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HALEY et al.(10) **Pub. No.: US 2011/0015396 A1**(43) **Pub. Date: Jan. 20, 2011**(54) **TUNABLE PHENYLACETYLENE HOSTS**(75) Inventors: **Michael M. HALEY**, Eugene, OR
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549/75; 546/2; 549/3(57) **ABSTRACT**Disclosed herein is a class of tunable phenylacetylene com-
pounds as well as compositions and methods for their use as
host compounds for ligand binding. In certain examples the
hosts report binding events by exhibiting altered spectro-
scopic properties, such as different fluorescent emission spec-
tra.

TUNABLE PHENYLACETYLENE HOSTS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional application under 35 U.S.C. §121 of copending application Ser. No. 11/957,243, filed Dec. 14, 2007, which in turn claims the benefit under 35 U.S.C. §119(e) of the earlier filing date of U.S. Provisional Application Ser. No. 60/875,055, filed Dec. 14, 2006; both of which are incorporated by reference in their entirety.

ACKNOWLEDGMENT OF GOVERNMENT SUPPORT

[0002] This invention was made with government support under Grant Nos. CHE-0414175 and CHE-0718242 awarded by the National Science Foundation. The government has certain rights in the invention.

FIELD

[0003] Disclosed herein is a class of tunable phenylacetylene compounds as well as compositions and methods for their use as host compounds for ligand binding.

BACKGROUND

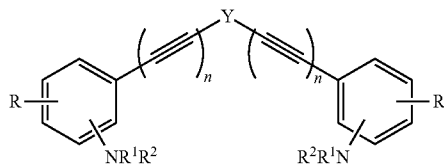
[0004] The synthesis of new molecules designed to bind or sense and report the presence of a particular substrate is an area of chemistry that is attracting attention. There exists a general lack of ligand-specific host molecules, such as specific hosts for toxic ions and small molecules of interest. There also is a dearth of specific hosts that report binding events, for example by exhibiting a spectral shift upon binding, such as an altered fluorescent response. In fact, structures of fluorescent coordination complexes are generally poorly understood, which makes the rational design of functional hosts and sensors a challenging undertaking.

[0005] The detection of ionic species, in particular the selective detection of a particular ionic species in the presence of another is difficult. The detection of anionic species is a particular challenge, as anions are difficult to bind and are generally larger than cations leading to a smaller charge-to-radius ratio.

SUMMARY

[0006] Disclosed herein are host or receptor compounds that bind targets of interest. In one embodiment the compounds bind ions, such as metal ions. In particular, toxic metal ions, including anions and cations are bound by embodiments of the disclosed host compounds.

[0007] In one embodiment the host compounds and salts thereof have the formula



[0008] wherein Y represents an optionally substituted aromatic group;

[0009] n is 1 or 2;

[0010] R is H or lower alkyl;

[0011] R¹ is H, lower alkyl or aralkyl;

[0012] R² is selected from H, acyl, aralkyl, phosphonyl, —SO₂R³, —(R⁴)C(O)R⁵, —N(R⁶)C(O)OR⁷ and —N(R⁸)C(O)NR⁹R¹⁰;

[0013] R³; R⁴; R⁵; R⁶; R⁷; R⁸ R⁹ and R¹⁰ independently are selected from H, lower alkyl, aralkyl and aryl.

[0014] Exemplary compounds exhibit shifts in their spectral properties upon ligand binding. Accordingly, also disclosed are methods for using the host compounds to detect targets of interest, including neutral, cationic and anionic targets.

[0015] The foregoing and other objects, features, and advantages of the invention will become more apparent from the following detailed description.

DETAILED DESCRIPTION

[0016] The following explanations of terms and methods are provided to better describe the present compounds, compositions and methods, and to guide those of ordinary skill in the art in the practice of the present disclosure. It is also to be understood that the terminology used in the disclosure is for the purpose of describing particular embodiments and examples only and is not intended to be limiting.

[0017] Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0018] “Acyl” refers group of the formula RC(O)— wherein R is an organic group.

[0019] The term “aliphatic” includes alkyl, alkenyl, alkynyl, halogenated alkyl and cycloalkyl groups as described above. A “lower aliphatic” group is a branched or unbranched aliphatic group having from 1 to 10 carbon atoms.

[0020] The term “alkyl” refers an aliphatic group that is a branched or unbranched saturated hydrocarbon group of 1 to 24 carbon atoms, such as methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, t-butyl, pentyl, hexyl, heptyl, octyl, decyl, tetradecyl, hexadecyl, eicosyl, tetracosyl and the like. A “lower alkyl” group is a saturated branched or unbranched hydrocarbon having from 1 to 10 carbon atoms.

[0021] The term “amine” or “amino” refers to a group of the formula —NRR', where R and R' can be, independently, hydrogen or an alkyl, alkenyl, alkynyl, aryl, aralkyl, cycloalkyl, halogenated alkyl, or heterocycloalkyl group described above.

[0022] The term “amide” refers to the formula —C(O)NRR', wherein R and R' independently can be a hydrogen, alkyl, alkenyl, alkynyl, aryl, aralkyl, cycloalkyl, halogenated alkyl, or heterocycloalkyl group described above.

[0023] The term “aralkyl” refers to an alkyl group that is substituted with one or more aryl groups (described below). A particular example of an aralkyl group is a benzyl group.

[0024] The term “aryl” refers to any carbon-based aromatic group including, but not limited to, benzene, naphthalene, etc. The term “aromatic” also includes “heteroaryl groups,” which are defined as aromatic groups that have at least one heteroatom incorporated within the ring of the aromatic group. Examples of heteroatoms include, but are not limited to, nitrogen, oxygen, sulfur, and phosphorous. The aryl group can be substituted with one or more groups including, but not limited to, alkyl, alkynyl, alkenyl, aryl, halide, nitro, amino,

ester, ketone, aldehyde, hydroxy, carboxylic acid, or alkoxy, or the aryl group can be unsubstituted.

[0025] "Carbonyl" refers to a radical of the formula —C(O)— . Carbonyl-containing groups include any substituent containing a carbon-oxygen double bond (C=O), including acyl groups, amides, carboxy groups, esters, ureas, carbamates, carbonates and ketones and aldehydes, such as substituents based on —COR or —RCHO where R is an aliphatic, heteroaliphatic, alkyl, heteroalkyl, hydroxyl, or a secondary, tertiary, or quaternary amine.

