ORGANIC
LETTERS

2010
Vol. 12, No. 12
2778−2781

Macrocyclic Amphiphiles with 1,8-Anthrylene Fluorophores: Synthesis and Attempts toward Two-Dimensional Organization

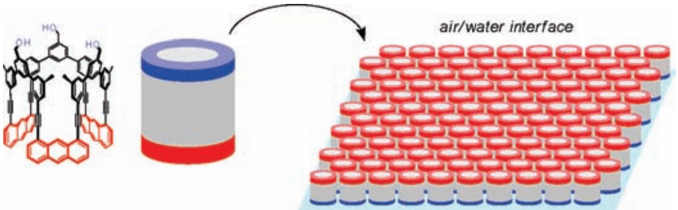
Patrick Kissel,[†] Jeroen van Heijst,[†] Raoul Enning,[‡] Andreas Stemmer,[‡] A. Dieter Schlüter,[*,†] and Junji Sakamoto[*,†]

Laboratory of Polymer Chemistry, Department of Materials, ETH Zurich,
Wolfgang-Pauli-Strasse 10, HCI J541, CH-8093 Zurich, Switzerland, and
Nanotechnology Group, Department of Mechanical and Process Engineering,
Tannenstrasse 3, CLA J13, CH-8092 Zurich, Switzerland

schlueter@mat.ethz.ch; sakamoto@mat.ethz.ch

Received April 16, 2010

ABSTRACT



New macrocyclic amphiphiles with two or three integrated 1,8-anthrylenes have been synthesized by an iterative Sonogashira cross-coupling protocol. The final cyclization has been conducted with 80% yield under cuprous-free dilution conditions. Formation of a monolayer at the air/water interface has also been demonstrated. These results open the intriguing possibility to construct large 2D supramolecular/macromolecular systems for which unique photophysical and -chemical properties are expected.

Photophysical and -chemical properties of anthracene derivatives are attractive for applications in photofunctional devices and materials.[1] Construction of single molecular or supramolecular/macromolecular systems in which anthracene units are integrated with a well-defined order is of particular interest. To control such functionality in terms of position and orientation, the use of macrocyclic scaffolds would be advantageous because of their reduced conformational freedom.[2]

We introduce here the synthesis of new macrocyclic amphiphiles, M3 (**1**) and M2 (**2**), in which three or two 1,8-anthrylene units are embedded, respectively (Figure 1). A barrel-like shape is expected for these compounds, whereby the hydroxyl groups are positioned at a rim on the side opposite to the anthrylene moieties. By taking advantage of this unique amphiphilic structure, feasibility of monolayer formation has been tested for M3 at the air/water interface aiming at two-dimensional organization. Note that such a 2D supramolecular structure containing the 1,8-anthrylene fluorophores in well-defined order may not only serve for sensing guest molecules, relaying energy/electron transfer, but also be converted into a 2D covalent periodic network (2D polymers), e.g., by [4 + 4]-cycloaddition between the anthrylenes.[3,4]

For the synthesis (Scheme 1), compounds **3**−**5** were selected as starting materials and prepared according to

---

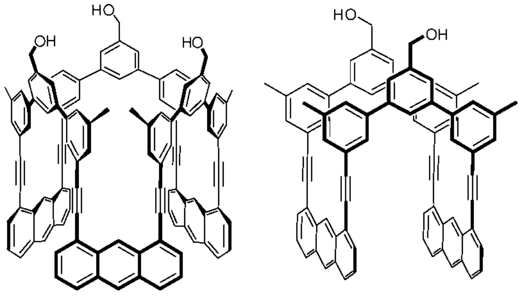
[†] ETH Zurich Wolfgang-Pauli-Strasse 10.

[‡] Nanotechnology Group.

(1) (a) Becker, H.-D. *Chem. Rev.* **1993**, *93*, 145. (b) Bouas-Laurent, H.; Desvergne, J.-P.; Castellan, A.; Lapouyade, R. *Chem. Soc. Rev.* **2000**, *29*, 43. (c) Bouas-Laurent, H.; Desvergne, J.-P.; Castellan, A.; Lapouyade, R. *Chem. Soc. Rev.* **2001**, *30*, 248.

