Steroid-Bridged Thiophenes: Synthesis and Self-Organization at the Solid/Liquid Interface

Martin S. Vollmer,[a] Franz Effenberger,*[a] Ralf Stecher,[b] Bruno Gompf,[b] and Wolfgang Eisenmenger*[b]

Abstract: The synthesis of the oligothiophene **6a** as well as the terminally mono- and diformylated oligothiophenes **6b** and **6c**, in which mono- and bithiophene units are bridged by androstene, is described. Starting from epiandrostane the thiophene units were linked in positions 3 and 17 by Grignard reaction. The synthesis was accomplished by introduction of formyl groups. The self-organization of compounds **6** on highly oriented pyrolytic graphite at the liquid/solid interface was studied by STM. Derivatives **6a,b,c** spontaneously formed ordered monolayers on graphite, although neither are they planar nor do they have alkyl chains. Due to their different energy gaps in all cases the thiophene units were imaged as bright areas and the steroid unit as a dark area representing a novel type of surface structuring. While **6a** and **6b** are loosely packed, resulting in an area per molecule of 3 nm^2, the dialdehyde **6c** self-assembles to form a closely packed monolayer (area per molecule 2 nm^2) obviously owing to interactions between the formyl groups.

Keywords: monolayers · oligothiophenes · scanning tunneling microscopy · self-assembly · steroids

Introduction

The design of well-defined supramolecular structures by self-assembly of molecules is an interesting and challenging goal.[1, 2] In particular, the self-organization of organic molecules on solid surfaces to form monolayers with a high degree of structural order is one way to develop novel nanostructures. Organic monolayers on solid substrates with a thickness in the molecular dimensions play an important role in many interfacial phenomena such as wetting, lubrication and adhesion processes, and open a wide range of applications, for example in optical and electronic devices or sensor systems.[3–6]

Monolayers have been fabricated for many years by means of the well-known Langmuir–Blodgett (LB) and self-assembly techniques.[3, 6] In addition, organic molecular beam epitaxy (OMBE) and related techniques are applied to generate organic monolayers and thin organic films.[7, 8] More recently, the formation of monolayers by spontaneous self-organization of molecules from solution to form highly ordered two-dimensional (2D) arrangements on solid substrates has been achieved.[5, 9] In order to investigate 2D monolayers of this type, scanning tunnelling microscopy (STM) in situ at the solid/liquid interface has become a powerful tool which allows adsorbates to be observed at molecular resolution and provides a unique opportunity to gain insight into the surface structure.[9, 10]

Since the first reports of physisorbed monolayers of long-chain alkanes and alcohols on highly oriented pyrolytic graphite (HOPG) as solid substrate,[5] the self-organization of numerous compounds at the liquid/graphite interface has been studied by STM.[11] Interesting monolayer structures of two-component systems,[12] photochromic systems[13] and liquid crystalline systems[14] were recently described. Monolayers of rigid saturated compounds such as steroids (cholesterol), however, could be observed by STM only with low resolution.[15] The formation of ordered monolayers of conjugated systems, for example oligothiophenes, is of particular interest because of their high potential for applications in optical and electronic devices.[16] The formation of 2D arrays of alkyloligothiophenes on graphite at the liquid/solid interface has recently been reported.[17, 18] The epitaxy depends on the length of both the oligothiophene and the alkyl chain, and moreover, it could be demonstrated that polar substituents like the formyl group influence the epitaxy.[17]

In our investigations of energy-transfer systems based on donor–acceptor-substituted oligothiophenes[19] we have also synthesized compounds in which a steroid spacer (androstene) is incorporated in the oligothiophene chain.[20] Oligo-

[a] Prof. Dr. F. Effenberger, Dr. M. S. Vollmer
Institut für Organische Chemie, Universität Stuttgart
Pfaffenwaldring 55, D-70569 Stuttgart (Germany)
Fax: (+49) 711-685-4269
E-mail: franz.effenberger@po.uni-stuttgart.de

[b] Prof. Dr. W. Eisenmenger, Dr. B. Gompf, Dipl.-Phys. R. Stecher
1. Physikalisches Institut, Universität Stuttgart
Pfaffenwaldring 57, D-70550 Stuttgart (Germany)

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thiophenes of this type seem to be challenging candidates for monolayer formation on graphite due to their molecular composition. The rigid hydrocarbon androstene with a length of about 9 Å is imbedded on both sides in thiophene units with distinct conjugation length. It is a general feature in STM images that aromatic regions appear brighter than aliphatic regions due to their lower energy gap.[11c] Therefore steroid-bridged thiophenes should assemble to form a monolayer with defined bright (thiophene) and dark (androstene) areas in the STM image, resulting in a novel type of surface structure.

