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Synthesis of Porphyrins Bearing *trans*-Thiols

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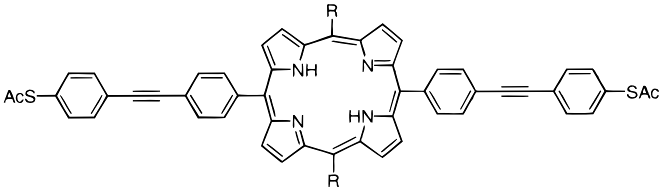
ABSTRACT



A route to porphyrins bearing *trans*-thiols is described using a thioacetyl-containing aldehyde or a thioacetyl-containing dipyrromethane in the presence of catalytic $BF_3 \cdot OEt_2$ followed by oxidation. Metal complexation and ammonium hydroxide induced acetyl removal provides a route to these important molecular systems for future electronics experiments in which the thiols would serve as the adhesion points to gold probes.

Future computational systems will likely consist of logic devices that are ultradense, ultrafast, and molecular-sized.[1] With the ultimate goal of constructing a molecular computer in which the fundamental switching elements and wires are fabricated from single, or very small packets of, molecules, we have been studying the responses of several classes of compounds in nanometer-sized arrays (nanopores) consisting of ∼1000 molecules per array.[2] Fundamental to their construction is the self-assembly of conjugated molecules in a 30-nm-diameter cavity; a pore size that is smaller than the defect density of the self-assembled monolayer or the underlying metal substrate. The oligomers are generally thiol-functionalized at the extremities for sandwiched adhesion between the proximal gold contacts. The first contact is formed by self-assembly from solution, and the second, by evaporation of gold to the juxtaposed end. To date, we have focused primarily on oligo(phenylene ethynylene)s and oligo(thiophene ethynylene)s.[3] Due to the plethora of interesting electrical properties that have been reported on porphyrins,[4] and to the modifications of their electronic properties through various *meso*-substituted patterns and the use of porphyrin/metal complexation, it behooves us to study this class of compounds in the nanopore embodiment. We describe here

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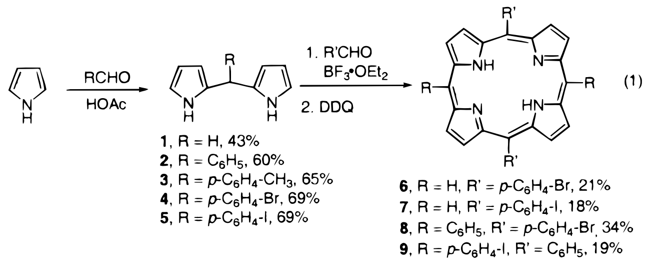
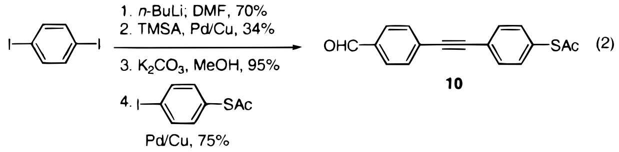
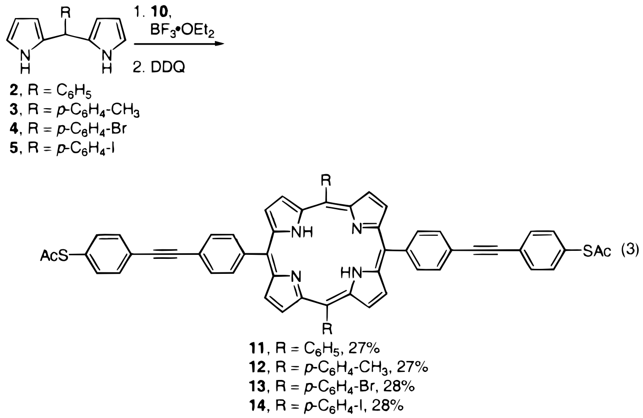
the synthetic methods used to prepare *meso*-substituted porphyrins bearing thiols in the *trans* positions. In all cases, the thiol end groups were attached to the porphyrin rings via phenylene ethynylene subunits, due to our experience in the manipulation, surface attachment, and characterization of these oligomers on surfaces.[5] These thiol-tipped systems may prove to be of utility in a number of approaches to self-assembled porphyrin structures where π-conjugation to the surface is important.

