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Hybrid Materials

Dendritic Ligands for Magnetic Suspensions in Liquid Crystals

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Abstract: The synthesis of long-chain, aliphatic and space filling dendritic ligands containing (pro)mesogenic, aliphatic or nitrile biphenyl moieties for the stabilization of magnetic nanoparticles in liquid crystal hosts is described. A Negishi or Sonogashira cross-coupling is exploited as a key step in the synthetic sequence. These synthetic procedures enable the synthesis of various ligands which can be easily adapted to different types of liquid crystals [e.g. 4-pentyl-4′-cyanobiphenyl (5CB)]. For instance, a three-step sequence (i.e. etherification, Sonogashira–Hagihara cross-coupling and Steglich-esterfication) yields a dendritic ligand in 77 % overall yield starting from literature known compounds. The length of the ligand is important to stabilize the magnetic nanoparticles, and, therefore, the length of the ligand may be easily modified by this approach. Indeed, the established synthesis can readily tackle this issue.

Introduction

Suspensions of magnetic nanoparticles (MNPs) in liquid crystals (LCs) combine physical properties of both materials. These properties of the hybrid materials include electro-optical, magneto-optical (static and dynamic) and magneto-rheological properties not observed for the individual components.[1] In 1970, Brochard and de Gennes suggested that doping of LCs with shape-anisotropic MNPs leads to an increase in magnetic susceptibility χ.[2] For the first time, the macroscopic collective behavior of ferromagnetic γ-Fe_2O_3 nanorods (500 × 70 nm) in *N*-(4-methoxy-benzylidene)-4-butylaniline (**MBBA**, Figure 1) was then demonstrated experimentally by Amer et al. in 1983.[3] In 2013, a ferromagnetic nematic phase with spontaneous magnetization was realized by Mertelj et al. embedding ferromagnetic $BaFe_{11.5}Sc_{0.5}O_{19}$ nanodiscs (70 × 5 nm) in 4-pentyl-4′-cyanobiphenyl (**5CB**, Figure 1).[4]

Despite the great interest in colloidal suspensions of MNPs in LCs, applications have been mainly hampered by a relatively low colloidal stability and a strong tendency to form aggregates. Examples in the literature have reported on the formation of aggregates [in particular for high particle concentrations (> 0.01 wt.-%)] leading to inhomogeneous particle distribution or even macroscopic phase separation.[5] Phase separation is caused by gravitational forces, magnetic field gradients and coagulation of solid particles due to elastic LC, van der Waals and/or magnetic dipole-dipole interactions. Lower particle concentrations minimize potential interactions and thus the number and size of aggregates.[3,4] In order to prevent particle aggregation and phase separation, specific (pro)mesogenic ligands have been introduced to functionalize the particle surface.

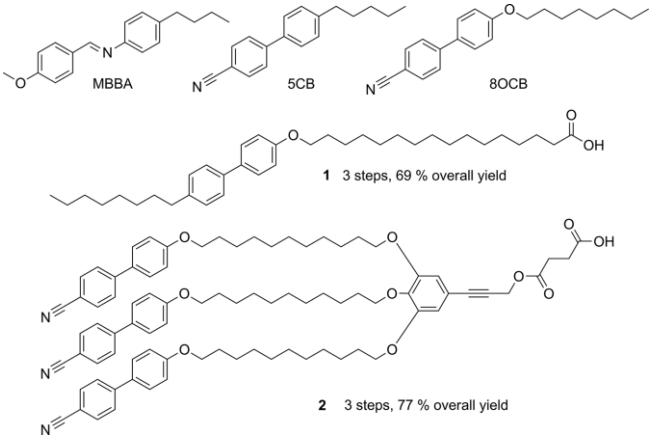

Figure 1. Aliphatic ligand **1** and dendritic ligand **2** are structurally highly-adapted to different liquid crystals e.g. MBBA, 5CB and 8OCB.

The role of these (pro)mesogenic ligands is not only the steric repulsion by a large exclusion volume, but also the "smoothing out" of the disturbance of the local LC director caused by the nanoparticles (especially at the MNP-LC interface).[6] Therefore, it is no coincidence that the most stable colloidal LCs have been obtained either with ligands bearing mesogenic entities or a combination of (pro)mesogenic and aliphatic ligands. Ligands exploited for the stabilization of nanoparticles in LCs are typically composed of three major structural parts: a) an anchoring group (e.g., carboxyl, phosphates and amines), b) an aliphatic linker/spacer connecting the binding group with c) the (pro)mesogenic unit. The choice of the (pro)mesogenic unit depends on the LC and may consist, e.g.,

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of a biphenyl residue bearing either a nitrile or an octyloxy end group in case of **8OCB**, respectively (Figure 1).

The functionalization of magnetic nanorods with an octyloxybiphenyl-based ligand, for example, was shown to significantly reduce aggregation, as compared to their oleic acid-coated counterparts.[7] Likewise a ligand consisting of a 4-cyanobiphenyl residue and an aliphatic C7- or C15-spacer, respectively, was previously demonstrated to stabilize 2.5 nm size $CoFe_2O_4$ MNPs in 5CB.[8] Increasing the linker length from C7 to C15, lead to a larger exclusion volume and thus to better steric stabilization and allowed for the stabilization of higher MNP concentrations in the LC (i.e. without macroscopic aggregation in an external magnetic field). This suggests that a longer aliphatic spacer may allow for the stabilization of larger MNPs or achieving higher MNP concentrations. If the MNPs are introduced into the LC, the mutual molecular alignment not only disturbs the local LC order in the vicinity of the MNPs, but also disturbs the originally isotropic, (pro)mesogenic ligand shell of the MNP from spherical to tactoidal, which can also lead to MNP agglomeration.[9]

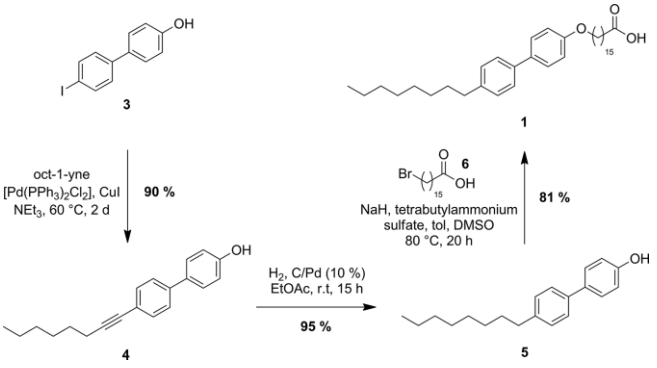
Dendritic ligands with a tree-like architecture may tackle this problem of equatorial ligand depletion on the nanoparticle surface. Dermortière et al. have reported on the functionalization of MNPs with a dendritic ligand which leads to the formation of a magnetic hybrid material with birefringent, optical properties.[10] Yet, the stabilization of the MNPs in a LC host was not investigated. Vashchenko et al. have reported a seven-step synthesis for dendritic ligands with different mesogenic units and end groups, respectively; however, the overall yield of this procedure was poor (i.e. 9–17 %).[11] The corresponding dendritic ligands based on 4′-octyloxy-biphenyl end groups were employed for the stabilization of 7.8 nm size $CoFe_2O_4$ MNPs.[5b] High particle concentrations (i.e. 1 wt.-%) were achieved while relatively few aggregates were formed.

Despite the successful stabilization of nanoparticles in LCs by (pro)mesogenic ligands with a linear or dendritic structure, their preparation typically requires multi-step synthesis methods that are complicated, deliver only small amounts of the target ligand and thus limit the overall application. Hence, it is not only important to design organic ligands with specific structures, topologies and properties but also to develop synthetic procedures that are both simple and versatile at the same time. Herein, we describe a practical approach for the synthesis of (pro)mesogenic ligands with linear and dendritic structures and compare alternative approaches. We address the spacer length and the space-filling nature of these ligands. The synthetic procedures described herein range from the synthesis of the linear ligand **1** to the simple, three-step synthesis of the dendritic ligand **2** with an overall yield of 77 % (Figure 1).

Results and Discussion

Linear (pro)mesogenic ligands

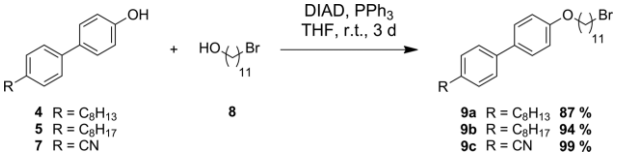
The aliphatic ligand **1** exhibiting a (pro)mesogenic octyl-biphenyl structural motif was obtained from iodide **3** in a three-step synthetic procedure (Scheme 1). The octyl group was introduced via a Sonogashira cross-coupling reaction, yielding alkyne **4** in 90 % yield after column chromatography.[12] Subsequently, the Pd-catalyzed hydrogenation of the triple bond in **4** led to alcohol **5**.[13] Eventually, the alcohol **5** and the commercial bromide **6** were treated with NaH. Since the alcoholate of **5** showed a poor solubility, tetrabutylammonium sulfate was employed as phase transfer agent. Nucleophilic substitution gave ligand **1** in an overall yield of 69 %.[8]



Scheme 1. Synthesis of aliphatic ligand **1**: i.) Sonogashira cross-coupling of iodide **3** and oct-1-yne, ii.) Pd-catalyzed reduction with hydrogen of the triple bond of alkyne **4**, and iii.) etherification of alcohol **5** and bromide **6**.

Long-chain ligands (n > 15) via Negishi cross-coupling

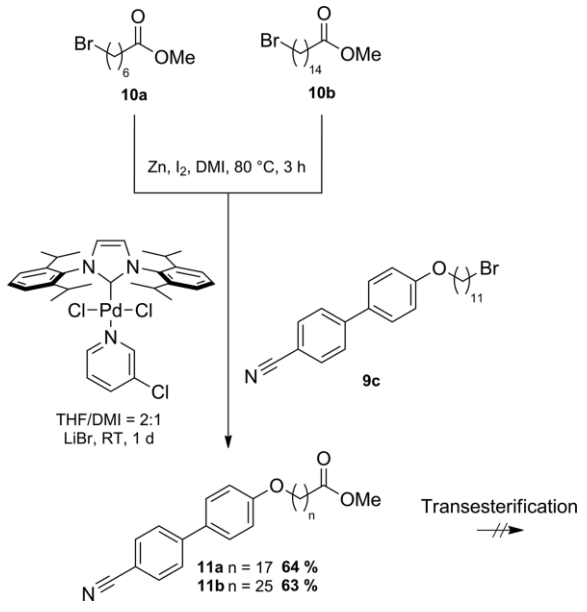
As mentioned earlier, the length of the aliphatic spacer influences nanoparticle stabilization, and the increase in chain length allows for stabilization of higher particle concentrations.[8] However, the etherification described in Scheme 1 is limited to *n*-bromocarbonic acids. As the chain length of the *n*-bromocarbonic acids increases, the solubility in common organic solvents decreases. Therefore, an alternative synthetic pathway is required to build up ligands with longer alkyl spacers [$(-CH_2-)_n$; n > 15]. Here, a $C(sp^3)$–$C(sp^3)$-Negishi cross-coupling of the corresponding methyl ester was employed to synthesize ligands with a spacer length of n = 17, 25.[14] First, as described earlier for bromide **9c**, a modified procedure of a Mitsunobu reaction of alcohol **4** and **5**, and 11-bromoundecan-1-ol (**8**) with diisopropyl azodicarboxylate (DIAD) gave bromide **9a** and **9c** in 87 % and 94 % yield, respectively (Scheme 2).[10]



Scheme 2. Mitsunobu reaction of DIAD, 11-bromoundecan-1-ol (**8**) and alcohol **4**, **5** and **7**, respectively.

Then, **9c** was treated with the commercial compound **10a** via $C(sp^3)$–$C(sp^3)$-Negishi cross-coupling to form the long-chain aliphatic ester **11a** (Scheme 3). Compound **10b** was obtained as a colorless solid (99 %) from the corresponding carbonic acid in a mixture of methanol with a catalytic amount of H_2SO_4.[15] Using the same reaction conditions in the Negishi cross-coupling, bromide **9c** and compound **10b** resulted in the formation

of the poorly soluble ester **11b**. Thus, ester **11b** could only be assigned with a ^{1}H NMR experiment not with a ^{13}C NMR experiment.