In this paper we report on the synthesis of the new steroid-bridged thiophenes **6** (Scheme 1) and their self-organization properties on graphite at the liquid/solid interface imaged by STM. Furthermore, we demonstrate the influence of the polar formyl substituent on the 2D arrangement which leads to extraordinary surface patterns. It is a particular characteristic that nonplanar molecules without alkyl chains such as **6** form ordered monolayers on graphite by physisorption from solution.

Results and Discussion

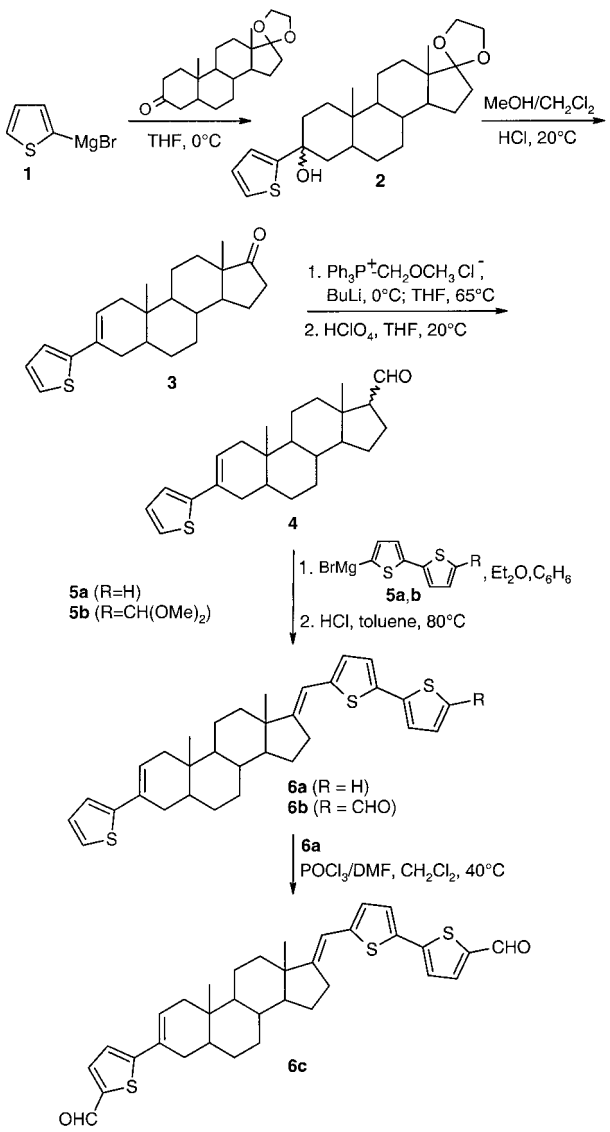
Synthesis: The synthetic approach to compound **6a** as well as to the mono- and diformylated derivatives **6b** and **6c**, respectively, is illustrated in Scheme 1.

According to a described methodology,[20] the thienyl-substituted steroid derivative **2** was accessible in 59% yield with an α/β isomeric ratio of approximately 1:1 (TLC detection) from 17-ethylenedioxy-5α-androstan-3-one[21] and thienylmagnesium bromide (**1**). The direct treatment of isomeric **2** with HCl in methanol resulted in regioselective water elimination, as stated by an X-ray crystallographic analysis of **3**, and simultaneous removal of the acetal protecting group to give **3** in 83% yield.

Using a Wittig reaction[20] we succeeded in the transformation of the keto group in position 17 of **3** to an aldehyde function with extension by one C atom by means of methoxymethyltriphenylphosphonium chloride. The ylide was generated with *n*BuLi at 0 °C and allowed to react with **3** in boiling THF. A total of 10 equiv of ylide were added. After aqueous workup, triphenylphosphine and unreacted **3** were separated by column chromatography on silica gel. Acidic hydrolysis of the intermediate enol ethers with aqueous $HClO_4$ and chromatographic purification gave aldehyde **4** in 57% yield as a 17α/β isomeric mixture which was used without further purification.

The bithienyl unit was coupled to the formyl group in **4** by a Grignard reaction.[20] Grignard reagent **5a**, derived from 5-bromo-2,2′-bithiophene,[19a, 20] was reacted with steroid aldehyde **4** at room temperature in diethyl ether/benzene and subsequently treated with HCl in toluene at 75 °C in order to eliminate water from the intermediate alcohol, yielding the steroid derivative **6a** in 78% yield.

