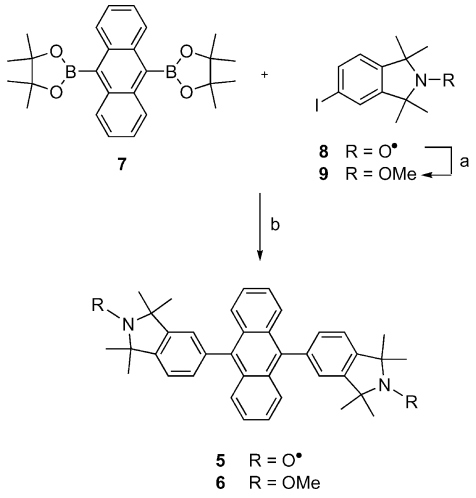


Scheme 1. Reagents and conditions: for **2**: (a) BnCl, $PhNHNH_2$, *t*BuOK, THF, 60%; for **3**: (b) H_2O_2, $FeSO_4.7H_2O$, DMSO, 20 min, 67%; (c) (i) *n*BuLi, THF, –78 °C, (ii) anthraquinone, THF, –78 °C to room temp. (iii) $SnCl_2$, AcOH/H_2O, 50 °C, 16 h, for **4**: 36%, for **6**: 38%; (d) (i) Pd/C, AcOH, H_2 (50 psi), 5 h, (ii) PbO_2, 30 min, 52%.

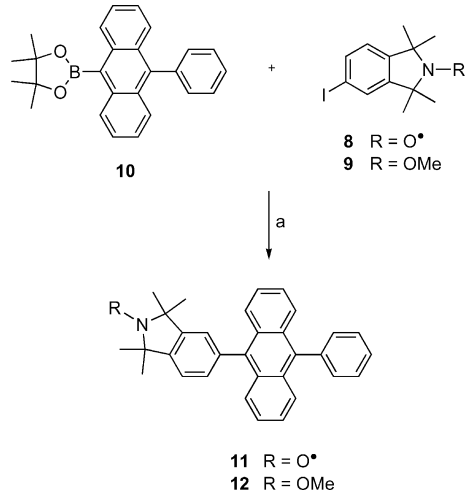
Both Hideg,[39–41] and Mayor[42] have shown that Suzuki couplings can be performed in the presence of a nitroxide moiety. Previous work in our group has shown Heck alkenylations[26] and Sonogashira couplings[43] are possible using the brominated nitroxide **1** but this electron-rich aryl ring exhibits lower reactivity in these palladium-catalysed reactions. Hence, the more reactive iodo-nitroxide, 5-iodo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**8**), was chosen as the coupling partner. The coupling of anthracene-9,10-diboronic acid with **8** under standard Suzuki conditions [$Pd(PPh_3)_4$, Na_2CO_3, THF/H_2O] gave BTMIOA **5** in 29% yield after heating at 80 °C for 72 h. Under the same conditions, the methoxyamine analogue, 9,10-bis(2-methoxy-1,1,3,3-tetramethylisoindolin-5-yl)anthracene (**6**) was obtained in somewhat increased yield (43%), following the reaction of anthracene-9,10-diboronic acid with the iodomethoxyamine, 5-iodo-2-methoxy-1,1,3,3-tetramethylisoindoline (**9**). This methoxyamine was prepared using Fenton chemistry by the reaction of 5-iodo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**8**) with methyl radicals generated from dimethyl sulfoxide, ferrous ions and hydrogen peroxide. In an effort to improve these yields, 9,10-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)anthracene (**7**) was employed as a coupling partner in the Suzuki reaction as pinacolate boronic ester derivatives are purported to promote multiple couplings with aryl iodides.[44] Coupling of **7** with iodo nitroxide **8** under aprotic conditions utilising $Pd(PPh_3)_4$ and silver carbonate in THF, furnished the desired product **5** in an improved (47%) yield. However, the coupling of **7** with **8** under standard Suzuki conditions [$Pd(PPh_3)_4$, Na_2CO_3, THF/H_2O] gave BTMIOA **5** in a better yield of 57% (Scheme 2). The yield of the methoxyamine analogue **6** could also be increased to 74% when 9,10-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)anthracene (**7**) was treated with the iodomethoxyamine **9** under standard Suzuki conditions [$Pd(PPh_3)_4$, Na_2CO_3, THF/H_2O] (Scheme 2).

In addition to preparing a diphenylanthracene-based di-nitroxide, we sought to synthesise the mono-nitroxide analogue, 10-phenyl-9-(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (**11**), in order to explore the impact of the number of nitroxides on fluorescence suppression. Reaction of 4,4,5,5-tetramethyl-2-(10-phenylanthracen-9-yl)dioxaborolane (**10**) with iodo nitroxide **8** under standard Suzuki conditions [$Pd(PPh_3)_4$, Na_2CO_3, THF/H_2O] gave the mono-nitroxide **11** in good yield (79%) (Scheme 3). Similarly, the methoxyamine derivative **12** was prepared by Suzuki coupling of **10** with iodo-methoxyamine **9** in high yield (88%) (Scheme 3).

The synthesis of the nitroxide probes containing 9,10-bis(phenylethynyl)anthracene cores was achieved using the Sonogashira cross-coupling reaction.[45–48] Sonogashira reactions in the presence of nitroxides have been detailed in the literature by Hideg,[39] Schiemann[49] and Mayor.[50]

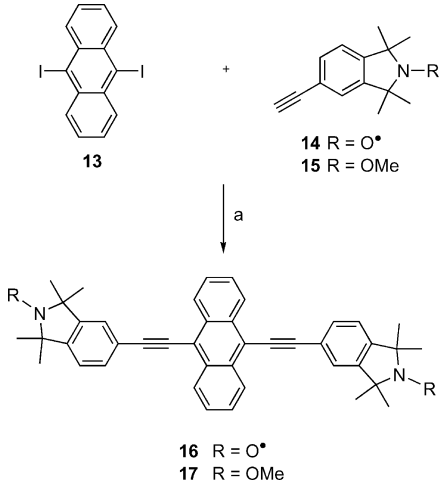


Scheme 2. Reagents and conditions: (a) $Fe_2SO_4.7H_2O$, H_2O_2, DMSO, 15 min, 76%; (b) $Pd(PPh_3)_4$, Na_2CO_3, THF/H_2O, 80 °C (for **5**: 57%, for **6**: 74%).



Scheme 3. Reagents and conditions: (a) $Pd(PPh_3)_4$, Na_2CO_3, THF/H_2O, 80 °C, 3 d, (for **11**: 79%, for **12**: 88%).