Scheme 3. Synthesis sequence for the preparation of long-chain aliphatic esters **11a** and **11b**.

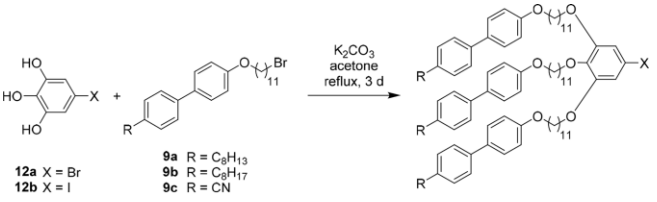
The poor solubility of the esters **11a** and **11b** made their transesterification even more difficult and attempts to deprotect them with TFA or LiOH in THF/MeOH (1:1) led to a precipitate. These precipitates were insoluble in common organic solvents (halogenated solvents, DMSO, DMF etc.). Hence, they could neither be further characterized nor directly exploited as ligands in the stabilization of magnetic nanoparticles. In order to overcome the issue of poor ligand solubility while maintaining large exclusion volumes of the ligands, a protocol for dendritic ligands was established in the following using a Sonogashira cross-coupling.

Synthesis of dendritic (pro)mesogenic ligands

A terminal anchoring group of the (pro)mesogenic ligand binds to the nanoparticle surface. Thereby, the binding efficiency depends strongly on both the type of anchoring group and the inorganic core. Several types of anchoring groups (e.g., carboxyl, amine) have been employed to directly bind organic ligands to the inorganic core of Co, $CoFe_2O_4$ or Fe_3O_4 nanoparticles, respectively. Alternatively, functional groups such as, hydroxyl,[16] alkenyl,[17] alkynyll[18] may be employed for covalent coupling to polymer-coated MNPs. In order to enable the functionalization of different types of nanoparticles with (pro)mesogenic ligands, we aimed for a scalable and variable method for a broad application spectrum and a high tolerance for functional groups. Therefore, a Sonogashira cross-coupling was investigated as a key step in the synthetic sequence of the (pro)mesogenic ligands.[12]

Triols **12a** and **12b** were obtained via deprotection of the corresponding methoxy derivatives with BBr_3 (Table 1).[19] Those triols were further reacted with bromide **9a**, **9b** and **9c**, respectively, under reflux in a suspension of anhydrous acetone and K_2CO_3 under inert conditions (Table 1).[10] In the case of iodide **13d** the yield could be increased by roughly 10 % via exclusion of light.

Table 1. Results of the etherification of triol **12a** and **12b** and bromides **9a**, **9b**, **9c**. Yields were determined after column chromatography.



#	R	X	Product	Yield
1	-C_8H_{13}	I	**13a**	75 %
2	-C_8H_{17}	Br	**13b**	90 %
3	-CN	Br	**13c**	81 %
4	-CN	I	**13d**	82 %

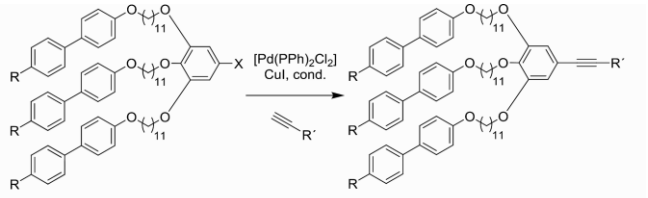
Dendritic ligands via Sonogashira cross-coupling

The hydroxyl and alkenyl group are orthogonal in the Sonogashira cross-coupling. The alkynyl group should be addressable via a two-step protocol of a TMS-protected alkyne in a Sonogashira cross-coupling and deprotection with K_2CO_3 in MeOH/THF.[20] For the carboxyl group, a benzyl protected carboxylic acid was introduced which may be removed by reduction with H_2/Pd.[21] First, alkyne **14a** was obtained from undec-10-ynoic acid and benzyl bromide in DMF with K_2CO_3 at ambient temperature (not shown). After 1 day, the combined organic phase was washed, dried with Na_2SO_4 and the solvent removed under high vacuum to give reactant **14a** in a yield of 95 %. Table 2 summarizes the results of the Sonogashira cross-coupling of **13b**–**13d** with different alkynes **14a**–**14c**, the reaction conditions and the corresponding yields.

The bromides **13b** and **13c** led to the benzyl esters **15a** and **15b** in moderate yields, respectively. In the case of # 2, 49 % of product **15b** were obtained as a colorless solid and 19 % of bromide **13c** were recovered. An increase of the yield was expected with iodide **13d** under similar conditions.[22] Indeed, the reaction already took place at room temperature and monitoring by thin layer chromatography indicated that the reaction was completed after 3 h to give ester **15b** in 84 % yield. If DMF was replaced by toluene and used as solvent, the yield could be further increased for **14b** and **14c**, respectively.[23] All products were obtained as pure compounds after purification with column chromatography and showed good solubility in common organic solvents (e.g. halogenated solvents).

Deprotection of ester **15a** was carried out with hydrogen using Pd on charcoal as a catalyst to give the dendritic ligand

Table 2. Results of the Sonogashira cross-coupling of halides **13b**–**13d** with different alkynes **14a**–**14c**. Yields were determined after column chromatography.

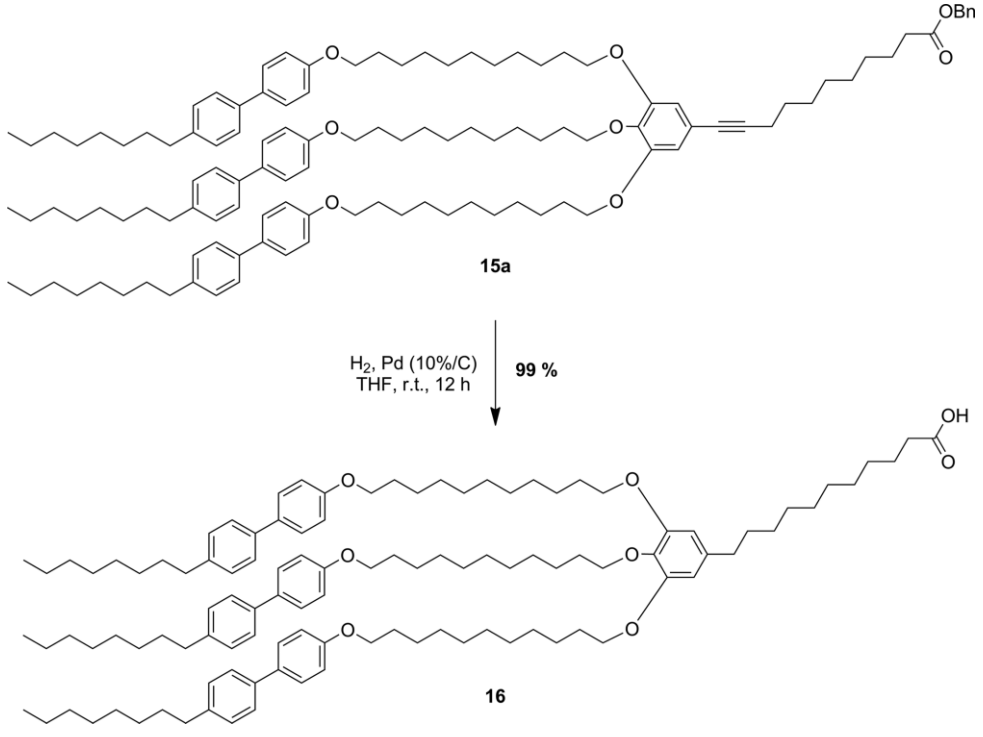


#	R	X	Alkyne	Condition	Product	Yield
1	-C_8H_{17}	Br	 **14a**	NEt_3, DMF 90 °C, 0.5 h	**15a**	40 %
2	-CN	Br		NEt_3, DMF 90 °C, 0.5 h	**15b**	49 %
3	-CN	I		NEt_3, DMF r.t., 3 h	**15b**	84 %
4	-CN	I	 **14b**	$HNEt_2$, tol r.t., 20 h	**15c**	89 %
5	-CN	I	 **14c**	$HNEt_2$, tol r.t., 20 h	**15d**	90 %

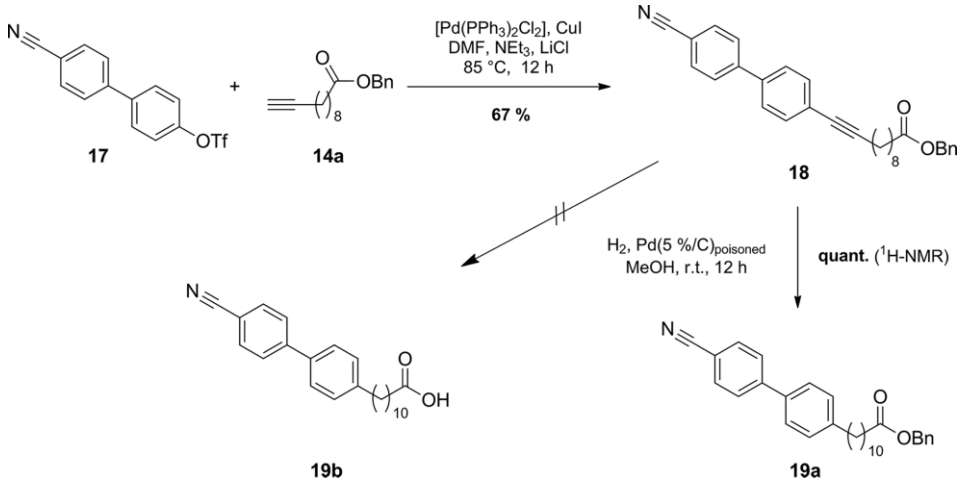
16 in quantitative yield (Scheme 4). In addition to the deprotection, the triple bond was also hydrogenated. In contrast, the reduction of ester **15b** bearing aromatic nitrile groups caused a by-product (approx. 10 %). Unfortunately, this by-product could neither be separated via column chromatographic purification nor removed sufficiently via recrystallization.

It has been previously demonstrated that the reductive deprotection with hydrogen and Pd works well alongside an aromatic nitrile group.[24] Using a Pd catalyst poisoned with Hünig's base, Mandle et al. succeeded in selectively reducing a triple bond in the presence of an aromatic nitrile group, while the aromatic nitrile was not reduced. Therefore, we investigated this reduction initially using **18** (Scheme 5) as a model compound. Starting from triflate **17**[25] and benzyl ester **14a**, the Pd-mediated cross-coupling led by addition of lithium chloride (1.3 equivalent) to model compound **18**. Without lithium chloride, no cross-coupling was observed under the chosen reaction conditions.[26]Then, **18** was hydrogenated exploiting the described poisoned Pd catalyst (0.1 wt.-%) in methanol. After 12 h, the ^{1}H-NMR spectrum revealed the complete conversion of the triple to the single bond – ester **19a** was obtained (Scheme 5). After 24 h, < 0.3 % of the ester group was deprotected. However, under these conditions, a reduction of the nitrile group to the amine was also observed. Thus, this approach was not suitable for the selective deprotection of the benzyl group of ester **15b**.