Grignard reagent **5b** was accessible from the acetal-protected 5-dimethoxymethyl-2,2′-bithiophene[22] by lithiation with *n*BuLi at 0 °C and subsequent transmetalation of the organolithium compound with anhydrous magnesium bromide. The transmetalation was found to be necessary



Scheme 1. Synthesis of model compounds **6a–c**.

because the reaction of the corresponding organolithium compound with **4** resulted only in product mixtures. Grignard reagent **5b** was reacted with **4** as previously described, and by acid-catalyzed water elimination combined with simultaneous deprotection in the medium HCl/toluene at 75 °C the mono-formylated compound **6b** was obtained in 47% yield after chromatographic purification.

The diformyl-substituted steroid derivative **6c** was prepared starting from **6a** by Vilsmeier–Haack formylation.[17] After 3.5 h reaction time and addition of an approximately 14-fold excess of Vilsmeier reagent, the crystalline dialdehyde **6c** could be isolated in 89% yield. The model compounds **6** are completely characterized by NMR spectroscopy, UV/Vis spectroscopy and elemental analysis.

STM investigations: The STM investigations of the synthesized steroid derivatives **6** yielded monolayers in all cases. The formation of multilayers can be excluded because STM images of the underlying graphite substrate were always observed after dragging away the molecular layer by lowering

the sample–tip distance. Furthermore, multilayer steps were never observed. Figure 1 shows a highly resolved tunnelling image of a monolayer of **6a** in phenyloctane.

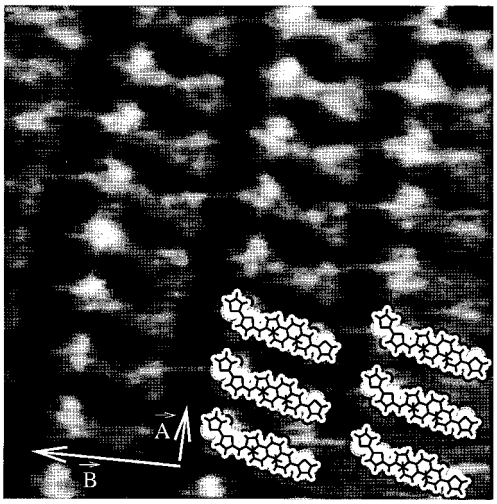


Figure 1. High-resolution image of a monolayer of **6a** in phenyloctane. The proposed structure shows a very open arrangement in lamellae without direct contact between the molecules (8.9 nm × 8.9 nm, $U = -1.26$ V, $I =$ 140 pA).

The molecules lie parallel to each other in lamellae. As expected, the image contrast corresponds to the electronic structure of the molecules: the aromatic thiophene areas appear brighter and more extended than the saturated steroid areas. In the images mono- and bithiophene sections are not discernible, so that a possible alternating structure parallel to the lamellae with two molecules rotated by 180° per unit cell can neither be confirmed nor excluded. Therefore one molecule per unit cell is assumed. The crystallographic structure is very open without direct contact between the molecules, illustrated by the structural model of the molecular arrangement in Figure 1, where the molecules are drawn with their van der Waals radii. The arrows mark the dimension of the unit cell. For **6a** on graphite only one fixed orientation of the unit cell with respect to the substrate is observed. This means that the monolayer is commensurate to the substrate. In this case the lattice vectors $\vec{A}$ and $\vec{B}$ of the adsorbed overlayer can be expressed in terms of the substrate lattice vectors $\vec{a}$ and $\vec{b}$ by the matrix notation given in Equation 1.

$$\begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} 1 & 4 \\ -13 & 8 \end{pmatrix} \cdot \begin{pmatrix} a \\ b \end{pmatrix} \quad (1)$$

The crystallographic parameters are $\vec{A} = 1.1$ nm, $\vec{B} = 2.7$ nm, the angle between the lattice vectors is 91° and the area per molecule is 3.0 nm^2. It is remarkable that **6a** self-assembles in the solvent dodecane with a similar molecular arrangement, however, with slightly varied crystallographic parameters. Again a commensurate superstructure is found. In this case the crystallographic data are $\vec{A} = 1.5$ nm, $\vec{B} = 2.7$ nm, the angle between $\vec{A}$ and $\vec{B}$ is 95° and the area per molecule is now 4.0 nm^2. These small changes lead to a slightly different matrix notation [Eq. (2)].

$$\begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} 1 & 4 \\ -11 & 11 \end{pmatrix} \cdot \begin{pmatrix} a \\ b \end{pmatrix} \quad (2)$$

Figure 2 shows a high-resolution image of a monolayer of aldehyde **6b** in dodecane. The molecules again arrange in lamellae with one molecule per unit cell. It is worth noting that the distance between the single lamellae is large (width about 1 nm) and many dislocations appear parallel to the lamellae.