[0026] "Carbonate" refers to a group of the formula —OC(O)O— . Likewise, as used herein the term "carbamate" refers to a group of the formula —OC(O)N(R)— , wherein R is H, or an aliphatic group, such as a lower alkyl group or an aralkyl group.

[0027] "Carboxyl" refers to a —COOH radical. Substituted carboxyl refers to —COOR where R is aliphatic, heteroaliphatic, alkyl, heteroalkyl, or a carboxylic acid or ester.

[0028] "Optional" or "optionally" means that the subsequently described event or circumstance can but need not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not. Optionally substituted groups, such as "substituted alkyl," refers to groups, such as an alkyl group, having from 1-5 substituents, typically from 1-3 substituents, selected from alkoxy, optionally substituted alkoxy, acyl, acylamino, acyloxy, amino, aminoacyl, aminoacyloxy, aryl, carboxyalkyl, optionally substituted cycloalkyl, optionally substituted cycloalkenyl, optionally substituted heteroaryl, optionally substituted heterocyclyl, hydroxy, thiol and thioalkoxy.

[0029] The term "phosphoryl" refers to moieties of the formula —P(O)OR— , wherein R may be H, an aliphatic or aromatic moiety, a cation or a lone pair of electrons. Phosphoryl moieties may be further substituted to form phosphoramidates, phosphates and phosphonates.

[0030] The term "sulfonyl" refers to the radical $\text{—SO}_2\text{—}$. The sulfonyl group can be further substituted with a variety of groups to form, for example, sulfonic acids, sulfonamides, sulfonate esters and sulfones.

[0031] Protected derivatives of the disclosed compound also are contemplated. A variety of suitable protecting groups for use with the disclosed compounds are disclosed in Greene and Wuts Protective Groups in Organic Synthesis; 3rd Ed.; John Wiley & Sons, New York, 1999.

[0032] It is understood that substituents and substitution patterns of the compounds described herein can be selected by one of ordinary skill in the art to provide compounds that are chemically stable and that can be readily synthesized by techniques known in the art and further by the methods set forth in this disclosure.

[0033] The disclosed host compounds are useful, inter alia, as ion binding compounds. By way of example, specific anions bound by the disclosed compounds include, but are not limited to, toxic metal anions, halide anions, carboxylates, phosphates, sulfates, oxalates, terephthalates, phospholipids, nucleotides, oligonucleotides, DNA, RNA, anionic polyoxometalates, or oxoanions such as pertechnetate.

[0034] The structural formulas provided herein include salts of the illustrated compounds. Such salts can be formed when disclosed host compounds possess at least one basic group that can form acid-base salts with acids. Examples of basic groups present in exemplary disclosed host compounds include amino groups or imino groups. Examples of inorganic acids that can form salts with such basic groups include, but are not limited to, mineral acids such as hydrochloric acid, hydrobromic acid, sulfuric acid or phosphoric acid. Basic groups also can form salts with organic carboxylic acids,

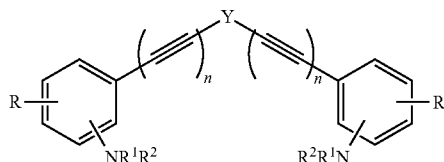
sulfonic acids, sulfo acids or phospho acids or N-substituted sulfamic acid, for example acetic acid, propionic acid, glycolic acid, succinic acid, maleic acid, hydroxymaleic acid, methylmaleic acid, fumaric acid, malic acid, tartaric acid, gluconic acid, glucaric acid, glucuronic acid, citric acid, benzoic acid, cinnamic acid, mandelic acid, salicylic acid, 4-aminosalicylic acid, 2-phenoxybenzoic acid, 2-acetoxybenzoic acid, embonic acid, nicotinic acid or isonicotinic acid, and, in addition, with amino acids, for example with α -amino acids, and also with methanesulfonic acid, ethanesulfonic acid, 2-hydroxymethanesulfonic acid, ethane-1,2-disulfonic acid, benzenedisulfonic acid, 4-methylbenzenesulfonic acid, naphthalene-2-sulfonic acid, 2- or 3-phosphoglycerate, glucose-6-phosphate or N-cyclohexylsulfamic acid (with formation of the cyclamates) or with other acidic organic compounds, such as ascorbic acid.

[0035] Similarly, salts can be formed when disclosed host compounds possess at least one acidic group that can form acid-base salts with bases. Examples of acidic groups present in exemplary disclosed host compounds include carboxylic acid moieties and sulfonamide groups. Compounds that include at least one acidic group can form acid-base salts with an inorganic or organic base. Examples of salts formed from inorganic bases include salts of the presently disclosed compounds with alkali metals such as potassium and sodium, alkaline earth metals, including calcium and magnesium and the like. Similarly, salts of acidic compounds with an organic base, such as an amine (as used herein terms that refer to amines should be understood to include their conjugate acids unless the context clearly indicates that the free amine is intended) are contemplated, including salts formed with basic amino acids, aliphatic amines, heterocyclic amines, aromatic amines, pyridines, guanidines and amidines. In addition, quaternary ammonium counterions also can be used.

[0036] Additionally, the structural formulas herein are intended to cover, where applicable, solvated as well as unsolvated forms of the compounds. "Solvate" refers to a compound physically associated with one or more solvent molecules. This physical association involves varying degrees of ionic and covalent bonding, including by way of example covalent adducts and hydrogen bonded solvates. In certain instances the solvate will be capable of isolation, for example when one or more solvent molecules are incorporated in the crystal lattice of the crystalline solid. "Solvate" encompasses both solution-phase and isolable solvates. Representative solvates include ethanol associated compounds, methanol associated compounds, and the like. "Hydrate" is a solvate wherein the solvent molecule(s) is/are H_2O . Solvate complexes may be described in shorthand form for example as $(1.\text{H}_2\text{O})_2$, which refers to a hydrate, more specifically a 2+2 complex of compound 1 with water.

[0037] Compounds disclosed herein can be crystallized and can be provided in a single crystalline form or as a combination of different crystal polymorphs. As such, the compounds can be provided in one or more physical form, such as different crystal forms, crystalline, liquid crystalline or non-crystalline (amorphous) forms. Such different physical forms of the compounds can be prepared using, for example different solvents or different mixtures of solvents for recrystallization. Alternatively or additionally, different polymorphs can be prepared, for example, by performing recrystallization at different temperatures and/or by altering cooling rates during recrystallization. The presence of polymorphs can be determined by X-ray crystallography, or in some cases by another spectroscopic technique, such as solid phase NMR spectroscopy, IR spectroscopy, or by differential scanning calorimetry.