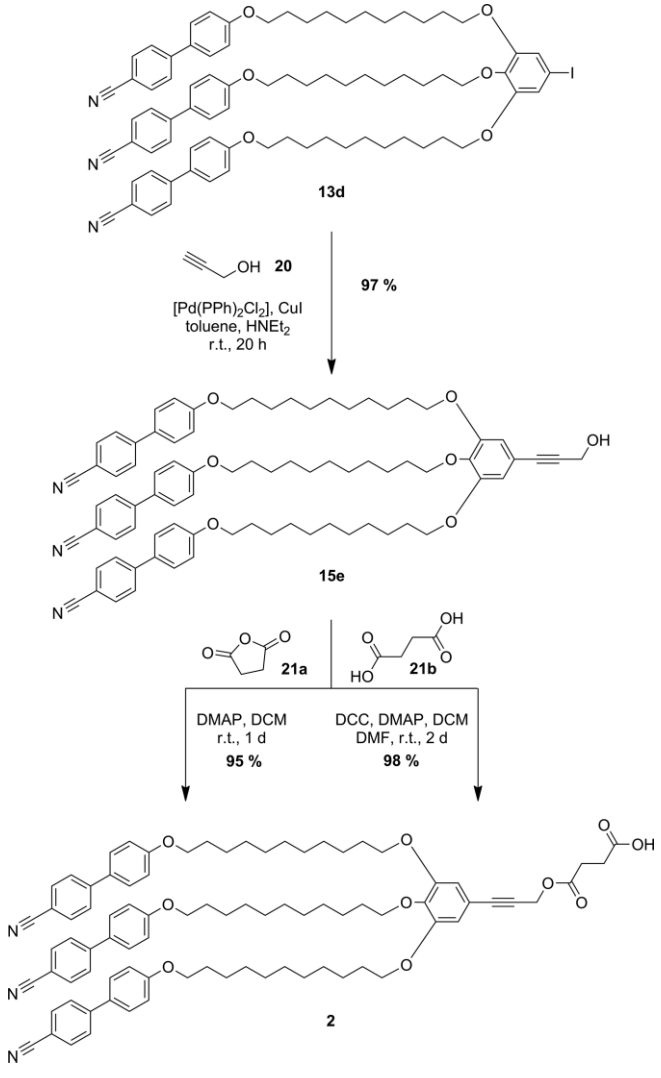
Therefore, an alternative strategy was developed in which a terminal carboxyl anchoring group was introduced for dendritic ligands bearing nitriles as end group of the (pro)mesogenic unit. First, a Sonogashria cross-coupling under the same reaction conditions as described before (**GP-5**) was performed with iodide **13d** and propargyl alcohol (**20**) yielding the dendritic ligand **15e** (Scheme 6). Ligand **15e** is suitable for covalent coupling to polymer-coated nanoparticles.[27] Second, we estab-



Scheme 4. Reductive deprotection of ester **15a** with H_2/Pd results in the formation of dendritic ligand **16** in quantitative yield. As expected, the triple bond was also hydrogenated to the single bond.



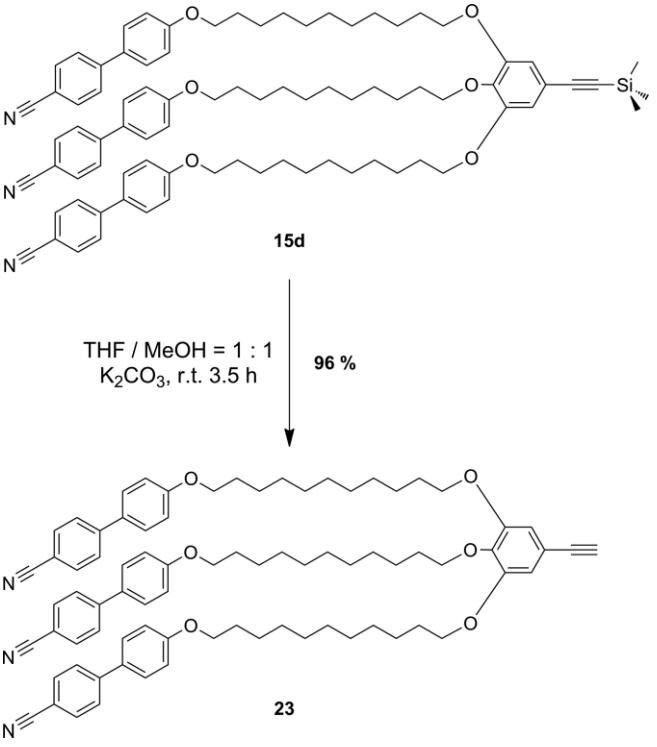
Scheme 5. Synthesis of model compound **18** and its hydrogenation with a poisoned Pd(5 %/C) catalyst led to the selective hydrogenation of the triple bond. The quantitative conversion to ester **19a** was assigned via ^{1}H NMR experiment.



Scheme 6. Synthesis of dendritic ligand **15e** via Sonogashira cross-coupling. Esterification of **15e** and a) succinic anhydride (**21a**) and b) succinic acid (**21b**) yielded dendritic ligand **2**.

lished a) an esterification[28] of dendritic ligand **15e** and succinic anhydride (**21a**) and b) a Steglich esterification[29] of dendritic ligand **15e** and succinic acid (**21b**). Both methods gave the dendritic ligand **2** in excellent yields simply by washing the combined organic phases. The overall yield starting from literature known triol **12b** is 77 % (in the case of method b). Since various dicarboxylic acids are commercially available, it should be possible to obtain the corresponding dendritic ligands with different spacer lengths also in good overall yields.

Moreover, deprotection of **15d** with K_2CO_3 in MeOH/THF (1:1) yielded the dendritic ligand **23** (Scheme 7).[20] The



Scheme 7. Deprotection of silane **15d** in a suspension of MeOH/THF (1:1) and K_2CO_3 yielded the dendritic ligand **23**.

dendritic ligand **23** may be further exploited to functionalize magnetic nanoparticles with (pro)mesogenic ligands via click chemistry.[18]

Conclusions

In summary, we have shown the synthesis of various (pro)mesogenic ligands with linear and dendritic structures using a Sonogashira cross-coupling reaction as a key step. Our approach represents a convenient and practical route which delivers the (pro)mesogenic ligands in good overall yields, minimizes the apparative effort and allows different end and anchoring groups to be introduced, respectively. This is an important issue with respect to the functionalization of MNPs in LC hosts and the future application of the resulting hybrid materials. For instance, the reductive deprotection of the benzyl ester **15a** with H_2/Pd led to the quantitative formation of the dendritic ligand **16** with a carboxyl anchoring and an octyl end group. The dendritic ligand **15c** with a terminal alkene was specifically designed for the future functionalization of polymer-coated nanoparticles (i.e. via cross metathesis) and received with an overall yield of 72 %. Moreover, the simple, three-step sequence of etherification, Sonogashira cross-coupling and esterification gave the (pro)mesogenic dendritic ligand **2** in an overall yield of 77 %. The dendritic ligand **2** with nitrile end group was specifically tailored for the stabilization of MNPs in LC hosts (e.g. 5CB). The synthetic sequence is versatile and may be extended to dendritic ligands with various spacer length and end groups. This will allow for a systematic investigation of the relationships between ligand structure and particle stability in LC matrices, which will be a subject of our future investigations.

Experimental Section

General Remarks

All chemicals and reagents were obtained from commercial sources and used as-received, unless otherwise noted. Dry solvents (i.e., acetone, dichloromethane, dimethylformamide, 1,3-dimethyl-2-imidazolidinone, dimethyl sulfoxide, methanol, tetrahydrofuran, toluene) were purchased from Sigma-Aldrich. Triethylamine and ethylamine were dried and stored over 3 Å molecular sieves.[30] Starting materials and reagents are purchased from commercial sources: Bis(triphenylphosphine) palladium(II) dichloride (98 %, Sigma-Aldrich), 16-bromo-hexadecanoic acid (99 %, Sigma-Aldrich), 11-bromoundecan-1-ol (99 %, abcr), 5-bromo-1,2,3-trimethoxybenzene (98 %, TCI), copper(I) iodide (98 %, abcr), dicyclohexylcarbodiimid (99 % abcr), diisopropyl azodicarboxylate (94 %, abcr), 4-dimethyl-aminopyridine (99 %, Sigma-Aldrich), hex-1-en-5-yne (98 %, abcr), 4′-hydroxy-[1,1′-biphenyl]-4-carbonitrile (98 %, Alfa Aesar), 4′-iodo-[1,1′-biphenyl]-4-ol (Alfa Aesar 98 %), 5-iodo-1,2,3-trimethoxybenzene (98 %, Alfa Aesar), lithium bromide (99.9 %, Sigma-Aldrich), lithium chloride (99.9 %, Sigma-Aldrich), methyl 7-bromo-heptanoate (98 %, abcr), oct-1-yne (97 %, Alfa aesar), ω-penta-decalactone (98 %, Sigma-Aldrich), potassium carbonate (99 %, abcr), propargyl alcohol (99 %, Sigma-Aldrich), sodium hydride (60 % dispersion, Sigma-Aldrich), succinic acid (99 %, Sigma-Aldrich), succinic anhydride (99 % Arcos organics), trimethylsilylacetylene (98 % Arcos organics), triphenylphosphine (99 % Sigma-Aldrich), undec-10-ynoic acid (95 %, Sigma-Aldrich). Manipulations under inert conditions were performed under an atmosphere of dry argon (6.0; Linde AG, Germany) using dry glassware and syringe-cannula techniques which were argon flushed.

Analytical thin layer chromatography (TLC) was performed on TLC-PET-sheets (pore size 60 Å, 25 µm). Components were visualized by observation either under UV light (254 nm or 365 nm) or by dyeing with $KMnO_4$ solution. Flash column chromatography was carried out using silica gel (pore size 60 Å, 40–63 µm) purchased from Sigma Aldrich. Melting points (not corrected) were measured with a Melting Point B-540 Büchi. ^{1}H-NMR spectra were recorded at room temperature on a Bruker Avance III 300 (250 MHz) and a Bruker Avance III 400 (400 MHz). The spectra were recorded in $CDCl_3$ and d6-DMSO, respectively, as indicated in each case. Chemical shifts (δ) were reported in parts per million (ppm) and referenced to the remaining non-deuterated solvent signals of the deuterated solvents.[31] The following abbreviations are used to indicate the signal multiplicity: s (singlet), d (doublet), t (triplet), dd (doublet of doublet), dt (doublet of triplet), b (broad signal), m (multiplet). All NMR spectra were integrated and processed using the software MestReNova. The coupling constants (J) are reported in Hertz. NMR spectra are provided in the supporting information (SI). Accurate mass spectra (MS) were determined at the MS facility of the Institute of Organic Chemistry, Heidelberg University. All ionization methods (EI+, DART+, ESI–, MALDI+/–) were applied using following mass spectrometers: Bruker FT-ICR Apex-Qe, Bruker AutoFlex Speed TOF and JEOL JMS-700. The signal intensity of mass spectral peaks is given relatively to the base peak intensity. IR spectra of the samples were recorded as pellets in potassium carbonate with the FT-IR-spectrometer Varian 660-IR (Agilent Technologies, USA). The position of the peaks is indicated in wavenumbers $\tilde{\nu}$ in cm^{-1}. The following abbreviations are used to characterize the signals: s (strong), m (medium), w (weak) and b (broad). Elementary analysis was determined using a vario MIKRO cube by Elementar.

Synthetic Procedures

Synthesis of Alkyne 4 via Sonogashira Cross-Coupling: Iodide **3** (1.00 g, 3.38 mmol), $Pd(PPh_3)_2Cl_2$ (120 mg, 0.17 mmol), and copper iodide (64.0 mg, 0.34 mmol) were added to a vial with a magnetic stirrer bar and purged with argon. Then, degassed NEt_3 (5 mL) and 1-octyne (550 µL, 411 mg, 3.73 mmol) were added and the reaction mixture was stirred at 60 °C. After 2 d, Et_2O (100 mL) was added and the organic phase was washed with sat. NH_4Cl solution and brine. The combined organic phase was dried with $CaCl_2$ and the solvent was removed. After column chromatography (pentane/EtOAc = 15:1) and removing the solvent under high vacuum, 834 mg (90 %) of alkyne **4** were obtained as an off-white solid. R_f = 0.23 (pentane/EtOAc, 15:1); m.p. 125 °C; ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.53–7.39 (m, 6H, Ar-H), 6.96–6.84 (m, 2H, Ar-H), 4.88 (s, 1H, -OH), 2.43 (t, 2H, $^3J_{H,H}$ = 7.0 Hz, C≡C-CH_2), 1.64 (dd, $^3J_{H,H}$ = 15.0, 7.1 Hz, C≡CCH$_2$-CH_2), 1.55–1.41 (m, 2H, CH_3CH_2-CH_2), 1.33 (dt, J = 7.0, 3.6 Hz, CH_3-CH_2), 0.98–0.85 (m, 3H, CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 155.3, 139.8, 133.4, 132.0, 128.4, 126.5, 122.5, 115.8, 91.2, 80.6, 31.5, 28.9/28.8, 19.7, 14.2. IR (KBr): $\tilde{\nu}$ = 3402 (bs), 3031 (w), 2954 (m), 2928 (m), 2856 (m), 1610 (m), 1597 (m), 1497 (m), 1467 (m), 1447 (m), 1403 (w), 1376 (m), 1302 (w), 1261 (m), 1116 (w), 1135 (w), 820 (s), 551 (w), 519 (m). MS (ESI, neg.): m/z calcd. for $C_{20}H_{22}O$-H$^-$: 277.1598, found 277.1597; elemental analysis calcd. (%) for $C_{20}H_2O$: C 86.29 H 7.97; found C 86.17 H 7.81.