(2) For example, see: (a) Grave, C.; Schlüter, A. D. *Eur. J. Org. Chem.* **2002**, 3075. (b) Sakamoto, J.; Schlüter, A. D. *Eur. J. Org. Chem.* **2007**, 2700.

10.1021/ol100877g



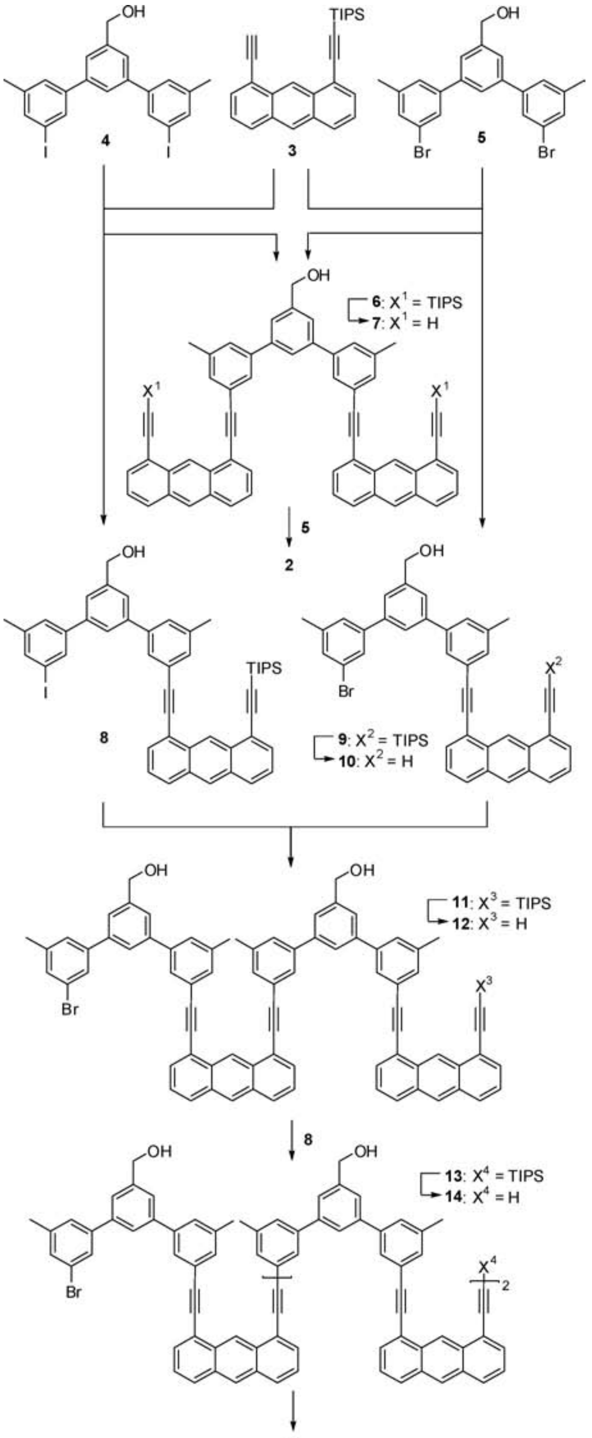
1 2

Figure 1. Macrocyclic amphiphiles M3 (**1**) and M2 (**2**) in which three or two 1,8-anthrylene units are embedded, respectively. The hydroxyl groups are positioned at a rim on the side opposite to the 1,8-anthrylene units.

reported procedures[5,6] on a scale of 15, 15, and 7 g, respectively. The Sonogashira cross-coupling reaction[7] was iteratively used for the subsequent build-up process with removal of the silyl protecting group. Note that no protection of the hydroxyl groups was required throughout the present scheme except for purification of **2** (see below) which facilitated the synthesis considerably. First, one molar equivalent of **3** was subjected to the Sonogashira coupling with **4** and **5** separately. These reactions afforded **8** and **9** as major products, respectively, together with **6** as common minor product. All these three compounds, **8**, **9**, and **6**, were prepared on the several gram scale and subsequently used for the syntheses of M3 (**1**) and M2 (**2**), respectively.