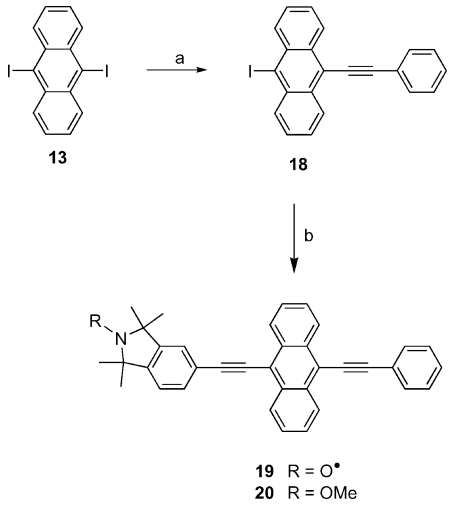
More recently, we have reported the copper-free Sonogashira coupling of isoindoline nitroxides to generate profluorescent acetylene-linked probes.[43] Interestingly, in our hands, standard Sonogashira conditions [CuI, $PdCl_2(PPh_3)_2$, Et_3N] gave none of the desired acetylene-linked products when the bromo nitroxide **1** was treated with (trimethylsilyl)acetylene or phenylacetylene. As the presence of CuI is known to hinder the Sonogashira cross coupling of less active aryl halides[51] (by promoting the homocoupling of the acetylene compounds), we initially chose to employ the more successful copper-free methodology originally reported by Li,[51] for the synthesis of probes possessing 9,10-bis(phenylethynyl)anthracene cores. Reaction of 9,10-diiodoanthracene (**13**) with 3 equiv. of the acetylene nitroxide **14** in the presence of DABCO and $Pd(OAc)_2$ gave the desired compound, 9,10-bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-ethynyl)anthracene (**16**), in an isolated yield of 15% after heating at 80 °C for 1 h (all alkyne nitroxide **14** consumed according to TLC). Repeating the reaction in solvents in which 9,10-diiodoanthracene (**13**) is more soluble, such as THF (16% isolated yield) and toluene (21% isolated yield), did not substantially improve the production of **16**. The low yield of the reaction reflects the competing homocoupling of the acetylene nitroxide **14**. However, the yield could be improved to 57% when a larger excess of acetylene nitroxide **14** (5 equiv.) was employed. For comparison, we attempted to prepare **16** using standard Sonogashira conditions [CuI, $PdCl_2(PPh_3)_2$, Et_3N]. Coupling of 9,10-diiodoanthracene (**13**) and the acetylene nitroxide **14** (3 equiv.) gave the desired bis-coupled product **16** in 41% yield after refluxing for 16 h. Under identical conditions, **16** was obtained in a good yield (67%) when a larger excess (5 equiv.) of **14** was used (Scheme 4). Thus, standard Sonogashira coupling can be achieved when the isoindoline nitroxide bears the alkyne moiety (and not the aryl halide moiety). The methoxyamine analogue, 9,10-bis(2-methoxy-1,1,3,3-tetramethylisoindolin-5-ethynyl)anthracene (**17**), was obtained in modest yield (37%), following reaction of acetylene methoxyamine **15** (3 equiv.) with 9,10-diiodoanthracene (**13**) under copper-free Sonogashira conditions [DABCO, $Pd(OAc)_2$, MeCN]. Alternatively, the desired methoxyamine **17** could be synthesised via a standard Sonogashira coupling reaction [CuI, $PdCl_2(PPh_3)_2$, Et_3N] using 5 equiv. of **15** in excellent yield (98%) (Scheme 4).



Scheme 4. Reagents and conditions: (a) CuI, $PdCl_2(PPh_3)_2$, Et_3N, 85 °C, 16 h, (for **16**: 67%, for **17**: 98%).

To aid our fluorescence suppression investigations, we also wished to synthesise the mono-nitroxide analogue, 10-(phenylethynyl)-9-(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-ethynyl)-anthracene (**19**). Pd/Cu-catalysed cross-coupling of phenylacetylene (0.33 equiv.) and 9,10-diiodoanthracene (**13**), following the procedure of Mårtensson,[52] furnished 10-iodo-9-phenylethynyl-anthracene (**18**) in 27% yield (Scheme 5). Subequent coupling of **18** and acetylene nitroxide **14** using standard Sonogashira conditions [CuI, $PdCl_2(PPh_3)_2$, Et_3N] produced the required mono-nitroxide

19 in good yield (63%) (Scheme 5). The copper-free Sonogashira methodology [DABCO, $Pd(OAc)_2$, MeCN] gave the desired product **19** in 46% yield. The methoxyamine derivative, 9-(2-methoxy-1,1,3,3-tetramethylisoindolin-5-ethynyl)-10-(phenylethynyl)anthracene (**20**), was prepared in good yield (78%) via the Cu/Pd-catalysed coupling of 10-iodo-9-(phenylethynyl)anthracene (**18**) and the alkyne **15** (Scheme 5).



Scheme 5. Reagents and conditions: (a) phenylacetylene, $Pd(PPh_3)_4$, CuI, Et_3N, 85 °C, 16 h, 27%; (b) 5-ethynyl-1,1,3,3-tetramethylisoindolin-2-yloxyl **14** or 5-ethynyl-2-methoxy-1,1,3,3-tetramethylisoindoline **15**, CuI, $PdCl_2(PPh_3)_2$, Et_3N, 85 °C, 16 h (for **19**: 63%, for **20**: 78%).

Table 1. Extinction coefficients and quantum yields for synthesised mono- and di-nitroxide probes and their methoxyamine adducts.

Compound	Extinction coefficient [$M^{-1}\,cm^{-1}$]	Quantum yield [Φ_F]
5	14 500[a]	0.0029[c]
6	13 740[a]	0.89[c]
11	17 060[a]	0.023[c]
12	17 380[a]	0.85[c]
16	29 030[b]	0.022[d]
17	31 320[b]	0.93[d]
19	29 640[b]	0.04[d]
20	27 450[b]	0.95[d]

[a] Measured in cyclohexane at 375 nm. [b] Measured in cyclohexane at 430 nm. [c] Measured in cyclohexane using 9,10-diphenylanthracene as standard (375 nm excitation). [d] Measured in cyclohexane using 9,10-bis(phenylethynyl)anthracene as standard (430 nm excitation).

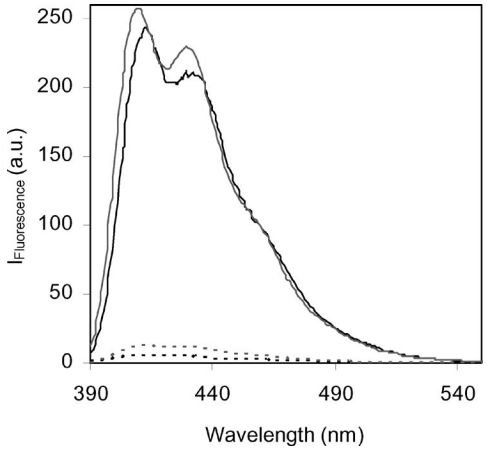


Figure 1. Fluorescence spectra of 9,10-diphenylanthracene-based probes **5** (···), **6** (–), **11** (···) and **12** (–), 2.5 μM in cyclohexane, following excitation at 375 nm.

Physical Properties

With the new profluorescent nitroxide probes (**5**, **11**, **16** and **19**) and their corresponding methoxyamine adducts (**6**, **12**, **17** and **20**) in hand, we examined their physical properties. The 9,10-diphenylanthracene-based compounds **5**, **6**, **11** and **12** displayed absorbance spectra and extinction coefficients characteristic of their parent compound, 9,10-diphenylanthracene (Table 1). A comparison of the fluorescence of the di-nitroxide **5** and its methoxyamine analogue **6** revealed a substantial fluorescence suppression arising from the presence of the two nitroxides (Figure 1). This effect was confirmed by the measured quantum yields (Φ_F) of 0.0029 and 0.89 for compounds **5** and **6** respectively (Table 1). Interestingly, the mono-nitroxide analogue **11** also demonstrated strongly suppressed fluorescence due to quenching by the single nitroxide group (Figure 1). This observation was evident from the quantum yields (Φ_F) of 0.023 and 0.85 obtained for compounds **11** and **12** respectively.

The compounds possessing 9,10-bis(phenylethynyl)anthracene cores (**16**, **17**, **19** and **20**) exhibited absorbance spectra and extinction coefficients reflecting the parent structure, 9,10-bis(phenylethynyl)anthracene (Table 1). Examination of the fluorescence of di-nitroxide **16** and its corresponding methoxyamine adduct **17** again showed a substantial quenching of fluorescence (Figure 2). Quantum yield measurements of 0.022 and 0.93 for compounds **16** and **17**, respectively, provided further evidence for this effect. The mono-nitroxide derivative **19** was also capable of strongly suppressing fluorescence (Figure 2) with quantum yields of 0.04 and 0.95 obtained for compounds **19** and **20** respectively (Table 1).