Pd-Catalyzed Hydration of Alkyne 4 to Alcohol 5: Palladium on charcoal (10 % Pd/C, 185 mg) was added to a solution of alkyne **4** (700 mg, 3.38 mmol) in EtOAc (40 mL). The flask was charged with H_2 (10 % in argon) and the reaction mixture was vigorously stirred at ambient conditions. After 15 h, Pd/C was filtered off and the

solvent was removed by rotary evaporation. After column chromatography (pentane/EtOAc = 10:1) and removing the solvent under high vacuum, 673 mg (95 %) of alcohol **5** were obtained as colorless solid. R_f = 0.49 (pentane/EtOAc, 10:1); m.p. 140 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.54 – 7.40 (m, 4H, Ar-H), 7.26 – 7.18 (m, 2H, Ar-H), 6.96 – 6.82 (m, 2H, Ar-3,5-H), 4.73 (s, 1H, OH), 2.63 (dd, $^3J_{H,H}$ = 8.8, 6.7 Hz, 2H, Ar-CH_2), 1.73 – 1.54 (m, 2H, Ar-CH_2-CH_2), 1.43–1.22 (m, 10H, -$(CH_2)_n$), 2.94 (m, 3H, -CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 154.9, 141.7, 138.2, 134.2, 128.9, 128.3, 126.7, 115.7, 35.7, 32.1, 31.7, 29.7, 29.5, 29.4, 22.8, 14.3. IR (KBr): $\tilde{\nu}$ = 3420 (bs), 3031 (w), 2957 (w), 2920 (m), 2848 (m), 1610 (m), 1501 (m), 1454 (w), 1378 (w), 1266 (m), 1245 (w), 814 (m), 785 (w), 506 (w). MS (ESI, neg.): *m/z* calcd. for $C_{20}H_{26}O$-H^-: 281.1911; found 281.1910; elemental analysis calcd. (%) for $C_{20}H_{26}O$: C 85.06 H 9.28; found C 85.18 H 9.19.

Synthesis of Aliphatic Ligand 1: Mixture **A**: 16-bromohexa-decanoic acid (**6**) (781 mg, 2.33 mmol) and NaH (60 % dispersion in mineral oil, 98 mg, 2.45 mmol) were added to a solution of dry toluene (25 mL) and dry DMSO (5 mL) and the reaction mixture was stirred at room temperature. After 4.5 h, tetrabutylammonium sulfate (38 mg, 0.11 mmol) was added and the reaction mixture was stirred at 60 °C for 30 min. Mixture **B**: Alcohol **5** (625 mg, 2.22 mmol) and NaH (60 % dispersion in mineral oil, 93 mg, 2.33 mmol) were added to a solution of dry toluene (25 mL) and dry DMSO (5 mL) and the mixture was stirred at RT. After 4 h, the reaction mixture was stirred at 60 °C for 1 h. Then, mixture **A** was added to mixture **B** with a syringe over a period of 30 min at 60 °C and after completion, the reaction mixture was stirred vigorously at 80 °C. After 20 h, 1 M HCl (30 mL) was added and the precipitate collected. The residue was washed with H_2O (2 × 10 mL), H_2O/EtOH = 3:2 (6 mL) and dried over-night under ambient conditions. The dry residue was suspended in refluxing MeOH (50 mL) and collected after cooling to ambient temperature. The white powder was suspended in $CHCl_3$ (120 mL) and TFA was added until the product was dissolved. The combined organic phase was washed with 1 M TFA (in H_2O, 3 × 10 mL), H_2O (20 mL) and the solvent was removed by rotary evaporation. Drying under high vacuum gave 965 mg (81 %) of aliphatic ligand **1** as a colorless solid. R_f = 0.23 (pentane/EtOAc = 15:1); m.p. 125 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.53–7.42 (m, 4H, Ar-H), 7.22 (d, $^3J_{H,H}$ = 8.1 Hz, 2H, Ar-H), 6.95 (d, $^3J_{H,H}$ = 8.8, 2H, Ar-3,5-H), 3.99 (t, $^3J_{H,H}$ = 6.5 Hz, 2H, OCH_2), 2.65–2.59 (m, 2H, Ar-CH_2), 2.35 (d, *J* = 7.5 Hz, 2H, OCH_2CH_2), 1.78 (q, $^3J_{H,H}$ = 6.9 Hz, 2H, Ar-CH_2-CH_2), 1.64–1.23 (m, 36H, -$(CH_2)_n$), 0.92–0.83 (m, 3H, -CH_3). 13C NMR: could not be measured due to poor solubility. IR (KBr): $\tilde{\nu}$ = 3031 (w), 2917 (s), 2850 (m), 1700 (m), 1653 (m), 1608 (m), 1501 (m), 1473 (m), 1430 (m), 1282 (m), 1251 (m), 1202 (m), 1182 (m), 1043 (m), 997 (w), 911 (w), 806 (m), 718 (m), 669 (m). MS (ESI, neg.): *m/z* calcd. for $C_{36}H_{56}O_3$ – H^-: 535.4157; found 535.4153; elemental analysis calcd. (%) for $C_{36}H_{56}O_3$: C 80.54 H 10.51; found C 80.37 H 10.57.

General Procedure for Mitsunobu Reaction (GP-1): Diisopropyl azodicarboxylate (2.4 equiv.) was added under argon with a syringe to a mixture of 11-bromoundecan-1-ol (**8**) (1.1 equiv.), alcohol (1.0 equiv.), PPh_3 (0.99 equiv.) and dry THF at 0 °C over a period of 20 min and after completion, the reaction mixture was allowed to stirr at ambient temperature. After 3 d, the solvent was removed under high vacuum. After column chromatography, washing with ethanol and removing the solvent under high vacuum, the bromides **9a**–**9c** were obtained.

Bromide 9a: Using the general procedure **GP-1**, DIAD (5.0 mL, 5.15 g, 25.4 mmol), 11-bromoundecan-1-ol **8** (2.86 g, 11.4 mmol), alkyne **4** (2.91 g, 10.4 mmol), PPh_3 (2.97 g, 11.3 mmol) and THF (24 mL) yielded 4.65 g (87 %) bromide **9a** as weak yellow solid after column chromatography (DCM/pentane = 3:5). R_f = 0.98 (DCM, stabilized with amylene); m.p. 82 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.56–7.40 (m, 6H, Ar-H), 7.01–6.90 (m, 2H, Ar-H), 3.99 (t, $^3J_{H,H}$ = 6.5 Hz, 2H), 3.41 (t, $^3J_{H,H}$ = 6.8 Hz, 2H), 2.42 (t, $^3J_{H,H}$ = 7.0 Hz, 2H), 1.83 (dt, $^3J_{H,H}$ = 14.1 Hz, 7.1 Hz, 2H), 1.69–1.55 (m, 2H), 1.45 (dt, $^3J_{H,H}$ = 10.4 Hz, 5.5 Hz, 6H), 1.39–1.22 (m, 22H, -CH_2-), 0.98–0.84 (m, 3H). 13C NMR (63 MHz, $CDCl_3$): δ = 159.0, 139.9, 132.0, 128.1, 126.5, 122.4, 114.9, 91.0, 80.6, 68.2, 34.2, 33.0, 31.5, 29.7, 29.6, 29.6, 29.5, 29.4, 28.9, 28.8, 28.3, 26.2, 22.7, 19.6, 14.2. IR (KBr): $\tilde{\nu}$ = 2919 (bs), 2849 (m), 1609 (m), 1578 (w), 1529 (m), 1496 (m), 1476 (m), 1466 (m), 1437 (w), 1391 (w), 1293 (m), 1252 (m), 1197 (m), 1178 (m), 1030 (m), 1010 (m), 828 (s), 724 (m), 652 (m), 564 (w), 521 (m). MS (DART, pos.): *m/z* calcd. for $C_{31}H_{43}Br^{79}$ + H^+: 511.2570; found 511.2574; elemental analysis calcd. (%) for $C_{31}H_{43}BrO$: C 72.78 H 8.47; found C 72.33 H 8.68.

Bromide 9b: Using the general procedure **GP-1**, DIAD (82.8 mg, 85 µL, 0.41 mmol), 11-bromoundecan-1-ol (**8**) (98.0 mg, 0.39 mmol), alcohol **4** (100 mg, 0.35 mmol), PPh_3 (102 mg, 0.39 mmol) and THF (0.4 mL) yielded 171 mg (94 %) bromide **9b** as colorless solid after column chromatography (DCM stabilized with amylene). R_f = 0.80 (DCM, stabilized with amylene); m.p. 62–67 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.48 (t, $^3J_{H,H}$ = 8.8 Hz, 4H, Ar-H), 7.29–7.16 (m, 2H, Ar-H), 6.95 (d, $^3J_{H,H}$ = 8.5 Hz, 2H), 3.99 (t, $^3J_{H,H}$ = 6.4 Hz, 2H, OCH_2), 3.41 (t, $^3J_{H,H}$ = 6.9 Hz, 2H, $BrCH_2$), 2.63 (t, $^3J_{H,H}$ = 7.9 Hz, 2H, $ArCH_2$), 1.92–1.75 (m, 4H, -CH_2-), 1.71–1.58 (m, 2H, -CH_2-), 1.56–1.22 (m, 22H, -CH_2-), 0.88 (t, $^3J_{H,H}$ = 7.9 Hz, -CH_2-). 13C NMR (63 MHz, $CDCl_3$): δ = 158.6, 141.5, 138.3 133.7, 128.0, 126.7, 114.8, 68.2, 35.7, 34.2, 33.0, 32.1, 31.7, 29.7, 29.6, 29.6, 29.5, 29.5, 29.4, 28.9, 28.3, 26.2, 22.8, 14.3. IR (KBr): $\tilde{\nu}$ = 2921 (s), 2851 (s), 1777 (w), 1647 (w), 1605 (m), 1582 (m), 1531 (w), 1501 (m), 1477 (m), 1463 (m), 1435 (w), 1397 (m), 1284 (m), 1270 (m), 1248 (m), 1213 (m), 1184 (m), 1139 (m), 1116 (m), 1039 (m), 861 (w), 814 (m), 782 (m), 723 (m), 651 (m), 592 (m), 509 (m), 491 (w). MS (DART, pos.): *m/z* calcd. for $C_{31}H_{47}BrO$ + H^+: 1048.5944; found 1048.5932; elemental analysis calcd. (%) for $C_{31}H_{47}BrO$: C 72.21 H 9.19; found C 72.22 H 9.31.

Bromide 9c: Using the general procedure **GP-1**, DIAD (5.69 g, 5.52 mL, 28.1 mmol), 11-bromoundecan-1-ol (**8**) (7.08 g, 29.9 mmol), alcohol **7** (.0 g, 25.6 mmol), PPh_3 (7.39 g, 28.2 mmol) and THF (20 mL) gave 10.9 g (99 %) bromide **9c** as colorless solid after column chromatography (DCM stabilized with amylene). R_f = 0.80 (DCM, stabilized with amylene); m.p. 78 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.67 (q, $^3J_{H,H}$ = 8.4 Hz, 4H, Ar-H), 7.58–7.47 (m, 2H, Ar-H), 6.99 (d, $^3J_{H,H}$ = 8.3 Hz, 2H), 4.00 (t, $^3J_{H,H}$ = 6.6 Hz, 2H, OCH_2), 3.41 (t, $^3J_{H,H}$ = 6.9 Hz, 2H, $BrCH_2$), 1.91–1.74 (m, 4H, -CH_2-), 1.54–1.22 (m, 16H, -CH_2-).