Regarding target **1**, compound **9** was first subjected to deprotection of the triisopropylsilyl (TIPS) group to give **10**, which was then followed by the Sonogashira coupling with **8** to afford **11**. Note that this coupling reaction took place selectively at the iodo carbon because of its higher reactivity than the bromo one.[8] Next, compound **11** was subjected to TIPS deprotection to give **12**, followed by the Sonogashira coupling with **8** to furnish **13** which is a linear precursor of **1** (3 g). The final intramolecular cyclization was carried out with in situ deprotection of the triisopropylsilyl (TIPS) groups (**13** to **14**) in a dilute solution (0.7 mM). Cuprous iodide was not used as cocatalyst for the Sonogashira reaction[9] due to the detrimental effect on cyclization expected from our previous results.[2b] Instead, an increased amount (20 mol %) of palladium(0) catalyst was used to accelerate the reaction. The cyclization proceeded efficiently under the present conditions to furnish the desired final product **1** in 80% isolated yield (180 mg) after purification by recycling gel-permeation chromatography (rGPC).[2b,4b]

Scheme 1. Syntheses of M3 (**1**) and M2 (**2**) from the Three Starting Compounds **3**−**5** by Iterative Use of the Sonogashira Coupling



Regarding target **2**, the compound **6** (300 mg) was subjected to an intermolecular cyclization with **5** (90 mg).

---

(3) (a) Zhang, A.; Sakamoto, J.; Schlüter, A. D. *Chimia* **2008**, *62*, 776. (b) Sakamoto, J.; van Heijst, J.; Lukin, O.; Schlüter, A. D. *Angew. Chem., Int. Ed.* **2009**, *48*, 1030.

(4) (a) Münzenberg, C.; Rossi, A.; Feldman, K.; Fiolka, R.; Stemmer, A.; Kita-Tokarczyk, K.; Meier, W.; Sakamoto, J.; Lukin, O.; Schlüter, A. D. *Chem.—Eur. J.* **2008**, *14*, 10797. (b) Kissel, P.; Schlüter, A. D.; Sakamoto, J. *Chem.—Eur. J.* **2009**, *15*, 8955.

(5) Kissel, P.; Weibel, F.; Federer, L.; Sakamoto, J.; Schlüter, A. D. *Synlett* **2008**, 1793.

(6) Kissel, P.; Breitler, S.; Reinmüller, V.; Lanz, P.; Federer, L.; Schlüter, A. D.; Sakamoto, J. *Eur. J. Org. Chem.* **2009**, 2953.

(7) Sonogashira, K.; Tohda, Y.; Hagihara, N. *Tetrahedron Lett.* **1975**, *16*, 4467.

(8) For example, see: Opris, D. M.; Franke, P.; Schlüter, A. D. *Eur. J. Org. Chem.* **2005**, 822.

The Sonogashira reaction was performed with in situ deprotection of the TIPS groups (**6** to **7**) in a dilute solution (0.7 mM), whereby **7** partially precipitated. The reaction was nevertheless continued for 10 days. Since the product mixture including **2** was poorly soluble in chloroform, the hydroxyl groups were acetylated prior to rGPC purification using chloroform (Supproting Information). Di-*O*-acetylated cyclic product **15** was isolated in 22% yield (49 mg). Because of the solubility problem, the cyclization conditions still need to be optimized.[10] The targeted compound **2** (33 mg) was finally furnished by deacetylation of **15** and subsequent precipitation from methanol. Note that all structures were confirmed by ^{1}H and ^{13}C NMR as well as high-resolution mass spectrometry (Supporting Information).

Both M3 (**1**) and M2 (**2**) could be recrystallized from chloroform and dioxane/water, and the crystals were found to exhibit yellowish green and yellow colors, respectively. The M2 single crystals could be grown large enough to be analyzed by X-ray diffraction revealing a structure of M2 with a triclinic unit cell (Supporting Information). It was found that M2 is nearly flattened within the single crystal structure to close the cavity (Figure 2). Given the considerable rotational freedom at the acetylene axes of M2, this was expected from related results reported by Toyota et al.[11] The crystal structure of M3 has not been elucidated yet because the crystal size is still too tiny to analyze (Supporting Information). It is nevertheless anticipated that M3 can hardly close its cavity in a way similar to M2 because this would cause increasing distortion due to the length mismatch between TAT and ATA (Note: "A" and "T" represent the anthrylene and the *m*-terphenylene bridge for which distances between the connection sites are ~5.0 and ~7.7 Å, respectively).