The fluorescence profile from our preliminary work on the use of BTMIOA **5** as a probe for mapping the early stages of polypropylene degradation suggested that the trapping of alkyl radicals occurs in two stages involving sequential trapping of the two nitroxides.[31] To further explore the significant fluorescence quenching observed in the presence of only one nitroxide radical and to examine radical trapping in solution, di-nitroxide **5** was titrated with methyl radicals [generated using Fenton chemistry from the reaction of hydrogen peroxide with iron(II) sulfate heptahydrate and DMSO]. Hydrogen peroxide was added portionwise (0.88 equiv. at a time) to a DMSO solution containing **5** and iron(II) sulfate heptahydrate. Aliquots of the

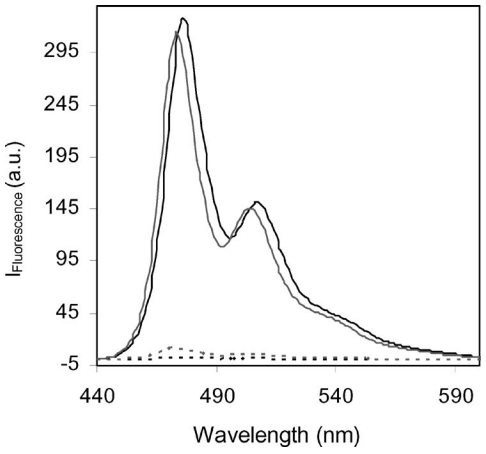


Figure 2. Fluorescence spectra of 9,10-bis(phenylethynyl)anthracene-based probes **16** (···), **17** (–), **19** (···) and **20** (–), 2.5 μM in cyclohexane, following excitation at 430 nm.

reaction mixture were removed every 10 min and another portion of hydrogen peroxide (0.88 equiv.) added. The aliquots were analysed by spectrofluorimetry (Figure 3) and analytical HPLC (see Figures 4 and 5). The HPLC traces and plot of integrated peak areas show the consumption of di-nitroxide **5** and formation of mono-methyl trapped species **21** (Figure 6) and di-methyl trapped product **6**. Initially, **21** is formed in higher proportions than **6**, due to the random nature of the radical trapping. This observation is reflected in the fluorescence trace which shows a small lag at the beginning (as the mono-trapped species **21** displays low fluorescence – as shown for compound **11**) before the fluorescence increases steadily with the conversion of **21** to the highly fluorescent compound **6**. Thus, in contrast to a polymer system in which radical trapping appeared to occur sequentially, in solution the radical trapping of di-nitroxide **5** occurs randomly as the nitroxide probe is not constrained within a polymer matrix.

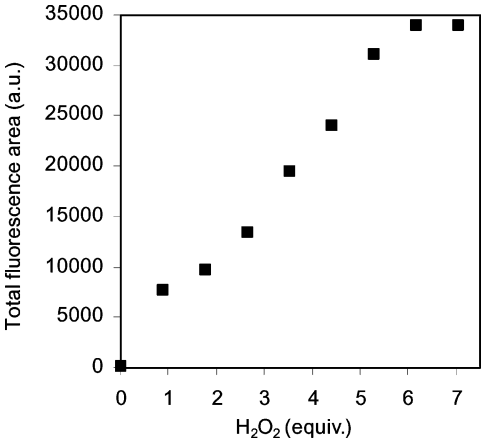


Figure 3. Fluorescence emission in THF from the titration of BTMIOA **5** with methyl radicals (375 nm excitation).

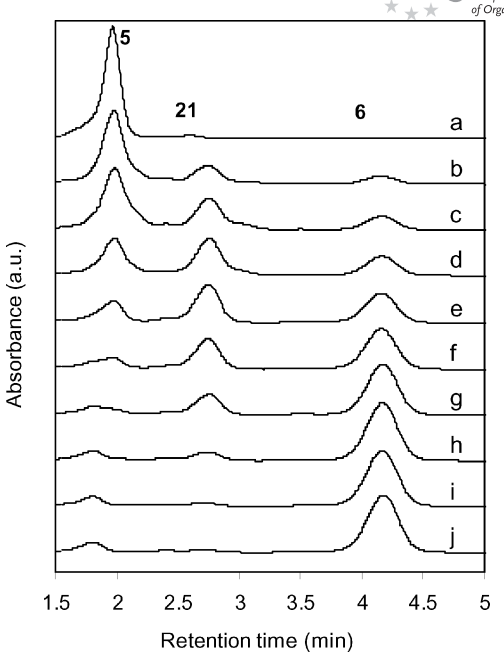


Figure 4. Analytical HPLC traces following the titration of **5** with methyl radicals (formed by the addition of H_2O_2 into a DMSO solution containing $FeSO_4 \cdot 7H_2O$); (a) 0 equiv. H_2O_2, (b) 0.88 equiv. H_2O_2, (c) 1.76 equiv. H_2O_2, (d) 2.64 equiv. H_2O_2, (e) 3.52 equiv. H_2O_2, (f) 4.4 equiv. H_2O_2, (g) 5.28 equiv. H_2O_2, (h) 6.16 equiv. H_2O_2, (i) 7.04 equiv. H_2O_2, (j) 7.92 equiv. H_2O_2.

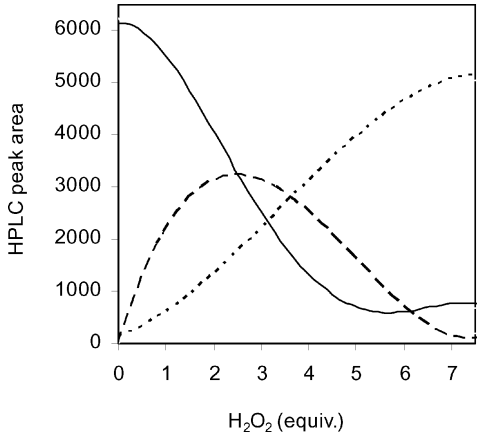


Figure 5. The change in concentration of **5** (——), **21** (– – –) and **6** (· · ·) with increasing addition of H_2O_2, as **5** is titrated with methyl radicals.

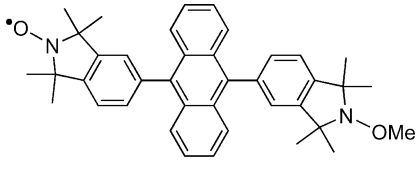


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Figure 6. Monomethyl-trapped compound **21**.

Conclusions

Novel profluoroescent mono- and di-isoindoline nitroxides possessing highly (masked) quantum yields were synthesised using palladium-catalysed couplings. 9,10-Diphenylanthracene based probes (**5** and **11**) and their respective methoxyamine adducts (**6** and **12**) were synthesised via Suzuki coupling reactions. The best yields (57–88%) were obtained when iodo-nitroxide **8** or iodo methoxyamine **9** and the corresponding anthracene pinacol boronate were utilised. Probes possessing 9,10-bis(phenylethynyl)anthracene cores (**16** and **19**) and their methoxyamine derivatives (**17** and **20**) were obtained through the Sonogashira coupling of acetylene nitroxide **14** or acetylene methoxyamine **15** and the corresponding iodinated anthracene. Couplings employing standard Sonogashira conditions [CuI, $PdCl_2(PPh_3)_2$, Et_3N] gave the highest yields (63–98%). Examination of the fluorescent properties of the prepared compounds revealed a substantial suppression of fluorescence for the nitroxide containing probes, even in the presence of only one nitroxide radical. Upon radical trapping to form methoxyamines, the fluorescence of the high emission fluorophores was restored. Titration of the di-nitroxide **5** with methyl radicals revealed that in solution, radical trapping occurs randomly. The use of these novel nitroxide probes as tools for imaging polymer degradation in polypropylene and other polymer systems is currently under investigation.