General Procedure for C(sp³)–C(sp³)-Negishi Cross-Coupling (GP-2): A vial was charged with zinc powder (2.4 equiv.), iodine (0.12 equiv.) and DMI and the mixture was stirred (slightly warmed). After the brownish color disappeared, compound **10a**–**10b** (1.6 equiv.) was added under inert atmosphere and the reaction mixture was stirred at 80 °C to give the corresponding organozinc compound (ca. 1.0 M) after 3 h. A second vial was charged with PEPPSI-IPr (1 mol-%), LiBr (1.6 equiv.) and dry THF and the mixture was stirred. After a solution was formed, the organozinc compound (1.6 equiv., 1.0 M in DMI) and bromide **9c** (1 equiv.) were added. The septum was replaced with a Teflon-lined screw cap under inert atmosphere and the reaction was stirred for 1 d. After this time, the mixture was diluted with THF (80 mL) and diethyl ether (40 mL) and washed successively with Na_3EDTA solution water, and brine. After drying over Na_2SO_4, the solution was filtered and the solvent removed in vacuo. After column chromatography (DCM; stabilized with amylene) and removing the solvent under high vacuum, ester **11a**–**11b** were obtained.

Ester 11a: Using the general procedure **GP-2**, zinc powder (79 mg, 1.2 mmol), iodine (10 mg, 0.06 mol), DMI (0.8 mL), methyl 7-bromoheptanoate (**10a**) (178 mg, 0.8 mmol), PEPPSI-IPr (3.4 mg,1 mol-%), LiBr (139 mg, 0.8 mmol), dry THF (1.6 mL), bromide **9c** (214 mg, 0.5 mmol) provided 157 mg (64 %) of ester **11a** as colorless solid. R_f = 0.47 (DCM, stabilized with amylene); m.p. 95 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.72–7.61 (m, 4H, Ar-H), 7.52 (d, $^3J_{H,H}$ = 8.5 Hz, 2H, Ar-H), 7.99 (d, $^3J_{H,H}$ = 8.5 Hz, 2H, Ar-H), 4.00 (t, $^3J_{H,H}$ = 6.5 Hz, 2H, OCH_2), 3.66 (s, 3H, CH_3), 2.30 (t, $^3J_{H,H}$ = 7.6 Hz, 2H, CCH_2), 1.81 (p, $^3J_{H,H}$ = 6.7 Hz, 2H, OCH_2CH_2), 1.61 (q, $^3J_{H,H}$ = 7.3 Hz, 2H, CCH_2CH_2), 1.51–1.42 (m, 2H, CCH_2CH_2), 1.41–1.10 (m, 28H, $(CH_2)_n$). 13C NMR (100 MHz, $CDCl_3$): δ = 174.5, 160.0, 145.5, 132.7, 131.4, 128.8, 127.2, 119.2, 115.3, 110.2, 68.4, 51.6, 34.3, 29.8, 29.8, 29.7, 29.6, 29.5, 29.4, 29.4, 29.3, 26.2, 25.1. IR (KBr): $\tilde{\nu}$ = 2916 (s), 2849 (s), 2226 (m), 1723 (s), 1603 (m), 1498 (m), 1471 (m), 1435 (m), 1393 (m), 1328 (m), 1293 (m), 1268 (m), 1248 (s), 1214 (m), 1197 (m), 1119 (m), 1040 (m), 887 (w), 860 (w), 825 (s), 802 (m), 716 (m), 668 (m), 564 (m), 531 (m). MS (DART, pos.): *m/z* calcd. for $C_{32}H_{45}NO_3 + NH_4^+$: 509.3738; found 509.3737; elemental analysis calcd. (%) for $C_{32}H_{45}NO_3$: C 78.17 H 9.22, N 2.85; found C 77.82 H 9.22 N 2.54.

Ester 11b: Using the general procedure **GP-2**, zinc powder (79 mg, 1.2 mmol), iodine (10 mg, 0.06 mol), DMI (0.8 mL), methyl 15-bromopentadecanoate (**10b**) (178 mg, 0.8 mmol), PEPPSI-IPr (3.4 mg,1 mol-%), LiBr (139 mg, 0.8 mmol), dry THF (1.6 mL), bromide **9c** (214 mg, 0.5 mmol) yielded 193 mg (63 %) ester **11a** as colorless solid. R_f = 0.55 (DCM, stabilized with amylene); m.p. 104 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.74–7.60 (m, 4H, Ar-H), 7.53 (d, $^3J_{H,H}$ = 8.7 Hz, 2H, Ar-H), 7.05–6.93 (m, Ar-H), 4.00 (t, $^3J_{H,H}$ = 6.5 Hz, 2H, OCH_2), 3.66 (s, 3H, CH_3, CH_3), 2.30 (t, $^3J_{H,H}$ = 6.8 Hz, 2H, CCH_2), 1.81 (p, $^3J_{H,H}$ = 6.8 Hz, 2H, OCH_2CH_2), 1.61 (t, $^3J_{H,H}$ = 6.5 Hz, 2H, CCH_2CH_2), 1.25 (bs, 48H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 132.7, 128.5, 127.2, 115.2, 111.2, 107.8, 97.4, 68.3, 51.6, 29.9 (m). IR (KBr): $\tilde{\nu}$ = 2916 (s), 2849 (s), 2226 (m), 1722 (m), 1603 (m), 1498 (m), 1472 (m), 1435 (m), 1393 (m), 1330 (w), 1289 (m), 1265 (m), 1249 (m), 1213 (m), 1186 (m), 1117 (w), 1043 (m), 999 (w), 886 (w), 825 (s), 717 (m), 668 (m), 568 (w), 531 (m). MS (DART, pos.): *m/z* calcd. for $C_{40}H_{61}NO_3 + NH_4^+$: 621.4990; found 621.4987; elemental analysis calcd. (%) for $C_{40}H_{61}NO_3{\cdot}CH_2Cl_2$: C 79.55 H 10.18 N 2.32; found C 75.49 H 9.83 1.73.

General Procedure for Etherfication (GP-3): Triol **12a–b** (1.0 equiv.), bromide **9a–c** (3.5 equiv.), K_2CO_3 (35 equiv.) and tetrabutylammonium hydrogensulfate (1 mol-%) were added under argon to dry acetone and the reaction mixture was stirred under reflux. After 3 days, the residue was collected.

Iodide 13a: Using the general procedure **GP-3**, triol **12b** (416 mg, 1.65 mmol), bromide **9a** (3.00 g, 5.80 mmol), K_2CO_3 (2.30 g, 58.0 mmol) and tetrabutylammonium hydrogensulfate (5 mg), dry acetone (40 mL) provided the crude product. After washing with acetone (3 × 40 mL), ethanol (2 × 40 mL) and cyclohexane (2 × 40 mL) the crude product was taken up onto Celite®. After column chromatography (DCM/pentane = 3:5) and removing the solvent under high vacuum 1.91 g (75 %) of iodide **13a** were obtained as colorless solid. R_f = 0.82 (DCM, stabilized with amylene); m.p. 109 °C, 1H NMR (250 MHz, $CDCl_3$): δ = 7.56–7.38 (m, 18H, Ar-H), 6.94 (dd, $^3J_{H,H}$ = 8.8 Hz, 3.0 Hz, 6H, Ar-H), 6.84 (s, 2H, Ar-H), 4.09–3.82 (m, 12H, $(OCH_2)_n$), 2.42 (t, *J* = 7.0 Hz, 6H, C≡C-CH_2) 1.77 (td, $^3J_{H,H}$ = 9.1 Hz, 4.4 Hz, 10H, $(CH_2)_n$), 1.66–1.53 (m, 64H, $(CH_2)_n$), 0.91 (td, $^3J_{H,H}$ = 6.8 Hz, 5.7 Hz, 2.9 Hz, 9H, -CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 159.0, 154.1, 139.9, 132.9, 132.0, 128.1, 126.5, 122.4, 116.2, 114.9, 91.0, 80.6, 69.4, 68.2, 31.5, 30.4, 29.9, 29.8, 29.7, 29.6, 29.5, 29.4, 28.9, 28.8, 26.2, 26.2, 22.7, 19.7, 14.2. IR (KBr): $\tilde{\nu}$ = 3038 (w), 2920 (s), 2851 (m), 1607 (m), 1580 (m), 1528 (m), 1496 (m), 1468 (m), 1415 (m), 1392 (m), 1287 (m), 1249 (m), 1197 (m), 1179 (m), 1121 (s), 1038 (m), 1000 (m), 822 (s), 721 (m), 653 (m), 567 (m), 521 (m), 479 (w), 331 (w). MS (MALDI, pos.): *m/z* calcd. for $C_{99}H_{131}IO_6^+$: 1543.9024; found 1543.9026; elemental analysis calcd. (%) for $C_{99}H_{131}IO_6$: C 77.01 H 8.55, found: C 77.00 H 8.77.

Bromide 13b: Using the general procedure **GP-3**, triol **12a** (315 mg, 2.50 mmol), bromide **9b** (3.75 g, 8.75 mmol), K_2CO_3 (3.46 g, 25.0 mmol) and tetrabutylammonium hydrogensulfate (5 mg), dry acetone (60 mL) provided the crude product. Then, DCM (600 mL) was added, the combined organic phase was washed with water (2 × 250 mL), brine (150 mL), dried with Na_2SO_4, Celite® was added and the solvent was removed inhigh vacuum. After column chromatography (DCM; stabilized with amylene) and removing the solvent under high vacuum, 2.83 g (90 %) of bromide **13b** were obtained as colorless solid. R_f = 0.40 (DCM, stabilized with amylene); m.p. 121–122 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.71–7.59 (m, 12H, Ar-H), 7.51 (dd, $^3J_{H,H}$ = 8.8 Hz, 3.0 Hz, 6H, Ar-H), 6.97 (dd, $^3J_{H,H}$ = 8.8 Hz, 3.8 Hz, 6H, Ar-H), 6.67 (s, 2H, Ar H), 4.04–3.87 (m, 12H, $(OCH_2)_n$), 1.86–1.67 (m, 12H, $(CH_2)_n$), 1.47 (s, 12H, $(CH_2)_n$), 1.31 (bs, 30H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 159.9, 153.9, 145.4, 137.4, 132.4, 131.4, 128.4, 127.2, 119.3, 115.7, 115.2, 110.2, 73.5, 69.4, 68.3, 30.4. 29.8, 29.8, 29.7, 29.7, 29.6, 29.5, 29.5, 29.4, 26.2, 26.2, 26.1. IR (KBr): $\tilde{\nu}$ = 2916 (s), 2850 (s), 2223 (m), 1603 (s), 1581 (m), 1521 (w), 1495 (s), 1473 (m), 1420 (m), 1391 (m), 1312 (w), 1291 (m), 1249 (s), 1180 (m), 1112 (m), 1035 (m), 998 (m), 819 (m), 718 (m), 560 (w), 530 (m). MS (DART, pos.): *m/z* calcd. for $C_{78}H_{92}BrN_3O_6 + Na^+$: 1268.6067; found 1268.6062; elemental analysis calcd. (%) for $C_{78}H_{92}BrN_3O_6$: C 75.10 H 7.34 N 3.37; found C 74.49 H 7.42 N 3.17.

Bromide 13c: Using the general procedure **GP-3**, triol **12a** (985 mg, 3.91 mmol), bromide **9c** (7.50 g, 17.5 mmol), K_2CO_3 (7.41 g, 53.6 mmol) and tetrabutylammonium hydrogensulfate (11 mg), dry acetone (140 mL) provided the crude product. After washing with acetone (2 × 80 mL) and EtOAc (2 × 80 mL), the crude product was taken up onto Celite®. After column chromatography (DCM, stabilized with amylene) and removing the solvent under high vacuum, 4.17 g (81 %) of bromide **13c** were obtained as colorless solid. R_f = 0.43 (DCM, stabilized with amylene); m.p. 126 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.73–7.58 (m, 12H, Ar-H), 7.51 (dd, $^3J_{H,H}$ = 8.8 Hz, 2.0 Hz, 6H, Ar-H), 6.98 (dd, $^3J_{H,H}$ = 8.9 Hz, 2.5 Hz, 6H, Ar-H), 6.84 (s, 2H, Ar H), 4.12–3.75 (m, 12H, $(OCH_2)_n$), 1.78 (dp, $^3J_{H,H}$ = 15.2 Hz, 8.7 Hz, 7.7 Hz 12H, $(CH_2)_n$), 1.62–1.25 (m, 32H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 159.9, 154.0, 145.4, 138.4, 132.7, 131.3, 128.4, 127.2, 119.3, 116.2, 115.2, 110.1, 69.4, 68.3, 30.4, 29.8, 29.8, 29.7, 29.7, 29.6, 29.5, 29.5, 29.4, 29.4, 26.2, 26.2, 26.1. IR (KBr): $\tilde{\nu}$ = 3042 (w), 2915 (s), 2850 (s), 2223 (m), 1734 (m), 1653 (w), 1603 (s), 1581 (m), 1521 (m), 1494 (s), 1473 (m), 1415 (m), 1395 (m), 1291 (m), 1249 (s), 1181 (m), 1110 (s), 1036 (m), 998 (m), 850 (m), 818 (s), 779 (m), 660 (w), 561 (m), 530 (m). Elemental analysis calcd. (%) for $C_{78}H_{92}IN_3O_6$: C 72.37 H 7.16 N 3.32; found C 72.40 H 7.04 N 3.02.