[0038] In one embodiment, the disclosed host compounds have the formula



[0039] wherein Y represents an optionally substituted aromatic group;

[0040] n is 1 or 2;

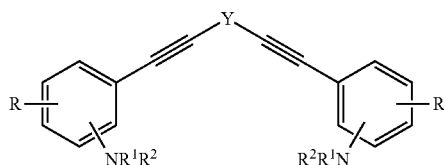
[0041] R is H or lower alkyl;

[0042] R¹ is H, lower alkyl or aralkyl;

[0043] R² is selected from H, acyl, aralkyl, phosphonyl, $-\text{SO}_2\text{R}^3$; $-(\text{R}^4)\text{C}(\text{O})\text{R}^5$; $-\text{N}(\text{R}^6)\text{C}(\text{O})\text{OR}^7$ and $-\text{N}(\text{R}^8)\text{C}(\text{O})\text{NR}^9\text{R}^{10}$;

[0044] R³; R⁴; R⁵; R⁶; R⁷; R⁸ R⁹ and R¹⁰ independently are selected from H, lower alkyl, aralkyl and aryl.

[0045] In embodiments wherein n is 1, the disclosed host compounds can be represented by the formula



[0046] With reference to the generic formulas above, a guest molecule can bind in the cavity created between the aromatic group “Y” and the functional groups appended to the aniline nitrogens “R¹ and R²”.

[0047] With continued reference to the general formula above, such compounds can be cyclized, for example, by covalently linking an R¹ or R² group to another. Thus, macrocyclic compounds can be formed by linking an R¹ or R² group to another R¹ or R² group on a different aniline nitrogen.

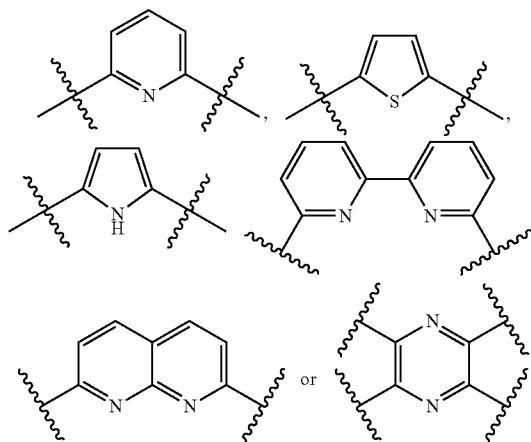
[0048] With continued reference to the formula above, the R group can be selected for several purposes. Typically, R is selected to tune or tailor the electronics of the ring by selecting an electron donating or electron withdrawing and/or conjugated group. In other examples, R is selected for detection purposes, or, for instance, to affect the solubility of the overall molecule. Suitable R groups include, without limitation those listed in Table 1.

Structure/name	Hammett constant (σ_{para})
$-\text{H}$	0.00
$-\text{OCH}_3$	-0.27
$-\text{CH}_3$	-0.04
$-\text{CH}_2\text{CH}_3$	-0.05
$-\text{C}(\text{CH}_3)_3$	
$-\text{F}$	0.06
$-\text{Cl}$	0.23
$-\text{Br}$	0.23
$-\text{I}$	0.18
$-\text{CF}_3$	0.54
$-\text{OCF}_3$	
$-\text{NO}_2$	0.78

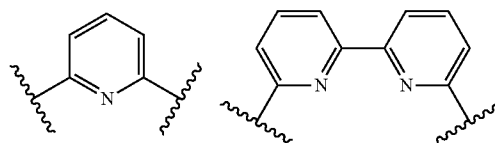
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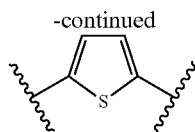
Structure/name	Hammett constant (σ_{para})
$-\text{N}_3$	
$-\text{CN}$	0.66
$-\text{OH}$	-0.37
$-\text{NH}_2$	-0.66
	-0.83
	0.45
$-\text{SO}_3^-$	0.09

[0049] The group “Y” can be any aromatic group, but typically Y comprises a heteroaromatic group. For example, in one embodiment, the group “Y” employed was a pyridyl group. Additional exemplary Y groups include, without limitation, bipyridyl, pyridinyl, pyrazinyl, pyrimidinyl, pyrrole, imidazole, triazole, thiophene, thiazole, furyl and oxazolyl groups. By way of example, such Y groups can be selected from



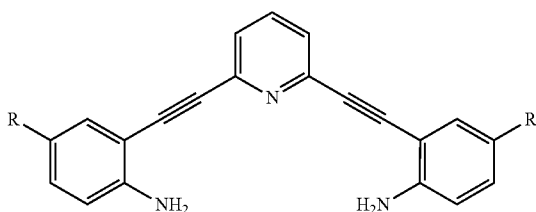
[0050] In other embodiments, Y is selected from, without limitation, the following hetero aromatic groups





Other appropriate Y groups can be identified by those of skill in the art using the guidance provided by the present disclosure and by considering factors such as: the ring topology, bond angles, geometry of coordination to the guest, and number of available hydrogen bonds.

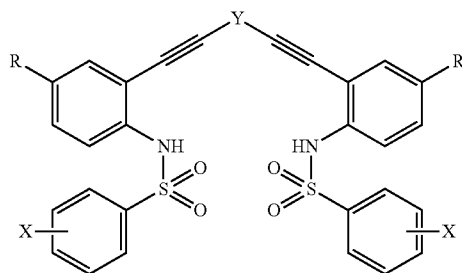
[0051] In one embodiment, the disclosed host compounds have the structure:



wherein R is H, aliphatic, such as lower alkyl (including optionally substituted lower alkyl), aralkyl, aryl, sulfonyl, phosphonyl, phosphate, sulfate, —XC(O)OR^6 and $\text{—XC(O)NR}^7\text{R}^8$; wherein X is optional and if present is selected from the group consisting of —O— , $\text{—N(R}^9\text{)—}$ or —S— ; R^6 is selected from lower alkyl, aralkyl and aryl; and R^7 , R^8 and R^9 independently are selected from H, lower alkyl, aralkyl and aryl.

[0052] In one embodiment, Y is a hydrogen bond acceptor and/or donor. For example when Y is pyridyl, it is a hydrogen bond acceptor at high (basic) pH and a hydrogen bond donor when it is in its conjugate acid form at low pH.