Experimental Section

General Methods: All air-sensitive reactions were carried out under ultra-high purity argon. Tetrahydrofuran (THF) was freshly distilled from sodium benzophenone ketal, and acetonitrile distilled from calcium hydride. Toluene was dried by storage over sodium wire and triethylamine by storage over potassium hydroxide. Tetrakis(triphenylphosphane)palladium(0) was prepared freshly using literature methods.[53] Anthracene-9,10-diboronic acid,[54] 9,10-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)anthracene[55] (**7**), 5-iodo-1,1,3,3-tetramethylisoindolin-2-yloxyl[31] (**8**), 5-iodo-2-methoxy-1,1,3,3-tetramethylisoindoline[31] (**9**), 5-ethynyl-1,1,3,3-tetramethylisoindolin-2-yloxyl[43] (**14**) and 5-ethynyl-2-methoxy-1,1,3,3-tetramethylisoindoline[43] (**15**), 4,4,5,5-tetramethyl-2-(10-phenylanthracen-9-yl)-dioxaborolane[55] (**10**), 9,10-diiodoanthracene[56] (**13**) and 9-phenylethynyl-10-iodoanthracene[52] (**18**) were synthesised using established literature procedures. All other reagents were purchased from commercial suppliers and used without further purification. ^1H and ^{13}C NMR spectra were recorded with a Bruker Avance 400 spectrometer and referenced to the relevant solvent peak. Low and high resolution mass spectra were recorded at the Australian National University (ANU) using either a Micromass autospec double focusing magnetic sector mass spectrometer (EI+ spectra) or a Bruker Apex 3 fourier transform ion cyclotron resonance mass spectrometer with a 4.7-T magnet (ESI+ spectra). Formulations were calculated in the elemental analysis programs of Mass Lynx 4.0 or Micromass Opus 3.6. Fourier transform infrared (FTIR) spectra were recorded with a Nicolet 870 Nexus Fourier Transform Infrared Spectrometer equipped with a DTGS TEC detector and an ATR objective. Elemental analyses were carried out by the University of Queensland Microanalytical Service. Melting points were measured with a Gallenkamp variable-temperature apparatus by the capillary method and are uncorrected. Analytical HPLC was carried out with an Agilent Technologies HP 1100 Series HPLC system using an Agilent Prep-C18 scalar column (4.6×150 mm, 10 μm) with a flow rate of 1 mL/min. Spectrofluorimetry was undertaken with a Varian Cary Eclipse fluorescence spectrophotometer. UV/Vis spectroscopy was performed with a Varian Cary 50 spectrophotometer.

2-Benzyloxy-5-bromo-1,1,3,3-tetramethylisoindoline (2): 5-Bromo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**1**, 0.60 g, 2.30 mmol) was dissolved in dry THF (20 mL) under argon. Following the addition of benzyl chloride (1.74 g, 1.58 mL, 13.80 mmol), phenylhydrazine (0.25 g, 0.22 mL, 2.30 mmol) was added slowly. After stirring for 5 min at room temperature, potassium *tert*-butoxide (0.52 g, 4.60 mmol) was added. The solution was left to stir for 2 h and then diluted with diethyl ether (40 mL). The reaction mixture was washed with water (2×50 mL) and brine (2×50 mL). The organic phase was dried (anhydrous $NaSO_4$) and concentrated at reduced pressure. The obtained residue was submitted to silica column chromatography (eluent 30% DCM, 70% hexane) to yield **2** as a colourless oil (500 mg, 60%). IR (ATR): $\tilde{\nu}$ = 2973 and 2928 (alkyl CH_3), 1479 and 1453 (aryl C–C), 1025 (O–CH_2), 694 cm^{-1}. (C-Br). ^1H NMR (400 MHz, $CDCl_3$): δ = 1.45 (br. s, 12 H, $4 \times CH_3$), 4.96 (s, 2 H, CH_2), 6.99 (d, J = 8.05 Hz, 1 H, 7-H), 7.25 (d, J = 1.84 Hz, 1 H, 4-H), 7.31–7.46 (m, 6 H, 6-H and Ar-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.1 (br., CH_3), 29.8 (br., CH_3), 67.36 (C), 67.44 (C), 79.5 (CH_2), 120.8 (C), 123.3 (CH), 124.8 (CH), 127.8 (CH), 128.3 (CH), 128.4 (CH), 130.3 (CH), 138.0 (C), 144.0 (C), 147.3 (C) ppm. MS (EI): *m/z* (%) = 359/361 (5) [M^+], 344/346 (10), 329/331 (25), 314/316 (≈ 1). HRMS: calcd. for $C_{19}H_{22}{}^{81}BrNO$ [M^+] 361.0864; found 361.0854. HRMS: calcd. for $C_{19}H_{22}{}^{79}BrNO$ [M^+] 359.0885; found 359.0880. $C_{19}H_{22}BrNO$ (359.09/361.09): calcd. C 63.34, H 6.15, N 3.89; found C 63.29, H 6.09, N 3.85.

9,10-Bis(2-benzyloxy-1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (4): *n*-Butyllithium (1.60 M in hexanes, 1.25 mL, 2.00 mmol) was added to a solution of 2-benzyloxy-5-bromo-1,1,3,3-tetramethylisoindoline (**2**) (0.60 g, 1.67 mmol) in dry THF (8 mL) at –78 °C under argon. The solution was stirred for 10 min and then transferred via syringe to a stirring suspension of anthraquinone (0.14 g, 0.71 mmol) in dry THF (18 mL) at –78 °C under argon. The cold bath was removed and the solution stirred for 2 h. The reaction mixture was treated with water/acetic acid (1:1, 18 mL) and tin(II) chloride dihydrate (5.58 g, 24.80 mmol) and heated at 50 °C for 16 h. The resultant yellow solution was concentrated in vacuo, then a mixture of chloroform and water (1:1, 60 mL) was added. The chloroform layer was removed and the aqueous phase washed with chloroform (3×30 mL). The combined organic phases were washed with water (3×30 mL), dried (anhydrous $NaSO_4$) and concentrated in vacuo. The resulting residue was purified by silica column chromatography (eluent 30% DCM, 70% hexane) to give **4** as a chalky white solid (190 mg, 36%). M.p. 274–276 °C. IR (ATR): $\tilde{\nu}$ = 2970 and 2924 (alkyl CH_3), 1495 and 1453 (aryl C–C), 1025 (O–CH_2) cm^{-1}. ^1H NMR (400 MHz. $CDCl_3$): δ = 1.53 (br. s, 12 H, $4 \times CH_3$), 1.63 (br. s, 12 H, $4 \times CH_3$), 5.07 (s, 4 H, $2 \times CH_2$), 7.21 (d, J = 10.0 Hz, 2 H, 7-H), 7.33–7.52 (m, 18 H, Ar-H), 7.62 (dd, J = 6.9, 3.0 Hz, 4 H, Ar-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.6 (br., CH_3), 29.9 (br., CH_3), 67.49 (C), 67.51 (C), 79.7 (CH_2), 121.4 (CH), 124.5 (CH), 125.0 (CH), 127.0 (CH), 127.7 (CH), 128.3 (CH), 128.5 (CH), 130.0 (CH), 130.2 (C), 137.4 (C), 137.9 (C), 138.4 (C), 144.3 (C), 145.4 (C) ppm. MS (ES): *m/z* (%) = 737 (2) [MH^+]. HRMS: calcd. for $C_{52}H_{53}N_2O_2$ [MH^+] 737.4107; found 737.4078.

9,10-Bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (5) from Anthraquinone: 9,10-Bis(2-benzyloxy-1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (**4**) (0.01 g, 0.014 mmol) was dissolved in glacial acetic acid (10 mL) and palladium on carbon (10 wt.-% loading, 0.01 g) added. The solution was placed in a Parr hydrogenator under hydrogen (50 psi) with shaking for 5 h. The resulting suspension was filtered through Celite and the Celite washed thoroughly with acetic acid. The combined filtrates were concentrated in vacuo and the residue taken up in chloroform (10 mL) and washed with sodium hydrogen carbonate (saturated aqueous solution, 3 × 10 mL). The organic layer was dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification of the resulting residue by silica gel chromatography (eluent 100% chloroform) gave **5** as a cream coloured powder (4 mg, 52%). M.p. 312–315 °C (dec.). IR (ATR): $\tilde{\nu}$ = 2970 and 2924 (alkyl CH), 1494 and 1451 (aryl C–C), 1437 (N–O) cm^{-1}.[57] MS (EI): *m*/*z* (%) = 554 (10) [M^+]. HRMS: calcd. for $C_{38}H_{38}N_2O_2$ [M^+] 554.2933; found 554.2936. $C_{38}H_{38}N_2O_2 \cdot H_2O$ (572.30): calcd. C 79.69, H 7.04, N 4.89; found C 79.84, H 6.99, N 4.83.