Iodide 13d: Using the general procedure **GP-3**, triol **12b** (177 mg, 0.86 mmol), bromide **9c** (1.56 g, 3.02 mmol), K_2CO_3 (1.20 g, 30.2 mmol) and tetrabutylammonium hydrogensulfate (5 mg), dry acetone (20 mL) provided the crude product under exclusion of light. After washing with acetone/water (3:2) (100 mL) and EtOAc (2 × 25 mL), the crude product was taken up onto Celite®. After column chromatography (DCM, stabilized with amylene) and removing the solvent under high vacuum, 1.07 g (82 %) of iodide **13d** were obtained as colorless solid. R_f = 0.81 (DCM/pentane, 3:5); m.p. 114 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.54–7.39 (m, 12H, Ar-H), 7.21 (d, $^3J_{H,H}$ = 7.9 Hz, 6H, Ar-H), 6.94 (dd, $^3J_{H,H}$ = 8.8 Hz, 2.4 Hz, 6H, Ar-H), 6.67 (s, 2H, Ar H), 4.04–3.87 (m, 12H, $(OCH_2)_n$), 2.69–2.53 (m, 6H, Ar-CH_2), 1.90–1.70 (m, 12H, $(CH_2)_n$), 1.71–1.58 (m, 6H, $(CH_2)_n$),

1.52–1.12 (m, 12H, $(CH_2)_n$), 0.97–0.79 (m, 9H, CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 158.6, 153.9, 141.5, 138.3, 137.4, 133.6, 128.9, 128.1, 126.7, 115.7, 114.8, 110.1, 35.7, 32.1, 31.7, 29.8, 29.7, 29.7, 29.6, 29.5, 29.4, 26.2, 26.2, 22.8. IR (KBr): $\tilde{\nu}$ = 3030 (w), 2918 (s), 2850 (s), 1608 (s), 1583 (m), 1530 (w), 1501 (m), 1467 (m), 1422 (m), 1383 (m), 1253 (m), 1218 (m), 1180 (m), 1123 (m), 1040 (m), 1000 (m), 861 (m), 810 (m), 720 (m), 691 (w), 593 (w), 577 (w), 501 (w). MS (MALDI, pos.): *m/z* calcd. for for $C_{99}H_{143}BrO_6 + H^+$: 1509.018; found 1509.005; elemental analysis calcd. (%) for $C_{78}H_{92}BrN_3O_6$: C 78.79 H 9.55; found C 78.32 H 9.66.

Synthesis of Alkyne 14a: Benzyl bromide (750 µL, 1078 mg, 6.30 mmol) was added dropwise at 0 °C to a mixture of undec-10-ynoic acid (1092 mg, 6.00 mmol), anhydrous K_2CO_3 (1.24 g, 9.00 mmol) and dry DMF (9 mL) and after completion, the reaction mixture was stirred at ambient temperature. After 1 day, ethyl acetate (50 mL) was added and the combined organic phase was washed with H_2O (2 × 50 mL) and brine (2 × 50 mL) and dried with Na_2SO_4. After removing the solvent under high vacuum, 1.49 g (95 %) of alkyne **14a** were obtained as yellow liquid. η(D/20) = 1.511; 1H NMR (250 MHz, $CDCl_3$): δ = 7.35 (bs, 5H, Ar-H), 5.11 (s, 2H, Bn-CH_2), 2.34 (d, $^3J_{H,H}$ = 7.6 Hz, 2H, C≡C-CH_2), 2.17 (td, $^3J_{H,H}$ = 7.0 Hz, 2.6 Hz, 2H, COO-CH_2), 1.94 (t, $^3J_{H,H}$ = 7.6 Hz, 1H, C≡C-H), 1.66 (q, $^3J_{H,H}$ = 7.0 Hz, 6.4 Hz, 2H, COO-CH_2-CH_2), 1.50 (q, $^3J_{H,H}$ = 7.5 Hz, 2H, C≡C-CH_2-CH_2), 1.45–1.19 (m, 8H, (-CH_2-)$_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 173.8, 136.2, 128.7, 128.3, 84.9, 68.2, 66.2, 34.4, 29.2, 29.2, 29.0, 28.8, 28.6, 25.1, 18.5. IR (KBr): $\tilde{\nu}$ = 3300 (m), 2932 (m), 2857 (m), 2117 (w), 1737 (s), 1587 (w), 1499 (m), 1461 (m), 1383 (m), 1352 (m), 1258 (m), 1235 (m), 1166 (m), 1099 (m), 1003 (m), 910 (m), 826 (w), 751 (m), 737 (m), 698 (m), 632 (m), 507 (m), 339 (m). MS (EI, pos.): *m/z* calcd. for $C_{18}H_{24}O_2 + H^+$: 273.1849; found 273.1845; elemental analysis calcd. (%) for $C_{18}H_{24}O_2$: C 79.37 H 8.88; found C 78.96 H 8.81.

General Procedure for the Sonogashria Cross-Coupling in DMF (GP-4): Compound **13b**–**d** (1.0 equiv.), $Pd(PPh_3)_2Cl_2$ (35 mol-%), copper iodide (38 mol-%) and a magnetic stirrer bar were added to a vial and purged with argon. Then, degassed DMF, NEt_3 and alkyne **14a** (3.05 equiv.) were added and the reaction mixture was stirred. After completion of the reaction, isopropyl alcohol was added. The crude product was collected and washed with isopropyl alcohol. Then, celite® and DCM was added and the solvent was removed.

Benzyl Ester 15a: Using the general procedure **GP-4**, bromide **13b** (532 mg, 353 µmol), $Pd(PPh_3)_2Cl_2$ (88.0 mg, 125 µmol), copper iodide (26.0 mg, 137 µmol), DMF (13 mL), NEt_3 (3.5 mL) and benzyl ester **14a** (295 mg, 1.08 mmol) provided the crude product after 35 min at 90 °C. The amount of isopropyl alcohol was 100 mL and 30 mL. After column chromatography (DCM/pentane = 3:1) and removing the solvent under high vacuum, 243 mg (40 %) of benzyl ester **15a** were obtained as a weak yellow solid. R_f = 0.34 (DCM/pentane = 4:5); m.p. 83–86 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.47 (t, $^3J_{H,H}$ = 8.3 Hz, 12H, Ar-H), 7.35 (s, 5H, ArBn-H), 7.21 (s, 5H, d, $^3J_{H,H}$ = 8.4 Hz, 6H, Ar H), 7.00–6.87 (m, 6H, Ar H), 6.59 (s, Ar-H), 5.11 (s, 2H, OBn-CH_2), 4.03–3.88 (m, 12H, O-CH_2), 2.62 (t, $^3J_{H,H}$ = 7.6 Hz, 6H, Ar-CH_2), 2.45–2.27 (m, 4H, $(CH_2)_n$), 1.93–1.69 (m, 12H, $(CH_2)_n$), 1.69–1.52 (m, 10H, $(CH_2)_n$), 1.52–1.07 (m, 84H, $(CH_2)_n$), 0.88 (t, $^3J_{H,H}$ = 6.4 Hz, 9H, -CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 173.8, 158.6, 141.5, 138.3, 133.6, 128.9, 128.1, 126.7, 118.6, 114.8, 35.7, 32.0, 29.7, 29.6, 29.5, 29.5, 29.4, 29.3, 29.2, 26.2, 22.8, 14.2. IR (KBr): $\tilde{\nu}$ = 3030 (w), 2920 (s), 2851 (s), 1737 (m), 1608 (m), 1572 (m), 1530 (w), 1501 (s), 1466 (m), 1418 (m), 1384 (w), 1254 (m), 1121 (m), 1041 (m), 999 (w), 811 (m), 721 (m), 696 (m), 501 (m). MS (MALDI, pos.): *m/z* calcd. for $C_{117}H_{166}O_8^+$: 1699.2577; found 1699.2577; elemental analysis calcd. (%) for $C_{117}H_{166}O_8$: C 82.63 H 9.84; found C 82.10 H 9.92.

Benzyl Ester 15b: Using the general procedure **GP-4**, iodide **13d** (50.0 mg, 38 µmol), $Pd(PPh_3)_2Cl_2$ (8.3 mg, 117 µmol), copper iodide (2.6 mg, 13 µmol), DMF (1.2 mL), NEt_3 (0.3 mL) and benzyl ester **14a** (13.3 mg, 49.0 mmol) provided the crude product after 3 h at room temperature. The amount of isopropyl alcohol was 10 mL and 3 mL. After column chromatography (DCM) and removing the solvent under high vacuum, 47 mg (84 %) of benzyl ester **15a** were obtained as a weak yellow solid. R_f = 0.47 (DCM); m.p. 78 °C; 1H NMR (400 MHz, $CDCl_3$): δ = 7.65 (q, $^3J_{H,H}$ = 8.4 Hz, 12H, Ar-H), 7.51 (d, $^3J_{H,H}$ = 8.7 Hz, 6H, Ar-H), 7.35 (s, 5H, ArBn-H), 6.98 (d, $^3J_{H,H}$ = 8.4 Hz, 6H, Ar-H), 6.59 (d, $^3J_{H,H}$ = 8.4 Hz, 2H, ArAlkyne-H), 5.11 (s, 2H, OBn-CH_2), 4.07–3.84 (m, 12H, O-CH_2), 2.41–2.29 (m, 4H, $(CH_2)_n$), 1.89–1.59 (m, 14H, $(CH_2)_n$), 1.56–1.18 (m, 52H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 159.9, 153.0, 145.4, 132.7, 131.4, 128.5, 127.2, 115.2, 110.2, 68.3, 34.4, 29.8, 29.7, 29.6, 29.5, 29.5, 29.4, 29.4, 26.2. IR (KBr): $\tilde{\nu}$ = 3030 (w), 2921 (m), 2851 (m), 2225 (m), 1742 (m), 1730 (m), 1604 (s), 1579 (m), 1524 (m), 1494 (m), 1468 (m), 1391 (m), 1353 (w), 1314 (w), 1290 (m), 1247 (s), 1181 (m), 1119 (s), 1031 (m), 1000 (m), 853 (m), 823 (s), 738 (m), 723 (m), 697 (w), 660 (m), 564 (m), 532 (m). MS (MALDI, pos.): *m/z* calcd. for $C_{96}H_{115}N_3O_{81} + H^+$: 1438.876; found 1438.868; elemental analysis calcd. (%) for $C_{96}H_{115}N_3O_{81}$ 1/6CH_2Cl_2: C 79.49 H 2.84 N 2.89; found C 79.25 H 8.09 N 2.56.

General Procedure for the Sonogashria Cross-Coupling in Toluene (GP-5): Iodide **13d** (1.0 equiv.), $Pd(PPh_3)_2Cl_2$ (4.75 mol-%), copper iodide (15.0 mol-%) were mixed, and, afterwards, degassed toluene and a magnetic stirrer bar were added and purged with argon. Then, $HNEt_2$ and alkyne (**14a**–**c**) (5.0 equiv.) were added and the reaction mixture was stirred at ambient conditions. After 20 h, DCM (40 mL) were added and washed with saturated NH_4Cl solution (2 × 40 mL) and brine (1 × 40 mL) and dried with Na_2SO_4. Then, celite® was added and the solvent was removed. Column chromatographic purification (DCM) gave the dendritic ligand **15c**–**e**.