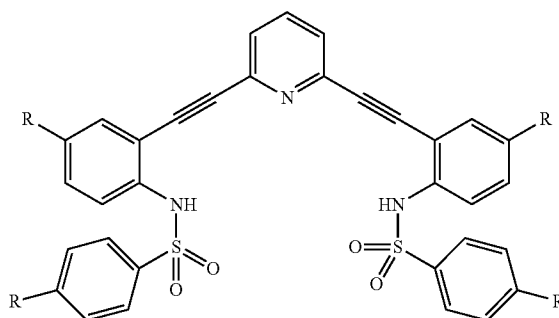
[0053] In one embodiment the disclosed host compounds have the structure:



[0054] wherein X is selected from halogen, —OR^{11} , nitro, sulfonyl, phosphonyl, phosphate, sulfate, or optionally substituted lower alkyl;

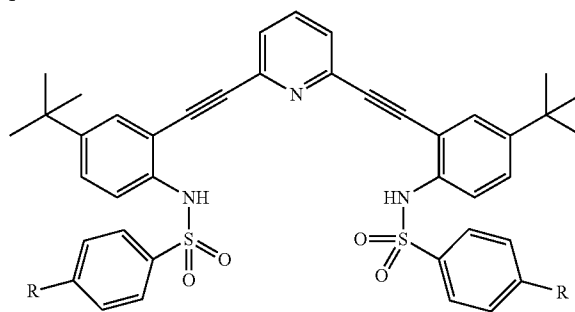
[0055] and R^{11} is H, acyl or optionally substituted lower alkyl. When X includes an optionally substituted lower alkyl moiety, optional substitutions include, without limitation hydroxy and sulfide moieties.

[0056] Particular examples of sulfonamide host compounds can be represented by the formula

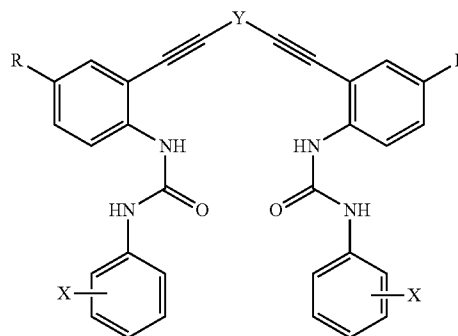


wherein R is selected from —OR , —SR , —Me , halo, such as —Br , and —NO_2 , and wherein R' is, for each occurrence selected from H, lower alkyl and acyl. With reference to such sulfonamide compounds, they include acidic NH groups, which are good hydrogen bond donors.

[0057] Particular examples of such sulfonamide compounds have the formula

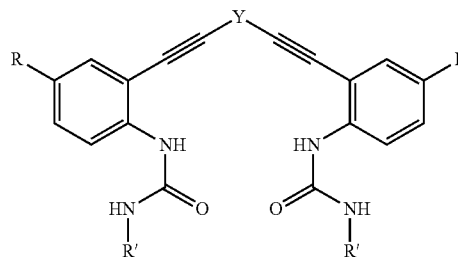


[0058] Additional embodiments include urea compounds, such as those of the formula:

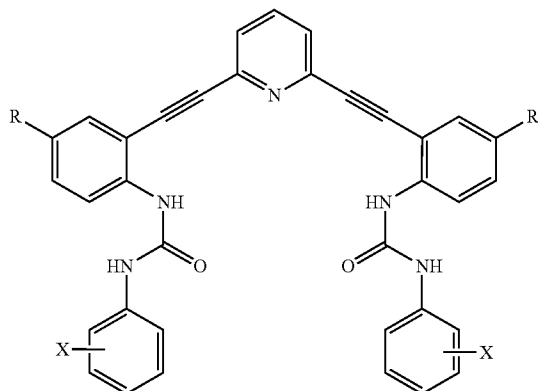


[0059] wherein R is lower alkyl and X is H, halogen, lower alkyl, phosphonyl, phosphate, sulfonyl or sulfate; and R^{11} is H, acyl or optionally substituted lower alkyl.

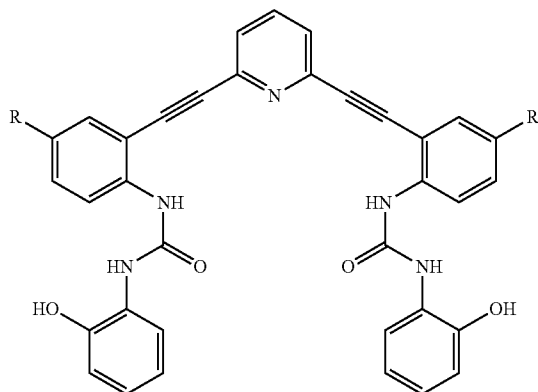
[0060] Other urea compounds have the formula



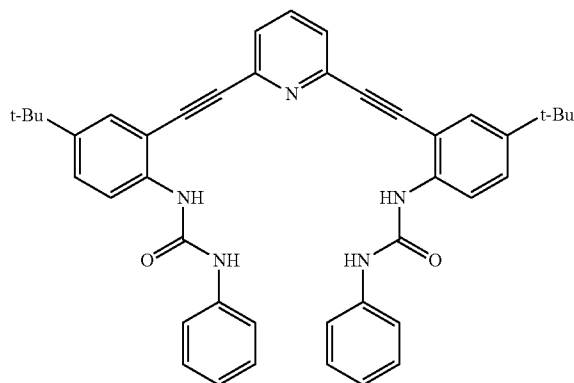
[0061] wherein R^1 is H or optionally substituted lower alkyl, such as methyl, t-butyl, octyl and the like. In one aspect, certain urea compounds can be represented by the formula



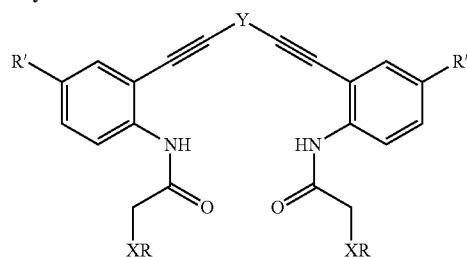
[0062] One such compound has the formula