5-Bromo-2-methoxy-1,1,3,3-tetramethylisoindoline (3): Hydrogen peroxide solution (30%, 0.17 mL) was added dropwise to a solution of 5-bromo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**1**) (0.20 g, 0.74 mmol) and iron(II) sulfate heptahydrate (0.42 g, 1.50 mmol) in DMSO (5 mL). The resulting solution was stirred at room temperature for 20 min and then poured into aqueous sodium hydroxide (1 M, 200 mL). The mixture was extracted with diethyl ether (3 × 150 mL) and the combined organic layers dried (anhydrous Na_2SO_4) and concentrated in vacuo. Purification by silica column chromatography (eluent 10% ethyl acetate, 90% hexane) gave **3** as a pale yellow oil (140 mg, 67%). IR (ATR): $\tilde{\nu}$ = 2974 and 2932 (alkyl CH_3), 1479 and 1462 (aryl C–C), 1050 (O–CH_2), 640 (C–Br) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 1.42 (br. s, 12 H, 4 × CH_3), 3.78 (s, 3 H, CH_3), 6.98 (d, *J* = 8.05 Hz, 1 H, 7-H), 7.23 (d, *J* = 1.84 Hz, 1 H, 4-H), 7.35 (dd, *J* = 8.05, 1.87 Hz, 1 H, 6-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 24.9 (br., CH_3), 29.7 (br., CH_3), 65.5 (CH_3), 67.0 (C), 67.1 (C), 120.7 (C), 123.3 (CH), 124.8 (CH), 130.3 (CH), 144.2 (C), 147.4 (C) ppm. MS (EI): *m*/*z* (%) = 283/285 (7) [M^+], 268/270 (100), 253/255 (5), 238/240 (7). HRMS: calcd. for $C_{13}H_{18}{}^{79}BrNO$ [M^+] 283.0572; found 283.0567. HRMS: calcd. for $C_{13}H_{18}{}^{81}BrNO$ [M^+] 285.0551; found 285.0544.

9,10-Bis(2-methoxy-1,1,3,3-tetramethylisoindolin-5-yl)anthracene (6) from Anthraquinone: *n*-Butyllithium (1.60 M in hexanes, 0.67 mL, 1.07 mmol) was added to a solution of 5-bromo-2-methoxy-1,1,3,3-tetramethylisoindoline (**3**) (0.20 g, 0.71 mmol) in dry THF (2 mL) at –78 °C under an atmosphere of argon. The solution was stirred for 10 min and then transferred via syringe to a stirring suspension of anthraquinone (0.037 g, 0.18 mmol) in dry THF (5 mL) at –78 °C under argon. The cold bath was removed and the reaction mixture was treated with water/acetic acid (1:1, 7 mL) and tin(II) chloride dihydrate (1.42 g, 6.30 mmol) and heated at 50 °C for 5 h. The yellow solution was concentrated in vacuo and then a mixture of chloroform and water (1:1, 20 mL) was added. The chloroform layer was removed and the aqueous phase washed with chloroform (3 × 10 mL). The combined chloroform phases were washed with water (3 × 20 mL), dried (anhydrous Na_2SO_4) and concentrated in vacuo. The resulting residue was purified by silica column chromatography (eluent 30% DCM, 70% hexane) to give **6** as a white solid (190 mg, 36%). M.p. >300 °C (dec). IR (ATR): $\tilde{\nu}$ = 2971 and 2930 (alkyl CH), 1461 and 1438 (aryl C–C), 1052 (C–O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 1.51 (br. s, 12 H, 4 × CH_3), 1.61 (br. s, 12 H, 4 × CH_3), 3.89 (s, 6 H, 2 × CH_3), 7.21 (d, *J* = 10.1 Hz, 2 H, 7-H), 7.32–7.38 (m, 8 H, Ar-H), 7.72 (dd, *J* = 6.8, 3.2 Hz, 4 H, Ar-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.0 (br., CH_3), 30.0 (br., CH_3), 65.6 (CH_3), 67.2 (C), 121.4 (CH), 124.4 (CH), 124.9 (CH), 127.0 (CH), 130.0 (CH), 130.2 (C), 137.3 (C), 137.9 (C), 144.3, (C), 145.4 (C) ppm. MS (EI): *m*/*z* (%) = 584 (35) [M^+]. HRMS: calcd. for $C_{40}H_{44}N_2O_2$ [M^+] 584.3403; found 584.3405.

9,10-Bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (5) via Suzuki Coupling: A solution of dry THF (4 mL) containing 9,10-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)anthracene (**7**) (0.16 g, 0.38 mmol), 5-iodo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**8**) (0.29 g, 0.94 mmol), anhydrous sodium carbonate (0.08 g, 0.75 mmol) and water (2 mL) was degassed by subjecting to three freeze-pump-thaw cycles using a JAVAC brand electrically driven oil-pump. Tetrakis(triphenylphosphane)palladium(0) (35.0 mg, 0.03 mmol) was added and the reaction mixture was heated at 80 °C under argon for 2 d. Water (20 mL) was added and the mixture extracted with chloroform (3 × 30 mL). The organic layers were washed with brine (2 × 20 mL), dried (anhydrous Na_2SO_4) and concentrated in vacuo. The resulting residue was purified by silica column chromatography (eluent 100% chloroform) to afford **5** as a cream-coloured solid (120 mg, 57%). The spectroscopic and physical data acquired was consistent with that obtained for a previously synthesised sample of **5**.

9,10-Bis(2-methoxy-1,1,3,3-tetramethylisoindolin-5-yl)anthracene (6) via Suzuki Coupling: A solution of dry THF (3 mL) containing 9,10-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)anthracene (**7**) (0.10 g, 0.23 mmol), 5-iodo-2-methoxy-1,1,3,3-tetramethylisoindoline (**9**) (0.19 g, 0.58 mmol), anhydrous sodium carbonate (49.0 mg, 0.45 mmol) and water (1.25 mL) was degassed using three freeze-pump-thaw cycles. Tetrakis(triphenylphosphane)palladium(0) (21.0 mg, 0.018 mmol) was added and the reaction mixture was heated at 80 °C under argon for 3 d. The solution was cooled, water (20 mL) added and extracted with chloroform (3 × 30 mL). The organic layers were washed with brine (2 × 20 mL), dried (anhydrous Na_2SO_4) and concentrated in vacuo. The resulting residue was purified by silica column chromatography (eluent 30% DCM, 70% hexane) to give **6** as a white solid (100 mg, 74%). The spectroscopic and physical data acquired was consistent with that obtained for a previously synthesised sample of **6**.

10-Phenyl-9-(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (11): A solution containing 5-iodo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**8**) (0.24 g, 0.76 mmol), 4,4,5,5-tetramethyl-2-(10-phenylanthracen-9-yl)dioxaborolane (**10**) (0.24 g, 0.63 mmol) and sodium carbonate (0.08 g, 0.76 mmol) in dry THF (10 mL) and water (5 mL) was prepared under argon. The solution was degassed using three freeze-pump-thaw cycles. Tetrakis(triphenylphosphane)palladium(0) (44 mg, 0.038 mmol) was added and the mixture heated at 80 °C for 3 d. Upon cooling, water (50 mL) was added and the solution was extracted with diethyl ether (4 × 50 mL). The combined ether layers were washed with brine (2 × 100 mL), dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification by silica column chromatography (SiO_2, eluent DCM) and subsequent recrystallisation from DCM/hexane gave the desired compound **11** as yellow needles (220 mg, 79%). M.p. 250–252 °C. IR (ATR): $\tilde{\nu}$ = 2975 and 2925 (alkyl CH), 1495 and 1452 (aryl C–C), 1439 (N–O) cm^{-1}. [57] MS (EI): *m*/*z* (%) = 442 (5) [M^+]. HRMS: calcd. for $C_{32}H_{28}NO$ [M^+] 442.2171; found 442.2172. $C_{32}H_{28}NO$ (442.22): calcd. C 86.84, H 6.38, N 3.16; found C 86.68, H 6.30, N 3.16.