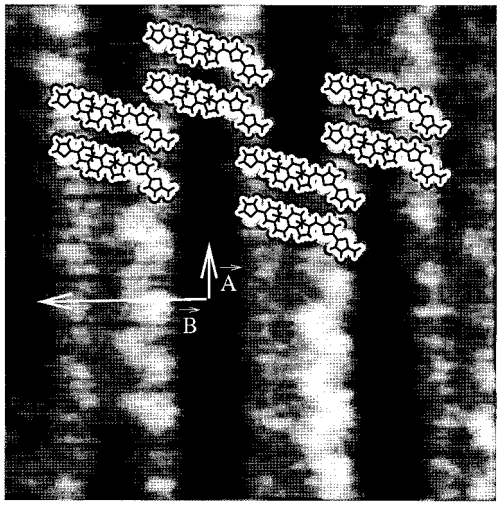


Figure 2. High-resolution image of a monolayer of **6b** in dodecane with a proposed structure. The molecules form lamellae with characteristic displacements and a loose packing (9.0 nm × 9.0 nm, $U = -1.34$ V, $I =$ 350 pA).

The crystallographic parameters are $\vec{A} = 0.9$ nm, $\vec{B} =$ 3.3 nm, angle = 97°. As in **6a**, the loose packing leads to an area per molecule of 3.0 nm^2. The molecule–molecule interaction is dominated in this case by the thiophene subunits; the steroid moieties act only as a spacer. This localized interaction seems to lead to a metastable phase with an increasing stress along the lamellae with increasing length. This stress could explain the many dislocations appearing along the lamellae with a periodicity of 6–8 molecules. The image contrast again reflects the electronic structure: the saturated steroid area causes a dark region in the middle of the molecule compared to the bright aromatic areas. In this case, the bithiophene section appears brighter and more extended than the monothiophene one. In contrast to **6a**, arbitrary orientations of the molecular unit cell with respect to the substrate were observed corresponding to an incommensurable structure.

Figure 3 depicts a submolecularly resolved monolayer of dialdehyde **6c** in dodecane. These molecules also arrange in lamellae with one molecule per unit cell. In contrast to **6a** and **6b**, however, the packing is very close and shows no dislocations even on larger areas. This is probably due to a stronger intermolecular interaction caused by the polar formyl groups on both sides of the molecules. The crystallographic data are $\vec{A} = 0.8$ nm, $\vec{B} = 2.3$ nm, angle = 98°. The area per molecule is only 2.0 nm^2. The observed image contrast corresponds with that for **6a** and **6b**: the dark zone in the middle of the lamellae has a width of about 1 nm, which is identical with the dimension of the steroid spacer in the middle of the molecules. The thiophene rings appear much

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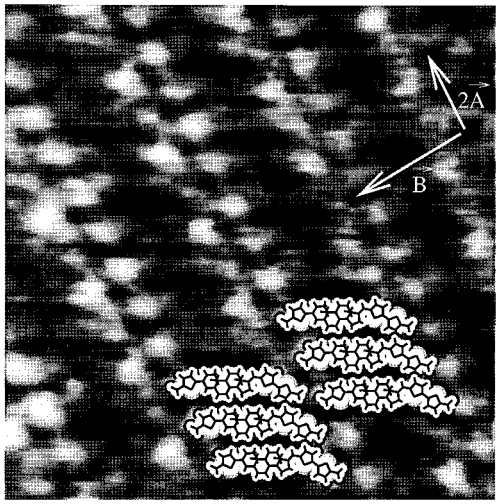

Figure 3. Highly resolved monolayer of **6c** in dodecane with a proposed structure. The molecules again arrange in lamellae with a very close packing (9.2 nm × 9.2 nm, $U = -1.50$ V, $I = 500$ pA).

brighter, but the varying extension of the mono- and bithiophene areas is not discernible. An incommensurable orientation with respect to the substrate as in the case of **6b** is found.

Generally, the order of a molecular monolayer is determined by a complex balance between the molecule–molecule and the molecule–substrate interaction. The molecule–molecule interaction depends strongly on the properties of the polar end groups. In the case of a flat-lying adsorption geometry the molecule–substrate interaction grows with respect to the extension of the molecules and tends to fix the orientation of the molecular monolayer with respect to the substrate.