[0063] A second such urea compound has the formula

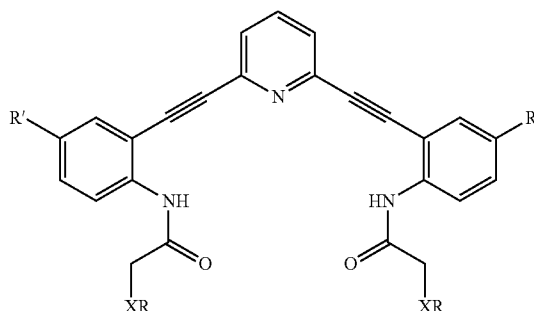


[0064] In one aspect, certain host compounds are represented by the formula

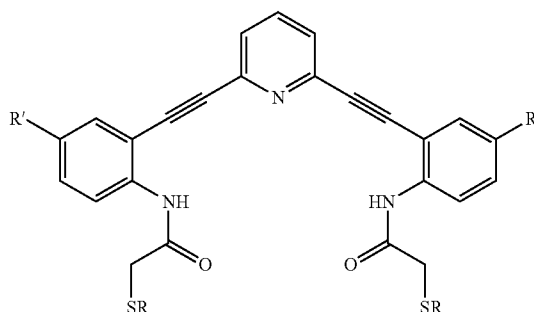


[0065] wherein X is O or S;

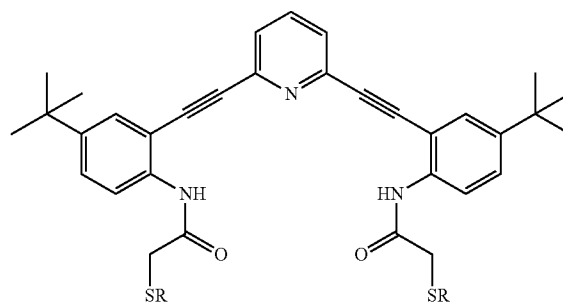
[0066] R is H, acyl, aralkyl or lower alkyl; and R' is H or lower alkyl, such as t-butyl. Examples of such compounds can be represented by the formula



When X is O, the host compounds are particularly useful for binding oxophilic ions, such as calcium. Other host compounds having the formula above, wherein X is S have been designed to bind thiophilic metals. Examples of such compounds can be represented by the formula:

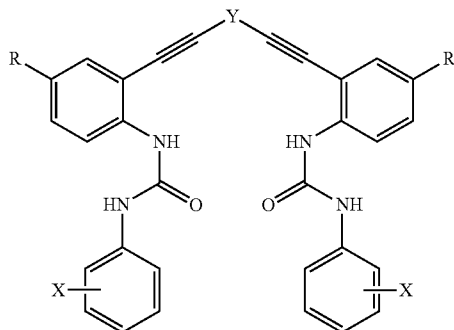


wherein R is H, acyl, aralkyl or lower alkyl; and R' is H, aliphatic, such as lower alkyl, aralkyl, aryl, sulfonyl, phosphoryl, phosphate, sulfate, $-XC(O)OR^6$ or $-XC(O)NR^7R^8$; wherein X is optional and if present is selected from the group consisting of $-O-$, $-N(R^9)-$ or $-S-$; R^6 is selected from lower alkyl, aralkyl and aryl; and R^7 , R^8 and R^9 independently are selected from H, lower alkyl, aralkyl and aryl. Particular examples of such compounds also can be represented by the formula



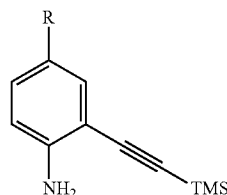
wherein R is H, acyl, aralkyl or lower alkyl.

[0067] Additional compounds useful for binding thiophilic metals include those of the formula

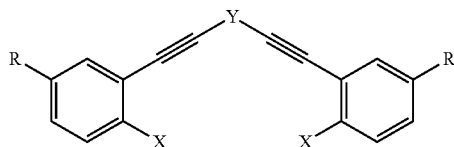


[0068] wherein X comprises an alkyl sulfide moiety.

[0069] Also disclosed herein are methods for making the disclosed receptor compounds as well as intermediates for preparing the receptors. One type of versatile intermediate employed in the synthesis of exemplary receptor compounds disclosed herein is represented by the formula



wherein R is H, lower alkyl, aralkyl or the like. Such compounds can be used to assemble (typically by an organometallic coupling reaction, such as a Sonogashira coupling) compounds of the formula



wherein X represents an aniline nitrogen, which optionally may be substituted. The aniline nitrogens can be converted into any one of many heteroatomic functional groups, including amides, sulfonamides, ureas, imines, and the like using standard synthetic techniques known to those of skill in the art of synthetic organic chemistry. The choice of group is dictated by several factors, including: optimizing guest interactions, changing the size of the binding cavity, preorganizing the binding cavity (by cyclization, for instance). Such factors are recognized and can be adjusted by those of skill in the art.

[0070] The disclosed host compounds are useful for binding and/or detecting ligands, in particular ionic ligands, including cationic and anionic ligands. The ligands may be inorganic or organic, but generally are inorganic. Typically, for binding anionic ligands, host compounds are protonated. Particular examples of anionic ligands bound and/or recognized by the disclosed host compounds include, without limi-

tation sulfate, hydrogen sulfate, perchlorate or nitrate. Exemplary host compounds exhibit ligand binding selectivity or recognition. The host compounds may exhibit selectivity in binding of the ligand or reporting of a ligand's presence. For example, a spectral property of a host compound, such as fluorescence, may shift upon binding certain ligands, but not others. Examples of the disclosed host compounds have been designed to bind to salts containing particular metals, particularly toxic metals, including without limitation Pb, As, Zn, U, Ca, Cd and Hg.

[0071] It has been demonstrated for exemplary compounds disclosed herein that the spectral properties, such as the UV-Vis spectra shift noticeably upon binding of different guests. For example, the extended conjugation inherent in 2,6-bis(2-anilinoethynyl)pyridines derivatives produces distinct emission properties that will be used to monitor interactions with guest molecules. Exemplary compounds can distinguish between different anionic guests such as between Cl^- , which induces a shift in the UV-vis spectra of certain compounds, and Br^- , which does not induce such shifts. This discriminatory ability is most marked when the receptor is protonated. This indicates that these specific receptors can discriminate between different guests and are pH sensitive and can be tailored for use in solutions of specific acidity.

[0072] Reference will now be made in detail to the presently preferred embodiments of the disclosed compounds, compositions and methods.