9-(2-Methoxy-1,1,3,3-tetramethylisoindolin-5-yl)-10-phenylanthracene (12): A solution containing 5-iodo-2-methoxy-1,1,3,3-tetramethylisoindoline (**9**) (0.16 g, 0.47 mmol), 4,4,5,5-tetramethyl-2-(10-phenylanthracen-9-yl)-dioxaborolane (**10**) (0.15 g, 0.39 mmol)

and sodium carbonate (0.10 g, 0.94 mmol) in dry THF (6 mL) and water (3 mL) was prepared under argon. The solution was degassed, tetrakis(triphenylphosphane)palladium(0) (28.0 mg, 0.024 mmol) added and the mixture heated at 80 °C for 3 d. Upon cooling, water (30 mL) was added and the mixture was extracted with diethyl ether (4 × 30 mL). The combined ether layers were washed with brine (2 × 50 mL), dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification by silica column chromatography (eluent 30% DCM, 70% hexane, sample loaded in DCM) gave the desired compound **12** as a cream-coloured solid (158 mg, 88%). M.p. 222–224 °C. IR (ATR): $\tilde{\nu}$ = 2975 and 2932 (alkyl CH), 1494 and 1456 (aryl C–C), 1439 (N–O), 1048 (C–O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 1.52 (br. s, 6 H, 2 × CH_3), 1.62 (br. s, 6 H, 2 × CH_3), 3.88 (s, 3 H, CH_3), 7.22 (s, 1 H, 7-H), 7.31–7.38 (m, 6 H, Ar-H), 7.46–7.52 (m, 2 H, Ar-H), 7.54–7.65 (m, 3 H, Ar-H), 7.68–7.75 (m, 4 H, Ar-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.2 (br., CH_3), 29.9 (br., CH_3), 65.5 (CH_3), 67.18 (C), 67.22 (C), 121.4 (CH), 124.4 (CH), 125.0 (CH), 126.9 (CH), 127.0 (CH), 127.4 (CH), 128.4 (CH), 129.9 (C), 130.0 (C), 130.2 (CH), 131.3 (CH), 137.0 (C), 137.4 (C), 137.8 (C), 139.1 (C), 144.3 (C), 145.4 (C) ppm. MS (EI): *m*/*z* (%) = 457 (85) [M^+]. HRMS: calcd. for $C_{33}H_{31}NO$ [M^+] 457.2406; found 457.2407.

9,10-Bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-ethynyl)anthracene (16): A solution of 9,10-diiodoanthracene (**13**) (37.5 mg, 0.088 mmol), bis(triphenylphosphane)palladium(II) dichloride (5 mg, 8.1 mol-%), copper iodide (1.3 mg, 7.8 mol-%) in triethylamine (5 mL) was degassed using three freeze-pump-thaw cycles. 5-Ethynyl-1,1,3,3-tetramethylisoindolin-2-yloxyl (**14**) (0.09 g, 0.43 mmol) was then added and the mixture heated at 85 °C for 16 h. The solvent was removed in vacuo and the resulting residue dissolved in DCM (50 mL). washed with water (2 × 50 mL) and brine (2 × 50 mL), dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification by silica column chromatography (eluent 20% EtOAc, 80% hexane, sample dry-loaded from DCM) afforded 9,10-bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-ethynyl)-anthracene (**16**) as a yellow solid (35 mg, 67%). M.p. 250 °C (dec). IR (ATR): $\tilde{\nu}$ = 2971 and 2926 (alkyl CH), 2195 (C≡C), 1489 and 1452 (aryl C–C), 1436 (N–O) cm^{-1}.[57] MS (ES): *m*/*z* (%) = 603 (40) [MH^+]. HRMS: calcd. for $C_{33}H_{32}NO$ [MH^+] 603.3016; found 603.2991.

9,10-Bis(2-methoxy-1,1,3,3-tetramethylisoindolin-5-ethynyl)anthracene (17): A solution of 9,10-diiodoanthracene (**13**) (38.5 mg, 0.09 mmol), bis(triphenylphosphane)palladium(II) dichloride (5.1 mg, 8.1 mol-%), copper iodide (1.4 mg, 8.1 mol-%) in triethylamine (5.1 mL) was degassed using three freeze-pump-thaw cycles. 5-Ethynyl-2-methoxy-1,1,3,3-tetramethylisoindoline (**15**) (0.1 g, 0.44 mmol) (0.09 g, 0.43 mmol) was then added and the mixture heated at 85 °C for 16 h. The solvent was removed in vacuo and the resulting residue dissolved in DCM (70 mL). washed with water (2 × 70 mL) and brine (2 × 70 mL), dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification by silica column chromatography (eluent 5% EtOAc, 95% hexane, sample dry-loaded from DCM) gave 9,10-bis(2-methoxy-1,1,3,3-tetramethylisoindolin-5-ethynyl)anthracene (**17**) as a yellow solid (55 mg, 98%). M.p. 248–252 °C. IR (ATR): $\tilde{\nu}$ = 2958 and 2925 (alkyl CH), 2199 (C≡C), 1488 and 1455 (aryl C–C), 1042 (C–O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 1.57 (s, 24 H, 8 × CH_3), 3.83 (s, 6 H, 2 × CH_3), 7.2 (d, *J* = 7.8 Hz, 2 H, 7-H), 7.5 (d, *J* = 0.94 Hz, 2 H, 4-H), 7.62–7.78 (m, 6 H, Ar-H), 8.7 (dd, *J* = 6.6, 3.3 Hz, 4 H, Ar-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.0 (br., CH_3), 29.8 (br., CH_3), 65.5 (CH_3), 67.13 (C), 67.22 (C), 85.8 (C≡), 102.7 (C≡), 118.5 (C), 121.8 (CH), 122.1 (C), 124.8 (CH), 126.8 (CH), 127.3 (CH), 131.0 (CH), 132.1 (C), 145.8 (C), 146.2 (C) ppm. MS (ES): *m*/*z* (%) = 633 (60) [MH^+]. HRMS: calcd. for $C_{44}H_{45}N_2O_2$ [MH^+] 633.3481; found 633.3490.

10-(Phenylethynyl)-9-(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-ethynyl)anthracene (19): A solution of 10-iodo-9-(phenylethynyl)anthracene (**18**) (30 mg, 0.074 mmol), bis(triphenylphosphane)palladium(II) dichloride (3.2 mg, 6.2 mol-%), copper iodide (0.86 mg, 6.1 mol-%) in triethylamine (5 mL) was degassed using three freeze-pump-thaw cycles. 5-Ethynyl-1,1,3,3-tetramethylisoindolin-2-yloxyl (**14**) (41 mg, 0.19 mmol) was then added and the mixture heated at 85 °C for 16 h. The solvent was removed in vacuo and the resulting residue dissolved in DCM (50 mL), washed with water (2 × 50 mL) and brine (2 × 50 mL), dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification by silica column chromatography (eluent 20% EtOAc, 80% hexane, sample dry-loaded from DCM) and subsequent recrystallisation from DCM/hexane gave 10-(phenylethynyl)-9-(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-ethynyl)anthracene (**19**) as orange needles (23 mg, 63%). M.p. 190–193 °C. IR (ATR): $\tilde{\nu}$ = 2920 and 2851 (alkyl CH), 2190 (C≡C), 1490 and 1459 (aryl C–C), 1435 (N–O) cm^{-1}.[57] MS (EI): *m*/*z* (%) = 490 (20) [M^+]. HRMS: calcd. for $C_{36}H_{28}NO$ [M^+] 490.2171; found 490.2170. $C_{36}H_{28}NO$ (490.22): calcd. C 88.13, H 5.75, N 2.85; found C 88.11, H 5.39, N 2.85.