Dendritic Ligand 15c: Using the general procedure **GP-4**, iodide **13d** (1.00 g, 772 µmol), $Pd(PPh_3)_2Cl_2$ (22.0 mg, 36.7 µmol), copper iodide (22.0 mg, 116 µmol), toluene (5.5 mL), $HNEt_2$ (400 µL) hex-1-en-5-yne (**14b**) (322 mg, 440 µL, 4.01 mmol) provided 865 mg (89 %) of dendritic ligand **15c** as a weak yellow waxy solid after removing the solvent under high vacuum. R_f = 0.45 (DCM); m.p. 63 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.65 (q, 12H, $^3J_{H,H}$ = 8.2 Hz, Ar-H), 7.51 (dd, $^3J_{H,H}$ = 8.8 Hz, 2.1 Hz, 6H, Ar-H), 6.98 (d, $^3J_{H,H}$ = 8.7 Hz, 6H, Ar-H), 6.60 (s, 2H, Aralkyne-H), 6.02–5.80 (m, 1H, CH=CH_2), 5.19–4.99 (m, 2H, 1H, CH=CH_2), 3.96 (dt, $^3J_{H,H}$ = 13.7 Hz, 12H, OCH_2), 1.81–1.56 (m, 4H, C-CH_2-CH_2), 1.91–1.62 (m, 12H, $(CH_2)_n$), 1.61–1.17 (m, 42H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 159.9, 153.0, 145.4, 137.1, 132.7, 131.3, 128.4, 127.2, 119.3, 118.5, 115.8, 115.2, 110.1, 100.1, 88.3, 73.6, 69.1, 68.3, 33.1, 30.4, 29.8, 29.8, 29.7, 29.7, 29.6, 29.5, 29.5, 29.5, 29.4, 26.1, 19.4. IR (KBr): $\tilde{\nu}$ = 3062 (w), 3042 (w), 2921 (m), 2851 (m), 2225 (m), 1604 (s), 1575 (m), 1521 (m), 1495 (s), 1473 (m), 1418 (m), 1390 (m), 1352 (w), 1290 (m), 1248 (s), 1180 (m), 1117 (m), 1033 (m), 1000 (m), 914 (w), 855 (m), 823 (s), 721 (w), 661 (w), 564 (m), 531 (m). MS (MALDI, pos.): *m/z* calcd. for $C_{84}H_{99}N_3O_6 + H^+$: 1246.7534; found 1246.7534; elemental analysis calcd. (%) for $C_{117}H_{166}O_8$: C 80.93 H 8.00 N 3.37; found C 80.64 H 7.99 N 3.08.

Dendritic Ligand 15d: Using the general procedure **GP-4**, iodide **13d** (600 mg, 463 µmol), $Pd(PPh_3)_2Cl_2$ (13.2 mg, 18.8 µmol), copper iodide (13.2 mg, 69.3 µmol), toluene (3.3 mL), $HNEt_2$ (240 µL) and trimethyl-silylacetylene (**14c**) (322 mg, 440 µL, 4.01 mmol) provided 533 mg (90 %) of dendritic ligand **15d** as colorless solid after removing the solvent under high vacuum. R_f = 0.36 (DCM); m.p. 91 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.65 (q, 12H, $^3J_{H,H}$ = 8.2 Hz, Ar-H),

7.75–7.59 (m, 12H, Ar-H), 7.51 (dd, $^3J_{H,H}$ = 8.8 Hz, 2.0 Hz, 6H, Ar-H), 6.98 (d, $^3J_{H,H}$ = 8.9 Hz, 6H, Ar-H), 6.66 (s, 2H, Ar-alkyne-H), 4.06–3.81 (m, 12H, OCH_2), 1.90–1.64 (m, 12H, $(CH_2)_n$), 1.45–1.15 (m, 42H, $(CH_2)_n$), 0.24 (s, 9H, CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 159.9, 153.0, 146.1, 145.8, 145.4, 132.7, 131.4, 128.4, 127.2, 119.3, 117.6, 115.2, 110.5, 110.1, 73.6, 69.1, 68.3, 33.1, 30.4, 29.8, 29.8, 29.7, 29.6, 29.6, 29.5, 29.5, 29.4, 29.4, 26.2, 0.2. IR (KBr): $\tilde{\nu}$ = 3039 (w), 2921 (m), 2852 (m), 2226 (m), 2150 (m), 1604 (m), 1576 (m), 1521 (m), 1495 (s), 1473 (m), 1419 (m), 1391 (m), 1340 (w), 1290 (m), 1248 (s), 1180 (m), 1118 (m), 1031 (m), 1000 (m), 822 (s), 759 (m), 721 (w), 661 (w), 634 (w), 564 (m), 531 (m). MS (MALDI, pos.): *m/z* calcd. for $C_{83}H_{101}N_3O_6Si$ + H^+: 1264.7464; found 1264.7538; elemental analysis calcd. (%) for $C_{83}H_{101}N_3O_6Si$: C 78.82 H 8.05 N 3.32; found C 78.58 H 8.21 N 3.11.

Dendritic Ligand 15e: Using the general procedure **GP-4**, iodide **13e** (1.11 g, 859 µmol), $Pd(PPh_3)_2Cl_2$ (25.0 mg, 42.8 µmol), copper iodide (25.0 mg, 131 µmol), toluene (6 mL), $HNEt_2$ (440 µL) and propargyl alcohol (**21**) (250 mg, 260 µL, 428 µmol) provided 1.02 g (97 %) of dendritic ligand **15e** as colorless solid after removing the solvent under high vacuum. 22 mg (2 %) of iodide **13d** were recovered. R_f = 0.42 (DCM); m.p. 103 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.77–7.57 (m, 12H, Ar-H), 7.55–7.42 (m, 6H), 6.98 (dd, $^3J_{H,H}$ = 8.9 Hz, 2.4 Hz, 6H, Ar-H), 6.64 (s, 2H, Ar-H), 4.47 (s, 2H, HO-CH_2), 4.12–3.83 (m, 12H, OCH_2), 1.91–1.62 (m, 14H, $(CH_2)_n$), 1.61–1.17 (m, 44H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 159.9, 153.0, 145.3, 139.2, 132.7, 131.3, 128.4, 127.1, 119.2, 117.1, 115.2, 110.3, 110.1, 86.1, 73.6, 69.2, 68.3, 51.7, 30.4, 29.8, 29.7, 29.7, 29.7, 29.5, 29.5, 29.4, 29.3, 26.2. IR (KBr): $\tilde{\nu}$ = 3451 (bm), 3042 (w), 2918 (m), 2850 (m), 2223 (m), 1603 (s), 1573 (m), 1523 (m), 1495 (s), 1468 (m), 1421 (m), 1390 (m), 1342 (m), 1291 (m), 1249 (s), 1181 (m), 1114 (m), 1055 (m), 1032 (m), 999 (m), 852 (m), 816 (s), 719 (w), 661 (w), 562 (m), 531 (m). MS (MALDI, pos.): *m/z* calcd. for $C_{81}H_{95}N_3O_7$ + Na^+: 1244.7068; found 1244.6340; elemental analysis calcd. (%) $C_{81}H_{95}N_3O_7$: C 79.57 H 7.83 N 3.44; found C 79.16 H 7.58 N 3.39.

Deprotection for Dendritic Ligand 16: Palladium on charcoal (10 % Pd/C, 120 mg) was added to a solution of benzyl ester **15a** (150 mg, 88.0 µmol) in THF (70 mL). The flask was charged with H_2 (10 % in argon) and the reaction mixture was vigorously stirred at ambient conditions. After 12 h, Pd/C was filtered off and the solvent was removed by rotary evaporation. After removing the solvent under high vacuum, 142 mg (99 %) of dendritic ligand **16** were obtained as colorless solid. M.p. 98–101 °C, 1H NMR (250 MHz, $CDCl_3$): δ = 7.53–7.40 (m, 12H, Ar-H), 7.21 (d, 6H, $^3J_{H,H}$ = 7.9 Hz, Ar-H), 6.93 (dd, 6H, $^3J_{H,H}$ = 8.8 Hz, 2.1 Hz, Ar-H), 6.36 (s, 2H Ar-H), 4.03–3.87 (m, 12H, O-CH_2), 2.70–2.56 (m, 6H, Ar-CH_2), 2.57–2.41 (m, 2H), 2.34 (t, $^3J_{H,H}$ = 7.5 Hz, 2H), 1.77 (h, $^3J_{H,H}$ = 6.1, 5.7 Hz, 12H, $(CH_2)_n$), 1.61 (q, $^3J_{H,H}$ = 7.5 Hz, 10H, $(CH_2)_n$), 1.54–1.12 (m, 90H, $(CH_2)_n$), 0.92–0.83 (m, 9H, -CH_3). 13C NMR (63 MHz, $CDCl_3$): δ = 189.9, 166.3, 161.3, 158.6, 157.0, 141.5, 138.3, 128.9, 128.0, 126.7, 114.8, 68.2, 35.7, 32.1, 31.7, 29.8, 29.7, 29.7, 29.6, 29.6, 29.4, 26.2, 22.8, 14.3. IR (KBr): $\tilde{\nu}$ = 3436 (bm), 3030 (w), 2919 (s), 2851 (s), 1708 (m), 1608 (m), 1583 (m), 1502 (m), 1466 (m), 1436 (m), 1384 (m), 1255 (m), 1214 (m), 1180 (m), 1121 (m),1043 (m), 812 (m), 722 (m), 593 (w), 500 (m). MS (MALDI, neg.): *m/z* calcd. for $C_{110}H_{164}O_8$ – H^-: 1613.238; found 1613.234; elemental analysis calcd. (%) for $C_{110}H_{164}O_8$ 1/8CH_2Cl_2: C 81.40 H 10.20, found: C 81.09 H 10.14.

Synthesis of Model Compound 18: Triflate **17** (327 mg, 1.00 mmol), $Pd(PPh_3)_2Cl_2$ (47.0 mg, 67.0 µmol), copper iodide (17.5 mg, 92.1 µmol), lithium chloride (55.1 mg, 1.3 mmol) and a magnetic stirrer bar were added to a vial and purged with argon. Then, degassed DMF (12.0 mL), NEt_3 (3.0 mL) and benzyl ester **14a** (350 mg, 1.22 mmol) were added and the reaction mixture was stirred at 85 °C. After 14 h, EtOAc (20 mL) was added at r.t., the combined organic phase was washed with sat. NH_4Cl (4 × 20 mL) and brine (2 × 20 mL) and dried with Na_2SO_4. The solved was removed under vacuum. After column chromatography (pentane/EtOAc = 10:1) and removing the solvent under high vacuum, 299 mg (67 %) of model compound **18** were obtained as a solid. R_f = 0.70 (DCM); m.p. 34–42 °C; 1H NMR (400 MHz, $CDCl_3$): δ = 7.77–7.62 (m, 4H, Ar-H), 7.58–7.44 (m, 2H, Ar-H), 7.35 (s, 5H, ArBn-H), 5.11 (s, 2H, OBn-CH_2), 2.42 (t, $^3J_{H,H}$ = 7.1 Hz, 2H, COO-CH_2), 2.36 (t, $^3J_{H,H}$ = 7.5 Hz, 2H, ≡C-CH_2), 1.63 (dt, $^3J_{H,H}$ = 15.0 Hz, 7.4 Hz, 2H, CH_2), 1.50–1.40 (m, 2H, CH_2), 1.33 (s, 6H, CH_2). 13C NMR (63 MHz, $CDCl_3$): δ = 173.8, 136.2, 133.0, 132.8, 132.4, 129.3, 128.7, 128.3 128.0, 127.7, 127.1, 122.3, 92.5, 66.2, 35.1, 34.5, 29.3, 29.2, 29.1, 29.0, 28.8, 25.1, 19.6. IR (KBr): $\tilde{\nu}$ = 3035 (w), 2931 (m), 2856 (m), 2227 (m), 1722 (m), 1605 (m), 1491 (m), 1468 (m), 1422 (m), 1391 (m), 1328 (w), 1247 (m), 1214 (m), 1170 (m), 1005 (w), 951 (m), 887 (m), 858 (m), 825 (s), 749 (m), 697 (m), 633 (m), 613 (m), 580 (m), 540 (m), 505 (w). MS (DART, pos.): *m/z* calcd. for $C_{32}H_{33}NO_2$ + H^+: 450.2428; found 450.2427.