In principle, the different balances of these two interaction forces depending on the molecular structure can explain the crystallography of the investigated steroid derivatives **6**. In the case of derivative **6a** the intermolecular forces are very weak because of the missing polar substituents. Thus, the molecule–substrate interaction dominates the crystallography, resulting in a coincident structure of the monolayer. The engaging of the molecules in certain substrate lattice positions also leads to a very open superstructure without any direct contact between the molecules. Although it is experimentally well confirmed that the solvent phenyloctane itself does not form ordered monolayers,[23] we cannot exclude the possibility that solvent molecules adsorb in a nearly liquid state in the free space between the steroid molecules and thereby stabilise the observed ordered structure. For an ordered arrangement of solvent molecules incorporated in the layer, one would expect additional features in the images. Derivative **6b** exhibits interaction only between the thiophene areas. The single formyl group leads to an open structure with a lamellae distance corresponding to the extension of the steroid area. The frequent dislocations probably result from the metastable character of this superstructure. Dialdehyde **6c** shows very close packing because of the interactions between the polar formyl groups. In the case of **6b**,**c** the molecule–molecule interaction is the dominating force leading to an incommensurable superstructure.

The STM image contrast is in agreement with the electronic structures of **6**. The different energy gaps of the steroid and thiophene moieties lead to the expected distribution of the tunnelling current corresponding to dark and bright areas, respectively, in the submolecularly resolved tunnelling images. Compound **6a** displays clearly the correlation of the tunnelling current with the aromatic and saturated areas of the molecules. Aldehyde **6b** shows differently extended brightness areas that render a distinction between mono- and bithiophene sides of the molecules. Also, in the case of dialdehyde **6c** the dark zone corresponding to low tunnelling current corresponds well with the extension of the steroid spacer.

Interestingly, all images are recorded at negative tunnelling voltages, that is, tunnelling of electrons *from* the sample *into* the tip. Possibly the acceptor behaviour of the thiophene parts of the molecules with respect to the substrate may lead to a larger distance between the lowest unoccupied molecular orbital (LUMO) and the Fermi level than between the latter and the highest occupied molecular orbital (HOMO). In STS (scanning tunnelling spectroscopy) measurements of PTCDA and NTCDA (perylene- and naphthalenetetracarboxylic dianhydride) this behaviour of acceptor-like molecules was also observed.[24, 25]

Conclusion

A new class of steroid-bridged oligothiophenes **6** have been synthesized and their self-organization properties on highly oriented pyrolytic graphite at the solid/liquid interface were studied with scanning tunnelling microscopy (STM). Compound **6a** as well as the aldehyde derivatives **6b**,**c** spontaneously form highly ordered monolayers on graphite with distinct structural patterns. The received image contrast and the molecular orientation with respect to the substrate agree with the electronic structure of **6** and allow a direct observation of the steroid units as dark areas with low tunnel current, imbedded in bright thiophene areas with high tunnel current. All compounds **6** arrange in lamellae with one molecule per unit cell assumed. In the case of **6a**, the 2D crystallographic structure is determined by both the molecule–molecule and the molecule–substrate interactions; these lead to monolayers with coincident structure. In contrast, in the aldehydes **6b** and **6c** the molecule–molecule interactions dominate owing to the polar formyl groups; this results in incommensurable structures. However, only dialdehyde **6c** forms a closely packed monolayer with unique structure, which consists of strongly alternating aliphatic (steroid) and aromatic (thiophene) ribbons, because of the polar intermolecular interactions in both directions.

Altogether, the results of our STM investigations reveal the different crystallography and the common electronic structure of the steroid derivatives **6** with submolecular resolution. The rigid steroid acts as a molecular spacer between aromatic subunits leading to patterned physisorbed monolayers.

The aldehyde function in **6b**,**c** opens a wide range of chemical modifications, for example, redox or carbonyl reactions to give a variety of possible self-assembling deriv-

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atives. Our future work will be focused on the introduction of polymerizable end groups directed towards the preparation of two-dimensional covalently linked organic networks.[26] The described engineering of ordered monolayers on solid substrates might provide a basis for the development of interfaces in electronic devices with tailor-made properties.

Experimental Section

General methods: Melting points were determined on a Büchi SMP-20 apparatus and are uncorrected. ^{1}H NMR spectra were recorded with TMS as an internal standard on a Bruker AC250F (250 MHz) instrument. Preparative column chromatography was carried out on columns of different sizes packed with silica gel S (Riedel – de Haen, size: 0.032 – 0.063 mm). UV/Vis spectra were recorded on a Perkin – Elmer Lambda 7 spectrophotometer. All solvents were dried and distilled. The reactions were carried out in dried glassware under argon atmosphere. (Methoxymethyl)triphenylphosphonium chloride was purchased from Fluka and dichloromethane (UVASOL) from Merck. The following compounds were prepared according to known procedures: 5-bromo-2,2′-bithiophene,[19a, 20] 5-dimethoxymethyl-2,2′-bithiophene[22] and 17-(ethylenedioxy)-5α-androstan-3-one.[21]