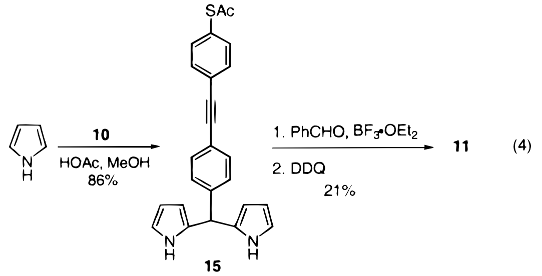
Initial efforts directed toward the porphyrin targets involved the preparation of dipyrromethane or aryl-substituted dipyrromethanes with the intent of subsequent Pd/Cu coupling[3] to the aryl halides for preparation of the final compounds. The porphyrin syntheses are shown in eq 1. The dipyrromethanes could be prepared in reasonable yield and further condensed with the complementary benzaldehyde component to generate the *trans*-(halophenyl)porphyrins.[4,6] Unfortunately, further attempts to elaborate the halogenated positions via lithium−halogen exchange and subsequent conversion directly to thioacetyl moieties (excess BuLi, sequential quenching with S_8 and AcCl)[3] were unsuccessful. Although Pd/Cu-catalyzed cross coupling reactions have been used successfully on porphyrins, employing the coupling partners here, the reactions were very low-yielding in our hands. Additionally, complexing the porphyrin with zinc did not change the unsuccessful course of the subsequent derivatizations of **6**−**9**. We are unclear on the source of this coupling difficulty and few attempts were made to remedy the problem. We immediately considered a more convergent route.



The strategy was therefore modified by preparing the aldehyde-bearing protected thiol using Pd/Cu-catalyzed coupling of 4-iodobenzaldehyde with trimethylsilylacetylene, subsequent deprotection, and another Pd/Cu coupling with 4-iodo-1-thioacetylbenzene (eq 2).[6] Protected thiol **10** was then condensed with the substituted dipyrromethanes (eq 3), or **10** was condensed with pyrrole to form **15** and then further condensed with benzaldehyde. Subsequent oxidation afforded the target *trans*-substituted products (eq 4).[7] Accordingly, no further functionalization of the porphyrin was needed. Furthermore, the thioacetyl moieties did not inhibit the reaction nor were they affected to a significant extent; the yields were similar to those obtained in reactions that did not have these thioacetyl functionalities. In a less controlled manner, the three-component system involving pyrrole, benzaldehyde, and **10** could be used to prepare **11** in 8% yield after oxidation with *p*-chloranil. Similarly, the tetra-(alligator clip)-substituted system **16** could be prepared from **10** and pyrrole (eq 5).[4,6]







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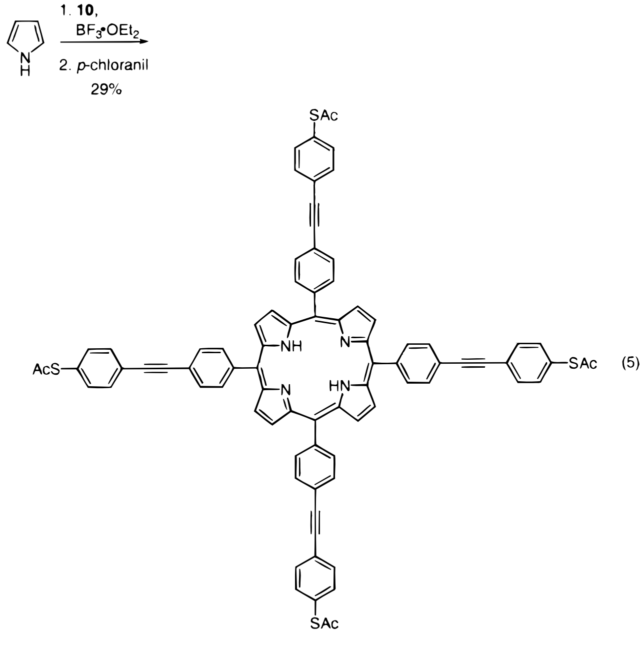

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The thioacetyl groups, after hydrolysis to the free thiols, are slated to serve as the molecular “alligator clips” for adhesion to gold probes.[2,3] We have previously shown that the free thiol can be liberated from its acetyl protection, during the self-assembly process, using ammonium hydroxide. If the α,ω-free aromatic thiols are used, they tend to undergo rapid unwanted oligomerization and precipitation in the presence of small amounts of oxygen. Hence the acetyl protection is particularly useful.[3]

Finally, we have demonstrated efficient removal of the acetyl groups in **11** using 6 μL of concentrated ammonium hydroxide per milligram of porphyrin.[8] Metal incorporation into **11**, specifically Zn (91%), Cu (95%), and Co (90%), using the corresponding hydrated metal acetates, followed by ammonium hydroxide-promoted thiol generation, proceeded without metal loss as indicated by ^{1}H NMR analysis. Therefore, we are poised for the study of the self-assembly and nanopore testing of these *trans*-alligator clip-containing porphyrin systems. Those results will be described separately.

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Supporting Information Available: Experimental procedures for the synthesis of compounds **10**−**16**. This material is available free of charge via the Internet at http://pubs.acs.org.

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