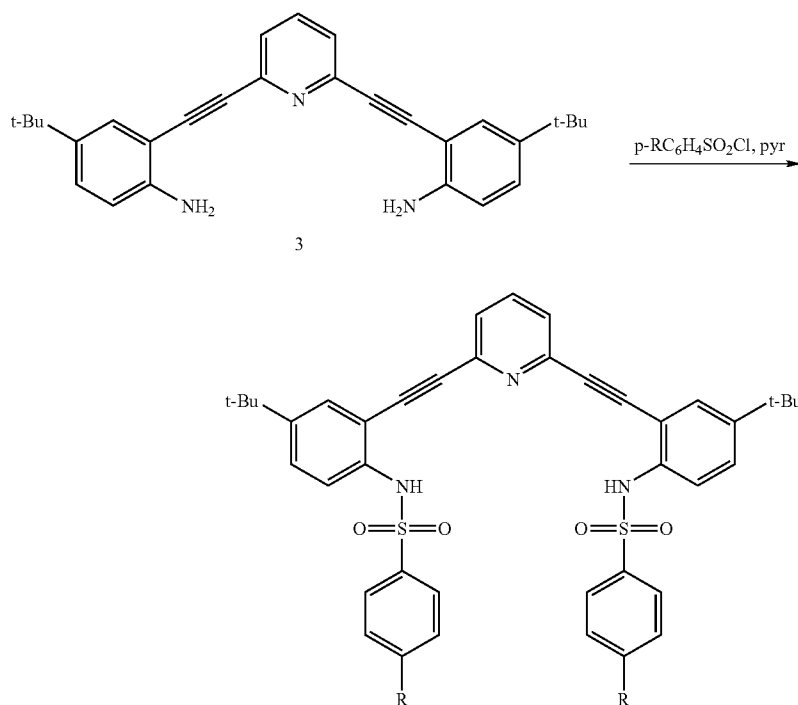
EXAMPLES

[0073] The following examples are provided to illustrate certain particular features and/or embodiments. These examples should not be construed to limit the invention to the particular features or embodiments described.

Example 1

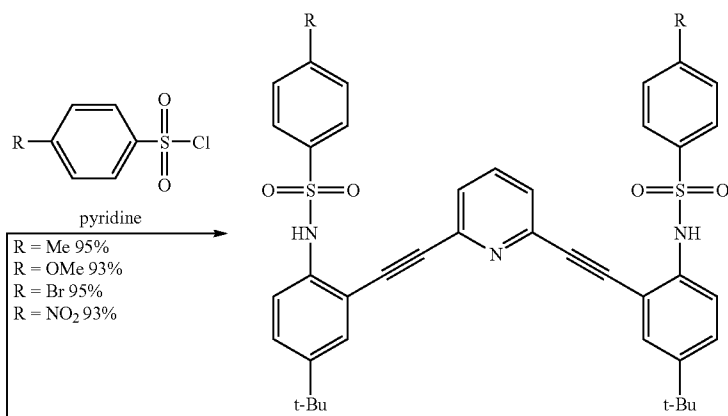
[0074] This example describes general materials and methods used in the synthesis and characterization of exemplary host compounds. All solvents were dried over 3 Å molecular sieves unless otherwise stated. THF, Et_3N , and CH_2Cl_2 were respectively distilled from potassium metal and CaH_2 prior to use. All other materials were obtained from TCI-America, Sigma-Aldrich, Acros and Strem and used as received. ^1H and ^{13}C NMR spectra were recorded using a Varian Inova 300 (^1H 299.95 MHz, ^{13}C 75.43 MHz) or Inova 500 (^1H 500.10 MHz, ^{13}C 125.75 MHz) spectrometer. Chemical shifts (δ) expressed as ppm downfield from tetramethylsilane using either the residual solvent peak as an internal standard (CDCl_3 ^1H : 7.27 ppm) or using CDCl_3 spiked with 1% trimethylsilane for the ^1H NMR spectra. For the ^{13}C NMR spectra the middle CDCl_3 peak (δ 77.00 ppm) was used as the internal standard. Signal patterns are indicated as b, broad; s, singlet; d, doublet; t, triplet; m, multiplet. Coupling constants (J) are given in hertz. UV-Vis spectra were recorded using a Hewlett-Packard 8453 spectrophotometer and extinction coefficients are expressed in $\text{M}^{-1}\text{cm}^{-1}$. Mass spectra were recorded using an Agilent 1100 Series LC/MSD. Emission spectra were recorded on a Hitachi F-4500 fluorescence spectrophotometer. Melting points were determined with a Meltemp II apparatus or a TA Instruments DSC 2920 Modulated DSC. Column chromatography was performed on Whatman reagent grade silica gel (230-400 mesh). Rotary chromatography was performed on a Harrison Research Chromatotron model 7924T with EM-Science 60PF₂₅₄ silica gel. Precoated silica gel plates (Sorbent Technology, UV₂₅₄, 200 μm , 5×20 cm) were used for analytical thin-layer chromatography.

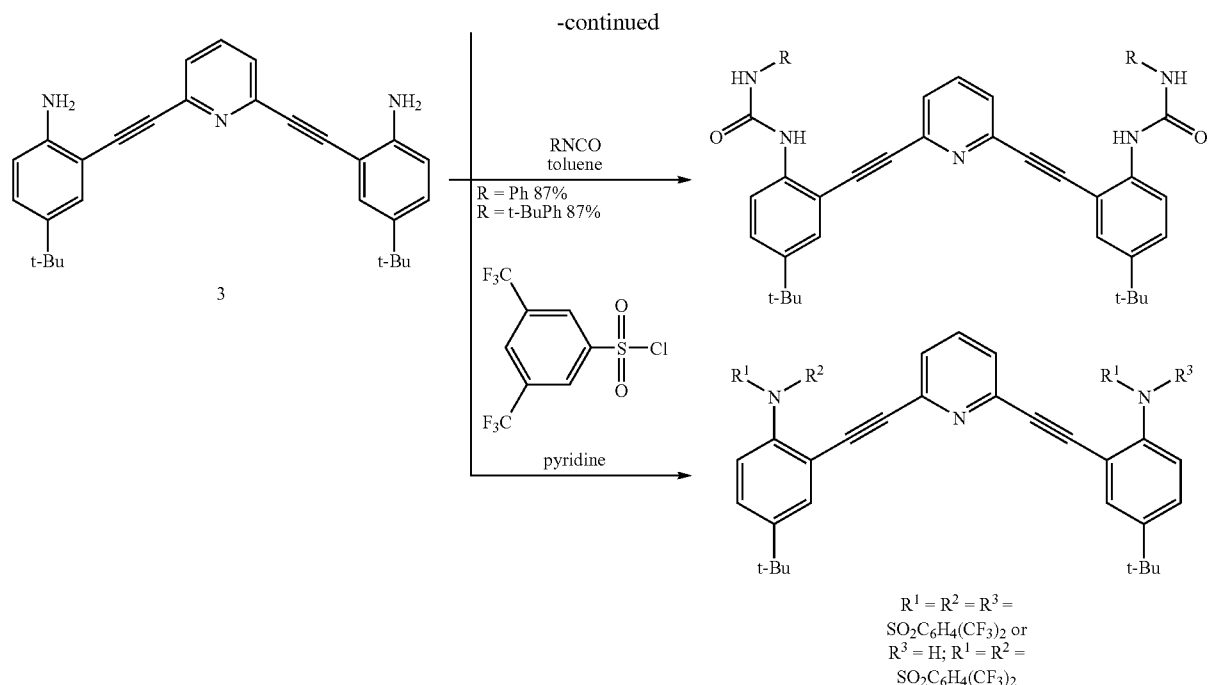
[0075] General Sulfonamide Synthesis: A general synthesis of sulfonamides followed the scheme:



A solution of arene 3 (1 equiv) and sulfonyl chloride (5 equiv) in pyridine (8-15 mM) was stirred for 3 hours under an N_2 environment. Following concentration in vacuo, the crude oil was filtered through a 2.5 cm silica plug and then chromatographed on silica gel.

[0076] The synthesis of several exemplary sulfonamides by the general method is illustrated by the scheme:





[0077] General salt preparation: A 10 mM stock solution of sulfonamide receptor dissolved in CDCl_3 with 1% TMS that had been passed through basic alumina and stored over 3 Å molecular sieves was prepared. With a 9 inch pipet and 10 ml pipet bulb HCl gas is passed through the sulfonamide solution 20 times. The resulting bright yellow solution is diluted to the original volume and an appropriate aliquot is removed for study.

[0078] Crystal growth conditions: Sulfonamide receptors were dissolved in a 10×75 mm test tube with EtOAc to a concentration >10 mM (for halide salts HX gas was passed through the EtOAc solution of receptor). Alternatively, 1 drop of concentrated HX is added and the resulting yellow solution is thoroughly mixed). Hexanes cooled to 0° C. were layered on top of receptor solutions and set aside. After 3 days colorless (neutral receptor complex) or yellow (protonated receptor complex) single crystals were harvested for X-ray diffraction studies.

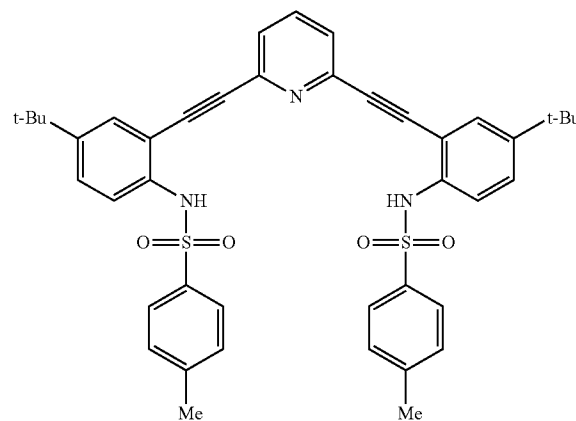
[0079] Single Crystal X-ray Diffraction: X-Ray diffraction data for $(1 \cdot \text{H}_2\text{O})_2$, $(2 \cdot \text{H}_2\text{O})_2$, $(\text{H}_2^+ \cdot \text{Cl}^-)_2$, $(\text{H}_1^+ \cdot \text{Cl}^-) \cdot (1 \cdot \text{H}_2\text{O})$ and $(\text{H}_1^+ \cdot \text{Br}^-)_2$ were collected on a Bruker SMART APEX diffractometer using MoK_α radiation ($\delta = 0.7107$ Å). Data were corrected for absorption using the SADABS v2.02 area absorption correction program. The structures were solved by direct methods and refined based on $|F|^2$. All non-hydrogen atoms were refined with anisotropic displacement parameters. Hydrogen atoms in the investigated structures were found from the residual density maps and refined with isotropic thermal parameters except those in terminal t-Bu groups in $(\text{H}_2^+ \cdot \text{Cl}^-)_2$, $(\text{H}_1^+ \cdot \text{Cl}^-) \cdot (1 \cdot \text{H}_2\text{O})$ and $(\text{H}_1^+ \cdot \text{Br}^-)_2$, which were placed in calculated positions and refined in a rigid group model with isotropic thermal parameters $U(\text{H}) = 1.5$ Ueq (C). One of the H atoms at the bridging solvent molecule in $(1 \cdot \text{H}_2\text{O})_2$ is disordered over two positions in a 1:1 ratio. The O atoms of the bridging water molecule and the Cl atom in

$(\text{H}_1^+ \cdot \text{Cl}^-) \cdot (1 \cdot \text{H}_2\text{O})$ are disordered over two positions corresponding to opposite orientations of the dimeric units. These O and Cl atoms were refined in the same positions with occupation factors $\mu = 1/2$. The H atoms attached to the O atom in the bridging water molecules were not found from the F-map. All calculations were performed with the SHELXTL v.6.1 program package.

Example 2

[0080] This example describes the synthesis of sulfonamide compound 1 via the general synthesis set forth above.

Compound 1

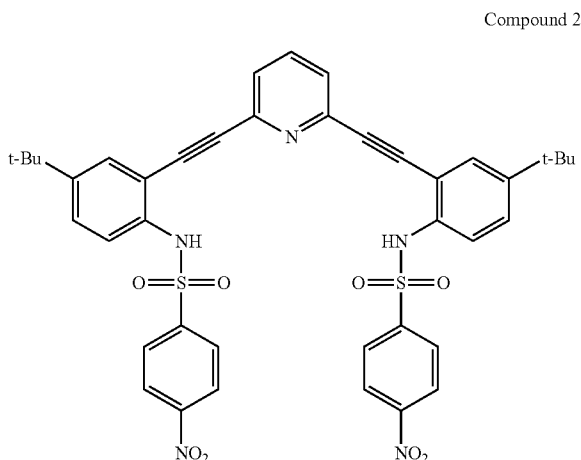


[0081] Arene 3 (150 mg, 0.36 mmol) was reacted with p-toluenesulfonyl chloride according to General Preparation for Sulfonamides (above). Purification by chromatography