17-Ethylenedioxy-3α-hydroxy-3β-(2-thienyl)-5α-androstane and 17-ethylenedioxy-3β-hydroxy-3α-(2-thienyl)-5α-androstane (**2**): Grignard reagent **1** was prepared from Mg (0.098 g, 4.03 mmol) in diethyl ether (4 mL) with 1,2-dibromoethane as entrainer, and dropwise addition of a solution of 2-bromothiophene (0.545 g, 3.34 mmol) in diethyl ether (8 mL). After heating under reflux for 2 h, the reaction mixture was cooled to 0 °C. A solution of 17-(ethylenedioxy)-5α-androstan-3-one (1.0 g, 3.01 mmol) in THF (8 mL) was added dropwise, and the reaction mixture stirred for a further 2 h at 0 °C and then allowed to warm to room temperature (22 h). After hydrolysis with ice-water, the aqueous phase was extracted with diethyl ether. The combined extracts were washed with water and concentrated. The residue was taken up in CH_2Cl_2, dried (Na_2SO_4), concentrated, and dried under high vacuum over P_4O_{10} and paraffin. Chromatography on silica gel with CH_2Cl_2 gave 0.74 g (59 %) of an α/β-isomeric mixture of **2** as a colourless solid. The isomers were separated as follows: recrystallization from *n*-hexane/ethyl acetate (2:1): β-isomer as colourless fine needles, m.p. 149 – 151 °C; ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.85 – 2.08 (m, 22H, steroid H), 0.85 (s, 6H, H18,19), 3.84 – 3.95 (m, 4H, CH_2), 6.93 – 6.98 (m, 2H, thiophene H3,4), 7.19 (dd, J = 4.6, 1.6 Hz, 1H, thiophene H5); $C_{25}H_{36}O_3S$ (416.6): calcd C 72.07, H 8.71, S 7.70; found C 72.03, H 8.79, S 7.83. Chromatography on silica gel with CH_2Cl_2: α-isomer as a colourless solid; ^{1}H NMR ($CDCl_3$): δ = 0.54 – 2.30 (m, 22H, steroid H), 0.81, 0.89 (each s, 6H, H18,19), 3.87 – 3.90 (m, 4H, CH_2), 6.98 (dd, J = 5.1, 3.6, 1.1 Hz, 1H, thiophene H4), 7.07 (dd, 1H, thiophene H3), 7.26 (dd, 1H, thiophene H5).

3-(2-Thienyl)-5α-androst-2-en-17-one (**3**): Concentrated HCl (0.25 mL) was added to a solution of **2** (0.316 g, 0.76 mmol) in methanol (20 mL) at room temperature, and the reaction mixture was stirred for 7 h. After hydrolysis with ice-water, the reaction mixture was extracted with CH_2Cl_2. The extracts were combined, washed with a solution of $NaHCO_3$ and water to neutral, dried (Na_2SO_4), and concentrated. Chromatography on silica gel with CH_2Cl_2 and recrystallization from *n*-hexane/ethyl acetate (3:1) afforded 0.223 g (83 %) **3** as colourless crystals: m.p. 215 – 217 °C; ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.76 – 2.51 (m, 20H, steroid H), 0.82, 0.88 (each s, 6H, H18,19), 6.07 – 6.10 (m, 1H, H2), 6.92 – 6.97 (m, 2H, thiophene H3,4), 7.09 (dd, J = 4.7, 1.5 Hz, 1H, thiophene H5); $C_{23}H_{30}OS$ (354.6): calcd C 77.92, H 8.53, S 9.04; found C 77.69, H 8.47, S 9.08.