Figure 3 shows UV−vis absorption and emission spectra obtained from dilute solutions of M3 and M2 in THF. They are typical for isolated anthracenes and support that the anthrylene units, despite their close proximity in the macrocycle, retain their intrinsic photophysical properties. While the M3 emission exhibits some tailing whose nature is not yet clarified, dominant monomer emission suggests that intramolecular face-to-face stacking of the anthrylenes is unlikely.[4b,11]

Next, monolayer formation of M3 was investigated. A chloroform solution was spread at the air/water interface on a Langmuir trough (Figure 4a). The monolayer was vertically transferred at 10 mN/m lateral pressure onto mica and gold substrates[12] for atomic force microscopy (AFM) and scanning tunneling microscopy (STM) analyses, respectively.

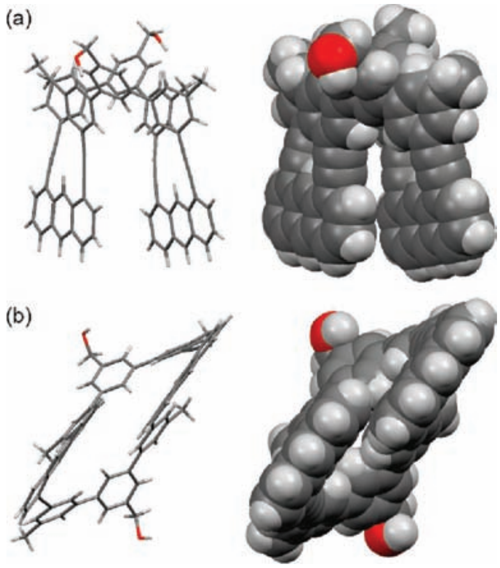


Figure 2. Conformation of **2** found in its X-ray single crystal structure obtained by recrystallization from 1,4-dioxane/water. Views from the side (a) and from the bottom (b) are presented with both stick (left) and space-filling display modes (right).

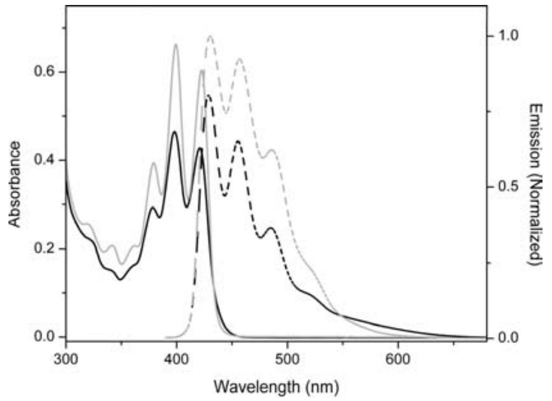


Figure 3. UV−vis absorption (solid lines) and emission spectra (broken lines) of **1** (black) and **2** (gray) in THF. Concentrations for absorption: 10 μM for **1** and 15 μM for **2**. Concentrations for emission: 2 μM for **1** and 3 μM for **2**. Excitation wavelength: 365 nm.

The square area in the AFM image (Figure 4b, recorded in tapping mode) was artificially created by scratching the monolayer away with the AFM tip under contact mode.[13] A height profile across the scratched area (Figure 4c) was recorded along the line indicated in the image providing a step height of approximately 1.3 nm. This proved the mica substrate to be covered with a film having this thickness which is in good agreement with the height of the M3 molecule and hence with the thickness of a monolayer.

---

(9) (a) Dieck, H. A.; Heck, F. R. *J. Organomet. Chem.* **1975**, *93*, 259. For the Sonogashira reaction without cuprous iodide, two different names are being used in the literature, namely, "copper-free Sonogashira reaction" and "Heck alkynylation." For comments on this matter, see: (b) Ljungdahl, T.; Pettersson, K.; Albinsson, B.; Martensson, J. *J. Org. Chem.* **2006**, *71*, 1677. (c) Chinchilla, R.; Nájera, C. *Chem. Rev.* **2007**, *107*, 874. We tend to agree to these comments, however, and as the former name is used much more often in the literature we will use it here as well.

(10) As an alternative, the linear compound **12** can also be considered as a precursor of **2** instead of **7** (with **4** or **5**).