9-(2-Methoxy-1,1,3,3-tetramethylisoindolin-5-ethynyl)-10-(phenylethynyl)anthracene (20): A solution of 10-iodo-9-(phenylethynyl)anthracene (**18**) (53 mg, 0.13 mmol), bis(triphenylphosphane)palladium(II) dichloride (5.5 mg, 6.0 mol-%), copper iodide (1.5 mg, 6.0 mol-%) in triethylamine (9 mL) was degassed using three freeze-pump-thaw cycles. 5-Ethynyl-2-methoxy-1,1,3,3-tetramethylisoindoline (**15**) (75 mg, 0.33 mmol) was then added and the mixture heated at 85 °C for 16 h. The solvent was removed in vacuo and the resulting residue dissolved in DCM (50 mL). washed with water (2 × 50 mL) and brine (2 × 50 mL), dried (anhydrous Na_2SO_4) and concentrated at reduced pressure. Purification by silica column chromatography (eluent 100% hexane → 10% ethyl acetate, 90% hexane; sample dry-loaded from DCM) gave 9-(2-methoxy-1,1,3,3-tetramethylisoindolin-5-ethynyl)-10-(phenylethynyl)anthracene (**20**) as a yellow solid (52 mg, 78%). M.p. 170–173 °C. IR (ATR): $\tilde{\nu}$ = 2956 and 2925 (alkyl CH), 2196 (C≡C), 1489 and 1455 (aryl C–C), 1052 (C–O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 1.47–1.57 (br. s, 12 H, 4 × CH_3), 3.83 (s, 3 H, CH_3), 7.20 (d, *J* = 7.8 Hz, 1 H, 7-H), 7.41–7.52 (m, 4 H, Ar-H), 7.64–7.69 (m, 5 H, Ar-H), 7.80 (dd, *J* = 8.0, 1.7 Hz, 2 H, Ar-H), 8.71 (ddd, *J* = 6.3, 3.6, 0.65 Hz, 4 H, Ar-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.0 (br., CH_3), 29.5 (br., CH_3), 65.5 (CH_3), 67.1 (C), 67.2 (C), 85.8 (C≡), 86.5 (C≡), 102.3 (C≡), 102.7 (C≡), 118.3 (C), 118.6 (C), 121.8 (CH), 122.1 (C), 123.4 (C), 124.8 (CH), 126.77 (CH), 126.81 (CH), 127.2 (CH), 127.3 (CH), 128.6 (CH), 128.7 (CH), 131.0 (CH), 131.7 (CH), 132.07 (C), 132.09 (C), 145.8 (C), 146.2 (C) ppm. MS (ES): *m*/*z* (%) = 506 (10) [MH^+]. HRMS: calcd. for $C_{37}H_{32}NO$ [MH^+] 506.2478; found 506.2484.

Quantum Yield and Extinction Coefficient Calculations: Quantum-yield efficiencies of fluorescence for compounds **5**, **6**, **11**, **12**, **16**, **17**, **19** and **20** were obtained from measurements at five different concentrations in cyclohexane using the following equation:

$$\Phi_{F\ sample} = \Phi_{F\ standard} \times (Abs_{standard}/Abs_{sample}) \times (\Sigma[F_{sample}]/\Sigma[F_{standard}])$$

where Abs and F denote the absorbance and fluorescence intensity, respectively, and Σ[F] denotes the peak area of the fluorescence spectra, calculated by summation of the fluorescence intensity. 9,10-Diphenylanthracene (Φ_F = 0.9) and 9,10-bis(phenylethynyl) anthracene (Φ_F = 1.0) were used as standards. Extinction coefficients were calculated from the obtained absorbance spectra.

Titration of 9,10-Bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (5) with Methyl Radicals: Iron(II) sulfate heptahydrate (15 mg, 4.17 mol) was added to a stirring solution of 9,10-bis(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (**5**) (1.39 mg, 2.51 mmol) in DMSO (10 mL). A solution of hydrogen peroxide (30%, 2.5 μL, 0.88 equiv.) in DMSO (97.5 μL) was added and after stirring at room temperature for 10 min, an aliquot (0.1 mL) was removed from the reaction and diluted with THF (0.4 mL). The addition of hydrogen peroxide and removal of aliquots after 10 min was repeated 8 times. The aliquots were analysed by analytical HPLC (mobile phase 72.5% THF in H_2O, detection at 254 nm) and their fluorescence measured. Authentic samples of **5**, **6** and **21** were prepared and gave retention times consistent with those observed in the titration.

9-(2-Methoxy-1,1,3,3-tetramethylisoindolin-5-yl)-10-(1,1,3,3-tetramethylisoindolin-2-yloxyl-5-yl)anthracene (21): A solution containing 9,10-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)anthracene (**7**) (0.2 g, 0.48 mmol), 5-iodo-1,1,3,3-tetramethylisoindolin-2-yloxyl (**8**) (0.18 g, 0.57 mmol), 5-iodo-2-methoxy-1,1,3,3-tetramethylisoindoline (**9**) (0.19 g, 0.57 mmol) and anhydrous sodium carbonate (0.1 g, 0.96 mmol) in dry THF (5 mL) and water (2 mL) was degassed by subjecting to three freeze-pump-thaw cycles. Tetrakis(triphenylphosphane)palladium(0) (44.0 mg, 0.038 mmol) was added and the reaction mixture was heated at 80 °C under argon for 3 d. The resulting solution was cooled, water (50 mL) added and the mixture extracted with chloroform (3 × 50 mL). The organic layers were washed with brine (2 × 50 mL), dried (anhydrous Na_2SO_4) and concentrated in vacuo. The obtained residue was purified by silica column chromatography (eluent 70% DCM, 30% hexane → 100% DCM) to afford **21** as a cream-coloured solid (112 mg, 41%). M.p. 299–301 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.51–1.58 (br. s, 12 H, 4 × CH_3), 3.89 (s, 3 H, CH_3), 7.20–7.25 (m, 1 H, Ar-H), 7.33–7.45 (m, 6 H, Ar-H), 7.71–7.79 (m, 2 H, Ar-H), protons near radical not observed. ^{13}C NMR (100 MHz, $CDCl_3$): no signals observed. MS (ES): *m*/*z* (%) = 570 (20) [MH^+]. HRMS: calcd. for $C_{39}H_{42}N_2O_2$ [MH^+] 570.3246; found 570.3237.

Supporting Information (see also the footnote on the first page of this article): ^{1}H and ^{13}C NMR spectra for compounds **3**, **4**, **6**, **12**, **17** and **20**.