17ξ-Formyl-3-(2-thienyl)-5α-androst-2-ene (**4**): To a vigorously stirred suspension of (methoxymethyl)triphenylphosphonium chloride (27.98 g, 81.63 mmol) in THF (150 mL) a solution of *n*BuLi (1.6 M) in *n*-hexane (51.02 mL, 81.63 mmol) was added dropwise at 0 °C within 1 h. 2.5 equiv of this solution (with respect to **3**) were added dropwise within 1 h to a solution of **3** (3.86 g, 10.88 mmol) in THF (75 mL) at 65 °C followed by two further additions of 2.5 equiv after 2 and 5 h. After heating to 65 °C for 15 h, the reaction mixture was poured onto ice-water, neutralized with dilute HCl, and extracted several times with CH_2Cl_2. The combined extracts were washed with water, dried (Na_2SO_4), and concentrated. The residue was chromatographed in five portions on silica gel with CH_2Cl_2 to separate starting material **3** (8 %) and triphenylphosphine. The crude product was dissolved in THF (230 mL), a solution of $HClO_4$ (30 %, 50 mL) was added, and the reaction mixture was stirred at room temperature for 5 h (TLC monitoring). After hydrolysis with ice-water, the reaction mixture was extracted with CH_2Cl_2. The combined extracts were washed with a solution of $NaHCO_3$ and water to neutral, dried (Na_2SO_4), and concentrated. Repeated chromatography on silica gel with CH_2Cl_2 and recrystallization from *n*-hexane/ethyl acetate (3:1) and drying under high vacuum over paraffin gave **4** (2.27 g, 57 %) as a colourless to pale yellow solid, m.p. 204 – 208 °C (sintering > 201 °C); ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.77 – 2.37 (m, 21H, steroid H), 0.77, 0.79 (each s, 6H, H18,19), 6.07 – 6.10 (m, 1H, H2), 6.92 – 6.97 (m, 2H, thiophene H3,4), 7.09 (dd, J = 4.7, 1.5 Hz, 1H, thiophene H5), 9.77 – 9.78 (m, 1H, CHO, isomeric mixture); $C_{24}H_{32}OS$ (368.6): calcd C 78.21, H 8.75, S 8.70; found C 77.96, H 8.76, S 8.43.

17-[(2,2′-bithienyl-5-yl)methylidene]-3-(2-thienyl)-5α-androst-2-ene (**6a**): A solution of **5a** [prepared as described above from Mg (0.088 g, 3.62 mmol) in diethyl ether (5 mL) and a solution of 5-bromo-2,2′-bithiophene (0.56 g, 2.27 mmol) in diethyl ether/benzene (2:1) (30 mL)] was added dropwise at room temperature to a solution of **4** (0.76 g, 2.06 mmol) in diethyl ether/benzene (1:1) (80 mL). The reaction mixture was stirred for 1 h (TLC monitoring), hydrolyzed with ice water and extracted several times with diethyl ether. Then the aqueous phase was acidified and extracted for the last time with diethyl ether. The combined extracts were washed with water, dried ($MgSO_4$), and concentrated. The residue was chromatographed on silica gel with dichloromethane. Intermediate 17α- and 17β-[(2,2′-bithienyl-5-yl)-hydroxymethyl]-3-(2-thienyl)-5α-androst-2-enes were dissolved in toluene/methanol (50:15 mL). Concentrated HCl (1 mL) was added, and the reaction mixture stirred at 75 °C for 1 h followed by workup as described above for **3**. Chromatography on silica gel with CH_2Cl_2 and recrystallization from ethyl acetate gave 0.83 g (78 %) of **6a** as fine yellow needles, m.p. > 210 °C; ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.76 – 2.63 (m, 20H, steroid H), 0.83, 0.87 (each s, 6H, H18,19), 6.09 – 6.11 (m, 1H, H2), 6.26 (m, 1H, =CH), 6.81 (d, J = 3.7 Hz, 1H, bithiophene H4), 6.94 – 6.97 (m, 2H, thiophene H3,4), 7.00 (dd, J = 5.1, 3.6 Hz, 1H, bithiophene H4′), 7.08 (d, J = 3.7 Hz, 1H, bithiophene H3), 7.08 – 7.11 (m, 1H, thiophene H5), 7.15 (dd, J = 3.6, 1.1 Hz, 1H, bithiophene H3′), 7.18 (dd, J = 5.1, 1.1 Hz, 1H, bithiophene H5′); UV/Vis (*n*-hexane): λ_{max} (ε) = 346 (25700), 336 (25400), 282 (14800), 255 (13900), 247 nm (16100); $C_{32}H_{36}S_3$ (516.8): calcd C 74.37, H 7.02, S 18.61; found C 74.45, H 7.15, S 18.47.