(11) (a) Toyota, S.; Goichi, M.; Kotani, M. *Angew. Chem., Int. Ed.* **2004**, *43*, 2248. (b) Toyota, S.; Goichi, M.; Kotani, M.; Takezaki, M. *Bull. Chem. Soc. Jpn.* **2005**, *78*, 2214. (c) Toyota, S.; Suzuki, S.; Goichi, M. *Chem.—Eur. J.* **2006**, *12*, 2482.

(12) Heger, M.; Wagner, P.; Semenza, G. *Surf. Sci.* **1993**, *291*, 39.

(13) For example, see: (a) Ton-That, C.; Shard, A. G.; Bradley, R. H. *Langmuir* **2000**, *16*, 2281. (b) Anariba, F.; DuVall, S. H.; McCreery, R. L. *Anal. Chem.* **2003**, *75*, 3837.

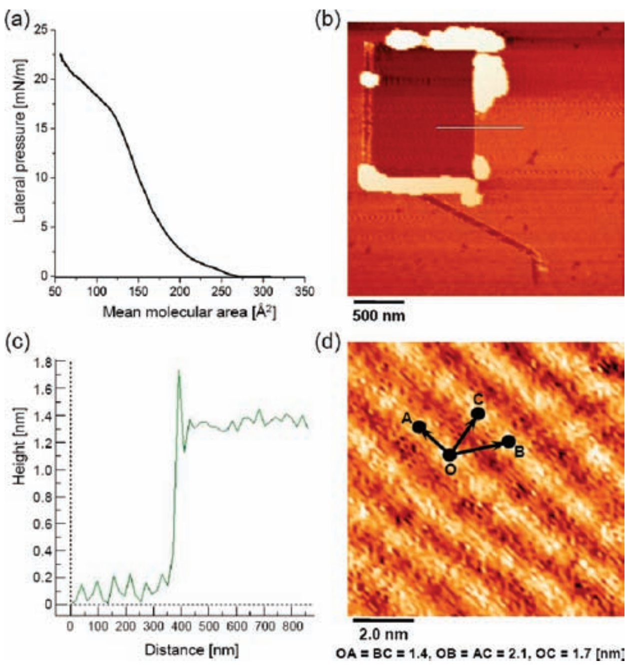


Figure 4. Preparation and structural analysis of the monolayer of M3. (a) Surface pressure/area isotherm of M3 at the air/water interface. (b) AFM tapping-mode image of the monolayer on a mica substrate after contact-mode scratching. (c) Height profile along the line indicated in the AFM image. (d) STM image of the monolayer on a gold substrate[12] with indication of periodicities.

To gain insight into the molecular arrangement within this monolayer, the film was also analyzed by STM. It could be observed that white dots in the image (Figure 4d) have the molecular dimension of M3. These dots also form one-dimensional parallel arrays. The periodicity within the lines is ~1.4 nm, and the one vertically across the lines is ~1.7 nm. Because it is difficult to propose a molecular model at the present stage, Figure 4d contains only some characteristic distances between constituents. The reason of the unexpected anisotropic pattern is not yet clear. Because of the length scale differences between typical Au−Au distances and those given in Figure 4d, the line formation does not seem to be associated with a gold surface pattern.[12] It might be due to a reorientation of the M3 molecules while transferring.[14] Further investigations are underway using fluorescence spectroscopy and high-resolution microscopies including STM, AFM, and transmission electron microscopy (TEM).

Acknowledgment. The authors deeply thank Dr. W. B. Schweizer (ETHZ) for X-ray crystallographic analysis, Dr. X. Zhang and L. Bertschi (ETHZ) for mass measurements, PhD candidate P. Wolfer (ETHZ) for his kind help in polarization optical microscopy, and PhD candidate T. Bauer (ETHZ) for his skillful help in the experiments with the Langmuir trough. Financial support by the ETH grant (TH-05 07-1) and the Swiss National Fund (200021-129660) are gratefully acknowledged.

Supporting Information Available: All experimental procedures, NMR & HR-MS data, GPC elution curves of cyclization experiments, optical microscopy images of crystals, and crystallographic data (CIF file).[15] This material is available free of charge via the Internet at http://pubs.acs.org.

OL100877G

---

(14) To address this issue, various modifications of M3 at the hydroxyl groups are now in progress.

(15) CCDC 772825.