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[1] G. Moad, E. Rizzardo, D. H. Solomon, *Macromolecules* **1982**, *15*, 909–914.
[2] P. G. Griffiths, E. Rizzardo, D. H. Solomon, *Tetrahedron Lett.* **1982**, *23*, 1309–1312.
[3] J. Shen, S. Bottle, N. Khan, O. Grinberg, D. Reid, A. Micallef, H. Swartz, *Appl. Magn. Reson.* **2002**, *22*, 357–368.
[4] A. S. Micallef, R. C. Bott, S. E. Bottle, G. Smith, J. M. White, K. Matsuda, H. Iwamura, *J. Chem. Soc. Perkin Trans. 2* **1999**, *2*, 65–71.
[5] N. V. Blough, D. J. Simpson, *J. Am. Chem. Soc.* **1988**, *110*, 1915–1917.
[6] S. A. Green, D. J. Simpson, G. Zhou, P. S. Ho, N. V. Blough, *J. Am. Chem. Soc.* **1990**, *112*, 7337–7346.
[7] J. L. Gerlock, P. J. Zacmanidis, D. R. Bauer, D. J. Simpson, N. V. Blough, I. T. Salmeen, *Free Radical Res. Commun.* **1990**, *10*, 119–121.
[8] D. J. Kieber, N. V. Blough, *Anal. Chem.* **1990**, *62*, 2275–2283.
[9] D. J. Kieber, N. V. Blough, *Free Radical Res. Commun.* **1990**, *10*, 109–117.
[10] S. E. Herbelin, N. V. Blough, *J. Phys. Chem. B* **1998**, *102*, 8170–8176.
[11] C. Coenjarts, O. Garcia, L. Llauger, J. Palfreyman, A. L. Vinette, J. C. Scaiano, *J. Am. Chem. Soc.* **2003**, *125*, 620–621.
[12] M. G. Ivan, J. C. Scaiano, *Photochem. Photobiol.* **2003**, *78*, 416–419.
[13] A. Aspee, O. Garcia, L. Maretti, R. Sastre, J. C. Scaiano, *Macromolecules* **2003**, *36*, 3550–3556.
[14] X.-F. Yang, X.-Q. Guo, *Analyst* **2001**, *126*, 1800–1804.
[15] X.-F. Yang, X.-Q. Guo, *Anal. Chim. Acta* **2001**, *434*, 169–177.
[16] G. Moad, D. A. Shipp, T. A. Smith, D. H. Solomons, *J. Phys. Chem. A* **1999**, *103*, 6580–6586.
[17] O. G. Ballasteros, L. Maretti, R. Sastre, J. C. Scaiano, *Macromolecules* **2001**, *34*, 6184–8187.
[18] Y.-M. Dang, X.-Q. Guo, *Appl. Spectrosc.* **2006**, *60*, 203–207.
[19] C. Toniolo, M. Crisma, F. Formaggio, *Biopolymers* **1998**, *47*, 153–158.
[20] B. Pispisa, A. Palleschi, L. Stella, M. Venanzi, C. Toniolo, *J. Phys. Chem. B* **1998**, *102*, 7890–7898.
[21] B. Pispisa, C. Mazzuca, A. Palleschi, L. Stella, M. Venanzi, M. Wakselman, J.-P. Mazaleyrat, M. Rainaldi, F. Formaggio, C. Toniolo, *Chem. Eur. J.* **2003**, *9*, 4084–4093.
[22] E. Hideg, T. Kalai, K. Hideg, I. Vass, *Biochemistry* **1998**, *37*, 11405–11411.
[23] T. Kalai, E. Hideg, I. Vass, K. Hideg, *Free Radical Biol. Med.* **1998**, *24*, 649–652.
[24] E. Lozinsky, V. V. Martin, T. A. Berezina, A. I. Shames, A. L. Weis, G. I. Likhtenshtein, *J. Biochem. Biophys. Methods* **1999**, *38*, 29–42.
[25] P. Bilski, K. Hideg, T. Kalai, M. A. Bilska, C. F. Chignell, *Free Radical Biol. Med.* **2003**, *34*, 489–495.
[26] D. J. Keddie, T. E. Johnson, D. P. Arnold, S. E. Bottle, *Org. Biomol. Chem.* **2005**, *3*, 2593–2598.
[27] J. P. Blinco, J. C. McMurtrie, S. E. Bottle, *Eur. J. Org. Chem.* **2007**, *48*, 4638–4641.
[28] A. S. Micallef, J. P. Blinco, G. A. George, D. A. Reid, E. Rizzardo, S. H. Thang, S. E. Bottle, *Polym. Degrad. Stab.* **2005**, *89*, 427–435.
[29] J. P. Blinco, G. A. George, S. E. Bottle, *Polym. Prepr.* **2007**, *48*, 629–630.
[30] A. Micallef, S. Bottle, J. Blinco, G. George in *ACS Symposium Series*, vol. 978, *Polymer Durability and Radation Effects* (Eds.: M. C. Celina, R. A. Assink), American Chemical Society, **2008**, 59–69.
[31] K. E. Fairfull-Smith, J. P. Blinco, D. J. Keddie, G. A. George, S. E. Bottle, *Macromolecules* **2008**, *41*, 1577–1580.
[32] M. A. Wolak, B.-B. Jang, L. C. Palilis, Z. H. Kafafi, *J. Phys. Chem. B* **2004**, *108*, 5492–5499.
[33] N. Ikemoto, S. L. Schreiber, *J. Am. Chem. Soc.* **1992**, *114*, 2524–2536.
[34] D. J. Hart, W.-P. Hong, L.-Y. Hsu, *J. Org. Chem.* **1987**, *52*, 4665–4673.
[35] D. S. Matteson, H.-W. Man, O. C. Ho, *J. Am. Chem. Soc.* **1996**, *118*, 4560–4566.
[36] N. Miyaura, A. Suzuki, *Chem. Rev.* **1995**, *95*, 2457–2483.
[37] A. Suzuki in *Handbook of Organopalladium Chemistry for Organic Synthesis* (Ed.: E. Negishi), Wiley-Interscience, New York, **2002**.
[38] *Cross-Coupling Reactions: A Practical Guide* (Ed.: N. Miyaura) Springer, New York, **2002**.
[39] T. Kalai, M. Balog, J. Jeko, W. L. Hubbell, K. Hideg, *Synthesis* **2002**, *16*, 2365–2372.
[40] T. Kalai, J. Jeko, Z. Berente, K. Hideg, *Synthesis* **2006**, *3*, 439–446.

[41] B. Bognar, E. Osz, K. Hideg, T. Kalai, *J. Heterocycl. Chem.* **2006**, *43*, 81–86.
[42] C. Stroh, M. Mayor, C. von Haenisch, *Eur. J. Org. Chem.* **2005**, *17*, 3697–3703.
[43] D. J. Keddie, K. E. Fairfull-Smith, S. E. Bottle, *Org. Biomol. Chem.* DOI: 10.1039/b806963h.
[44] M. S. Sherburn, D. J. Sinclair, *J. Org. Chem.* **2005**, *70*, 3730–3733.
[45] H. A. Dieck, F. R. Heck, *J. Organomet. Chem.* **1975**, *93*, 259–263.
[46] L. J. Cassar, *J. Organomet. Chem.* **1975**, *93*, 253–257.
[47] K. Sonogashira, Y. Tohda, N. Hagihara, *Tetrahedron Lett.* **1975**, *16*, 4467–4470.
[48] K. Sonogashira in *Handbook of Organopalladium Chemistry for Organic Synthesis* (Ed.: E. Negishi), Wiley-Interscience, New York, **2002**.
[49] O. Schiemann, N. Piton, J. Plackmeyer, B. E. Bode, T. F. Prisner, J. W. Engels, *Nat. Protoc.* **2007**, *2*, 904–923.
[50] C. Stroh, M. Mayor, C. von Haenisch, *Tetrahedron Lett.* **2004**, *45*, 9623–9626.
[51] J.-H. Li, Y. Liang, Y.-X. Xie, *J. Org. Chem.* **2005**, *70*, 4393–4396.
[52] J. Kajanus, S. B. van Berlekom, B. Albinsson, J. Mårtensson, *Synthesis* **1999**, 1155–1162.
[53] D. R. Coulson, *Inorg. Synth.* **1971**, *13*, 121–124.
[54] Y. Kim, D. Shin, S. Kim, C. Ko, H. Yu, Y. Chae, S. Kwon, *Adv. Mater.* **2001**, *13*, 1690–1693.
[55] C. Yang, J. Jacob, K. Müllen, *Macromolecules* **2006**, *39*, 5696–5704.
[56] B. F. Duerr, Y. S. Ching, A. W. Czarnik, *J. Org. Chem.* **1988**, *53*, 2120–2122.
[57] The diagnostic IR band for a nitroxide is 1431 cm^{-1}, see L. Rintoul, A. S. Micallef, D. A. Reid, S. E. Bottle, *Spectrochim. Acta, Part A* **2006**, *63*, 398–402.

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