Synthesis of Dendritic Ligand 2: Method **A**: Dendritic ligand **15e** (679 mg, 555 µmol), succinic anhydride (**21a**) (76.6 mg, 765 µmol), and DMAP (155 mg, 1.27 mmol) were solved in dry DCM (3.3 mL) under argon and the reaction mixture was stirred at room temperature. After 1 day, DCM (70 mL) was added and the combined organic phase was washed with 0.5 M HCl solution (2 × 120 mL) and water (100 mL). After removing the solvent under high vacuum, 719 mg (95 %) of dendritic ligand **2** were obtained as a colorless solid. Method **B**: First, DMAP (51.5 mg, 442 µmol) was added to a solution of succinic acid (**21b**) (24.0 mg, 203 µmol) and DCC (8.9 mg, 43.1 µmol) in dry DCM/DMF = 1:1 (1 mL) under argon. Second, dendron **15e** (50.0 mg, 40.9 µmol) was added under argon and the reaction mixture was stirred at room temperature. After 2 days, DCM (10 mL) was added and the combined organic phase was washed with 0.5 M HCl solution (2 × 10 mL) and water (3 × 10 mL). After removing the solvent under high vacuum, 53.1 mg (98 %) of dendritic ligand **2** were obtained as a colorless solid. M.p. 88–95 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.78–7.56 (m, 12H, Ar-H), 7.51 (dd, $^3J_{H,H}$ = 8.8 Hz, $^3J_{H,H}$ = 1.9 Hz, 6H), 6.98 (dd, $^3J_{H,H}$ = 8.8 Hz, 2.4 Hz, 6H, Ar-H), 6.65 (s, 2H, Ar-H), 4.13–3.80 (m, 12H, OCH_2), 2.71 (s, 4H, COO-CH_2), 1.91–1.62 (m, 12H, $(CH_2)_n$), 1.61–1.17 (m, 42H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ = 176.6, 171.6, 159.9, 153.0, 145.4, 132.7, 131.4, 128.4, 127.2, 119.2, 116.5, 115.2, 110.6, 110.2, 87.1, 81.5, 73.6, 69.2, 68.3, 53.4, 30.4, 29.8, 29.8, 29.7, 29.7, 29.6, 29.5, 29.5, 29.4, 29.4, 29.4, 28.8, 28.7, 26.2. IR (KBr): $\tilde{\nu}$ = 3040 (w), 2923 (m), 2852 (m), 2225 (m), 1742 (m), 1713 (m), 1604 (m), 1577 (m), 1523 (m), 1495 (m), 1468 (m), 1420 (m), 1389 (m), 1337 (m), 1291 (m), 1250 (s), 1180 (m), 1115 (m), 1065 (m), 1031 (m), 1000 (m), 966 (m), 821 (s), 722 (m), 660 (m), 633 (m), 563 (m), 532 (m). MS (MALDI, neg.): *m/z* calcd. for $C_{85}H_{99}N_3O_{10}$ – H^-: 1320.7258; found 1320.7272; elemental analysis calcd. (%) $C_{85}H_{99}N_3O_{10}$: C 77.18 H 7.54 N 3.18; found C 76.91 H 7.82 N 3.13.

Synthesis of Dendritic Ligand 23: Silane **15e** (385 mg, 0.30 mmol) and K_2CO_3 (150 mg, 1.09 mmol) were added to dry MeOH/THF = 1:1 (20 mL) and the reaction mixture was stirred at room temperature. After 3.5 h, *n*-hexane (50 mL) was added and the precipitate was collected. The combined organic phase was washed with MeOH (50 mL). After column chromatography (DCM, stab. with amylene) and removing the solvent under high vacuum, 349 mg (96 %) of dendritic ligand **23** were obtained as a colorless solid. R_f = 0.29 (DCM, stab. with amylene); m.p. 62 °C; 1H NMR (250 MHz, $CDCl_3$): δ = 7.80–7.58 (m, 12H, Ar-H), 7.51 (dd, $^3J_{H,H}$ = 8.8 Hz, *J* = 2.0 Hz, 6H), 6.98 (dd, $^3J_{H,H}$ = 8.8 Hz, 2.4 Hz, 6H, Ar-H), 6.69 (s, 2H, Ar-H), 4.09–3.81 (m, 12H, OCH_2), 3.00 (s, 1H, C-H), 1.92–1.64 (m, 12H, $(CH_2)_n$), 1.55–1.14 (m, 42H, $(CH_2)_n$). 13C NMR (63 MHz, $CDCl_3$): δ =

159.9, 153.0, 145.4, 139.5, 132.7, 131.3, 128.4, 127.2, 119.3, 116.5, 115.2, 110.7, 100.1, 91.7, 84.1, 73.6, 69.2, 68.3, 30.4, 29.8, 29.8, 29.7, 29.6, 29.5, 29.5, 29.4, 29.4, 29.4, 26.2. IR (KBr): $\tilde{\nu}$ = 3236 (m), 3042 (w), 2916 (m), 2850 (m), 2224 (m), 1603 (s), 1578 (m), 1524 (m), 1495 (s), 1474 (m), 1421 (m), 1391 (m), 1333 (m), 1291 (m), 1249 (s), 1181 (m), 1113 (m), 1037 (m), 999 (m), 851 (m), 819 (m), 718 (m), 661 (m), 632 (m), 562 (m), 531 (m). MS (MALDI, neg.): *m/z* calcd. for $C_{80}H_{93}N_3O_6^+$: 1192.7143; found 1192.7086; elemental analysis calcd. (%) $C_{80}H_{93}N_3O_6$: C 80.57 H 7.86 N 3.52; found C 80.47 H 7.95 N 3.16.

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[1] O. Stamatoiu, J. Mirzaei, X. Feng, T. Hegmann, in *Liquid Crystals: Materials Design and Self-assembly* (Ed.: C. Tschierske), Springer, Berlin, Heidelberg, **2012**, vol. 1, pp. 331–393.
[2] F. Brochard, P. G. de Gennes, *J. Phys. (Paris)* **1970**, *31*, 691–708.
[3] S.-H. Chen, N. M. Amer, *Phys. Rev. Lett.* **1983**, *51*, 2298–2301.
[4] A. Mertelj, D. Lisjak, M. Drofenik, M. Čopič, *Nature* **2013**, *504*, 237–241.
[5] a) E. Jarkova, H. Pleiner, H.-W. Müller, H. R. Brand, *J. Chem. Phys.* **2003**, *118*, 2422–2430; b) M. F. Prodanov, O. G. Buluy, E. V. Popova, S. A. Gamzaeva, Y. O. Reznikov, V. V. Vashchenko, *Soft Matter* **2016**, *12*, 6601–6609.
[6] M. F. Prodanov, N. V. Pogorelova, A. P. Kryshtal, A. S. Klymchenko, Y. Mely, V. P. Semynozhenko, A. I. Krivoshey, Y. A. Reznikov, S. N. Yarmolenko, J. W. Goodby, V. V. Vashchenko, *Langmuir* **2013**, *29*, 9301–9309.
[7] N. Podoliak, O. Buchnev, D. V. Bavykin, A. N. Kulak, M. Kaczmarek, T. J. Sluckin, *J. Colloid Interface Sci.* **2012**, *386*, 158–166.
[8] I. Appel, H. Nádasi, C. Reitz, N. Sebastián, H. Hahn, A. Eremin, R. Stannarius, S. S. Behrens, *Phys. Chem. Chem. Phys.* **2017**, *19*, 12127–12135.
[9] M. Draper, I. M. Saez, S. J. Cowling, P. Gai, B. Heinrich, B. Donnio, D. Guillon, J. W. Goodby, *Adv. Funct. Mater.* **2011**, *21*, 1260–1278.
[10] A. Demortière, S. Buathong, B. P. Pichon, P. Panissod, D. Guillon, S. Bégin-Colin, B. Donnio, *Small* **2010**, *6*, 1341–1346.
[11] M. F. Prodanov, O. V. Vashchenko, V. V. Vashchenko, *Tetrahedron Lett.* **2014**, *55*, 275–278.
[12] K. Sonogashira, *J. Organomet. Chem.* **2002**, *653*, 46–49.
[13] J. E. Bullock, R. Carmieli, S. M. Mickley, J. Vura-Weis, M. R. Wasielewski, *J. Am. Chem. Soc.* **2009**, *131*, 11919–11929.
[14] M. G. Organ, S. Avola, I. Dubovyk, N. Hadei, E. A. B. Kantchev, C. J. O'Brien, C. Valente, *Chem. Eur. J.* **2006**, *12*, 4749–4755.
[15] B. A. Pindzola, B. P. Hoag, D. L. Gin, *J. Am. Chem. Soc.* **2001**, *123*, 4617–4618.
[16] E. Peng, E. S. G. Choo, C. S. H. Tan, X. Tang, Y. Sheng, J. Xue, *Nanoscale* **2013**, *5*, 5994–6005.
[17] T. Perrier, P. Saulnier, J.-P. Benoît, *Chem. Eur. J.* **2010**, *16*, 11516–11529.
[18] O. Altintas, J. Willenbacher, K. N. R. Wuest, K. K. Oehlenschlaeger, P. Krolla-Sidenstein, H. Gliemann, C. Barner-Kowollik, *Macromolecules* **2013**, *46*, 8092–8101.
[19] a) T. Yasuda, T. Shimizu, F. Liu, G. Ungar, T. Kato, *J. Am. Chem. Soc.* **2011**, *133*, 13437–13444; b) T. Cardolaccia, Y. Li, K. S. Schanze, *J. Am. Chem. Soc.* **2008**, *130*, 2535–2545.
[20] C. Cai, A. Vasella, *Helv. Chim. Acta* **1995**, *78*, 732–757.
[21] H. Sajiki, *Tetrahedron Lett.* **1995**, *36*, 3465–3468.
[22] L. Kürti, B. Czako, in *Strategic Applications of Named Reactions in Organic Synthesis* (Eds.: L. Kürti, B. Czako), Elsevier Academic Press, **2005**, vol. 1, pp. 424–425.
[23] K. Sato, T. Yoshimura, M. Shindo, K. Shishido, *J. Org. Chem.* **2001**, *66*, 309–314.
[24] R. J. Mandle, C. T. Archbold, J. P. Sarju, J. L. Andrews, J. W. Goodby, *Sci. Rep.* **2016**, *6*, 36682.
[25] C. Zhu, M. R. Tuchband, A. Young, M. Shuai, A. Scarbrough, D. A. Walba, J. E. Maclennan, C. Wang, A. Hexemer, N. A. Clark, *Phys. Rev. Lett.* **2016**, *116*, 147803–147806.
[26] S. P. Shukla, R. K. Tiwari, A. K. Verma, *J. Org. Chem.* **2012**, *77*, 10382–10392.
[27] R. D. Corato, A. Quarta, P. Piacenza, A. Ragusa, A. Figuerola, R. Buonsanti, R. Cingolani, L. Manna, T. Pellegrino, *J. Mater. Chem.* **2008**, *18*, 1991–1996.
[28] V. Percec, P. Leowanawat, H.-J. Sun, O. Kulikov, C. D. Nusbaum, T. M. Tran, A. Bertin, D. A. Wilson, M. Peterca, S. Zhang, N. P. Kamat, K. Vargo, D. Moock, E. D. Johnston, D. A. Hammer, D. J. Pochan, Y. Chen, Y. M. Chabre, T. C. Shiao, M. Bergeron-Brlek, S. André, R. Roy, H.-J. Gabius, P. A. Heiney, *J. Am. Chem. Soc.* **2013**, *135*, 9055–9077.
[29] B. Neises, W. Steglich, *Angew. Chem. Int. Ed. Engl.* **1978**, *17*, 522–524; *Angew. Chem.* **1978**, *90*, 556.
[30] D. B. G. Williams, M. Lawton, *J. Org. Chem.* **2010**, *75*, 8351–8354.
[31] G. R. Fulmer, A. J. M. Miller, N. H. Sherden, H. E. Gottlieb, A. Nudelman, B. M. Stoltz, J. E. Bercaw, K. I. Goldberg, *Organometallics* **2010**, *29*, 2176–2179.

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