17-[(5′-formyl-2,2′-bithienyl-5-yl)-methylidene]-3-(2-thienyl)-5α-androst-2-ene (**6b**): To a solution of 5-dimethoxymethylbithiophene[22] (0.424 g, 1.76 mmol) in THF (3.5 mL) at 0 °C a solution of *n*BuLi (1.6 M) in hexane (1.16 mL, 1.85 mmol) was added dropwise. After stirring for 1 h (reaction followed by NMR), a solution of magnesium bromide [prepared from Mg (0.051 g, 2.10 mmol) in diethyl ether (3 mL) and 1,2-dibromoethane (0.33 g, 1.76 mmol)] was added with a syringe, and the reaction mixture was stirred for 1 h. This solution containing **5b** was added dropwise to a solution of **4** (0.5 g, 1.36 mmol) in diethyl ether/benzene (1:1) (50 mL). After stirring for 2 h, the reaction mixture was hydrolyzed with ice-water and extracted with diethyl ether/benzene (1:1). The aqueous phase was acidified and then extracted for the last time with diethyl ether/benzene. The combined extracts were washed with water and concentrated. The residue was chromatographed on silica gel with CH_2Cl_2 to separate unreacted bithiophenes. The product-containing fractions were concentrated, taken up in toluene (135 mL) and treated with concentrated HCl (3 mL) at 75 °C. After 30 min further concentrated HCl (2.5 mL) was added, and the reaction mixture stirred for a total of 1.5 h. Workup as described above, repeated chromatography on silica gel with CH_2Cl_2 and recrystallization from ethyl acetate gave 0.35 g (47 %) **6b** as dark red dendritic crystals, m.p. 232 – 233 °C; ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.69 – 2.64 (m, 20H, steroid H), 0.83, 0.88 (each s, 6H, H18,19), 6.09 – 6.11 (m, 1H, H2), 6.29 (br s, 1H, =CH), 6.87 (d, J = 3.9 Hz, 1H, bithiophene H4), 6.94 – 6.98 (m, 2H, thiophene H3,4), 7.10 (dd, J = 4.6, 1.6 Hz, 1H, thiophene H5), 7.21 (d, J = 4.0 Hz, 1H, bithiophene H3′), 7.28 (d, J = 3.9 Hz, 1H, bithiophene H3), 7.66 (d, J = 4.0 Hz, 1H, bithiophene H4′), 9.84 (s, 1H, CHO); UV/Vis (*n*-hexane): λ_{max} (ε) = 390 (31600), 275 nm (17900); $C_{33}H_{36}OS_3$ (544.8): calcd C 72.75, H 6.66, S 17.65; found C 72.55, H 6.56, S 17.82.

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17-[(5′-formyl-2,2′-bithienyl-5-yl)-methylidene]-3-(5-formyl-2-thienyl)-5α-androst-2-ene (6c): To a boiling solution of **6a** (0.2 g, 0.39 mmol) in CH_2Cl_2 (5 mL) a solution of the Vilsmeier reagent[17] (1.25 mL, 1 mL ≈ 2.15 mmol of reagent) was added, followed by further Vilsmeier reagent (1.25 mL) after 2 h. After a total of 3.5 h, $NaHCO_3$ (1M) solution was added, and the reaction mixture stirred for 2 h. Then it was diluted with water and extracted several times with CH_2Cl_2. The combined extracts were washed with water to neutral, dried (Na_2SO_4), and concentrated. Chromatography on silica gel with CH_2Cl_2 and recrystallization from ethyl acetate afforded 0.198 g (89%) **6c** as fine yellow needles, m.p. 231 °C (decomp); ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.79-2.71$ (m, 20H, steroid H), 0.83, 0.88 (each s, 6H, H18,19), 6.29 (brs, 1H, =CH), 6.36–6.38 (m, 1H, H2), 6.87 (d, J = 3.8 Hz, 1H, bithiophene H4), 7.05 (d, $J = 3.9$ Hz, 1H, thiophene H3), 7.21 (d, $J = 4.0$ Hz, 1H, bithiophene H3′), 7.28 (d, $J = 3.8$ Hz, 1H, bithiophene H3), 7.63 (d, $J = 3.9$ Hz, 1H, thiophene H4), 7.66 (d, $J = 4.0$ Hz, 1H, bithiophene H4′), 9.82, 9.84 (each s, 2H, CHO); UV/Vis (*n*-hexane/CH_2Cl_2 (1:1)): λ_{max} (ε) = 398 (31800), 338 (25400), 277 nm (11600); $C_{34}H_{36}O_2S_3$ (572.9): calcd C 71.29, H 6.33, S 16.79; found C 71.05, H 6.20, S 16.66.

Scanning tunnelling microscopy: The STM investigations were carried out at room temperature in a home-built Video-STM with mechanically formed Pt/Ir tips. All images shown are recorded in the constant height mode at negative tunnelling voltages with a scanning frequency of 1 kHz corresponding to 4 frames s^{-1}. For noise reduction, 4–8 frames were averaged on-line. Monolayers of the molecules were prepared by spontaneous adsorption on the basal plane of HOPG from almost saturated solutions in dodecane (Aldrich) or phenyloctane (Merck). The solvents are chosen mainly because of their low conductivity. The solubilities of the derivatives **6** in these solvents are very low. Saturation is not necessary for the formation of monolayers, but we found that it increases the tendency of the molecules to adsorb on the substrate. The STM measurements were performed in situ at the liquid/solid interface. In some cases abrupt changes of the tunnelling polarity were helpful to induce the monolayer formation.

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