(1:1 hexanes:EtOAc) afforded $(1.H_2O)_2$ (249 mg, 95%) as a pale yellow solid. Recrystallization by diffusion (hexanes:EtOAc) afforded colorless crystals. Mp: 133-135° C. 1H NMR (300 MHz, $CDCl_3$): δ 7.85-7.71 (m, 5H), 7.52-7.43 (m, 6H), 7.35 (dd, $J=8.5, 2.3$ Hz, 2H), 7.15 (d, $J=8.5$ Hz, 4H), 2.34 (s, 6H), 1.26 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.53, 143.73, 142.85, 136.93, 136.49, 135.84, 129.54 (2C), 127.89, 127.25, 126.29, 120.52, 112.89, 93.20, 85.56, 34.29, 31.03, 21.45. UV-Vis (CH_2Cl_2): λ_{max} (ϵ) 234 (58,000), 287 (31,000), 330 (27,600) nm. Fluorescent emission ($[(1.H_2O)_2] \leq 0.057$ mM in $CHCl_3$; 354 nm excitation): λ_{max} 388 nm. IR (neat): ν 3266, 2961, 2899, 2877, 2213, 1555, 1156 cm^{-1} . MS (CI pos) m/z (%): 732 ($M^+ + 2$, 21), 731 (MH^+ , 56), 730 (M^+ , 100); $C_{43}H_{43}N_3O_4S_2$ (729.95).

Example 3

[0082] This example describes the synthesis of sulfonamide compound 2 via the general synthesis set forth above.



[0083] Arene 3 (150 mg, 0.36 mmol) was reacted with p-nitrobenzenesulfonyl chloride according to General Preparation for Sulfonamides (above). Purification by chromatography (20:1 CH_2Cl_2 :EtOAc) afforded $(2.H_2O)_2$ (285 mg, 93%) as a pale yellow solid. Recrystallization by diffusion (pentane: $CHCl_3$ or hexanes:EtOAc) afforded pale yellow crystals. Mp: 136-139° C. 1H NMR (300 MHz, $CDCl_3$): δ 8.15 (d, $J=8.7$ Hz, 4H), 8.03 (d, $J=8.7$ Hz, 4H), 7.74 (t, $J=7.8$ Hz, 1H), 7.55 (d, $J=8.7$ Hz, 2H), 7.48-7.37 (m, 6H), 1.29 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 150.10, 149.33, 145.32, 142.68, 137.20, 134.63, 129.82, 128.68, 128.28, 126.31, 124.12, 123.31, 114.59, 92.68, 85.71, 34.51, 31.05. UV-Vis (CH_2Cl_2): λ_{max} (ϵ) 242 (56,200), 285 (35,500), 319 (23,000) nm. Fluorescent emission ($[(2.H_2O)_2] \leq 0.057$ mM in $CHCl_3$; 364 nm excitation): λ_{max} 428 nm. IR (neat): ν 3271, 2964, 2869, 2213, 1348, 1171 cm^{-1} . MS (CI pos) m/z (%): 794 ($M^+ + 2$, 24), 793 (MH^+ , 53), 792 (M^+ , 100), 608 (17), 607 (44); $C_{41}H_{37}N_5O_8S_2$ (791.89).

Example 4

[0084] This example describes the synthesis of the p-methoxy analog of compounds 1 and 2. Arene 3 (110 mg, 0.26 mmol) was reacted with p-methoxybenzenesulfonyl chloride according to General Preparation for Sulfonamides (above). Purification by chromatography (20:1 CH_2Cl_2 :EtOAc)

afforded $(pMeO.H_2O)_2$ (185 mg, 93%) as a white crystalline solid. Recrystallization by diffusion (hexanes: CH_2Cl_2) afforded colorless crystals. Mp: 141-143° C. 1H NMR (300 MHz, $CDCl_3$): δ 7.77 (d, $J=9$ Hz, 4H), 7.76 (t, $J=9$ Hz, 1H), 7.53-7.45 (m, 5H), 7.37 (dd, $J=9, 3$ Hz, 2H), 6.84 (d, $J=9$ Hz, 4H), 3.77 (s, 6H), 1.28 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 163.06, 147.62, 142.93, 136.75, 135.70, 130.85, 129.60, 129.43, 127.85, 126.44, 120.64, 114.09, 113.02, 93.28, 85.33, 55.45, 34.31, 31.03. UV-Vis (CH_2Cl_2): λ_{max} (ϵ) 239 (71,700), 292 (30,200), 343 (23,000) nm. Fluorescent emission ($[(pMeO.H_2O)_2] \leq 0.05$ mM in $CHCl_3$; 353 nm excitation): λ_{max} 389 nm. IR (neat): ν 3248, 2962, 2902, 2870, 2214, 1498, 1161 cm^{-1} . MS (CI pos) m/z (%): 764 ($M^+ + 2$, 22), 763 (MH^+ , 49), 762 (M^+ , 100); $C_{43}H_{43}N_3O_6S_2$ (761.95).

Example 5

[0085] This example describes the characterization of the solid state and solution phase ion binding properties of exemplary host molecules disclosed herein. Colorless single crystals of compounds 1 and 2 suitable for X-ray diffraction were grown by layering hexane onto ethyl acetate solutions of each receptor. As suggested from the 1H NMR spectroscopic data, complexes $(1.H_2O)_2$ and $(2.H_2O)_2$ both crystallize as dimers in space group P-1 with two receptor molecules and two water molecules per unit cell; consequently, each dimer has crystallographic inversion symmetry. A prominent feature of each crystal structure is the presence of two hydrogen bonding water molecules stitching the receptor dimers together. Both pyridine nitrogens accept hydrogen bonds from a different water molecule [2.797(4)-2.804(2) Å, O—H...N angles 172(4)-175(3)°], while one water-water hydrogen bond is present [2.917(5)-3.006(7) Å, O—H...O angles 164(4)-178(6)°]. All of the N-substituted sulfonamides adopt the energetically most-favored 'staggered' conformation, and both sulfonamide protons on each receptor donate a hydrogen bond to a different water molecule [2.855(4)-2.860(3) Å, 157(2)-164(3)° and 3.028(4)-3.039(3) Å, 158(2)-164(3)°] such that the 2+2 dimer structure is held together by four sulfonamide-water hydrogen bonds, two pyridine-water hydrogen bonds, one water-water hydrogen bond and two π -stacking interactions between receptors ranging from 3.42-3.44 Å.

[0086] The dimerization of receptor 1 was further investigated in $CDCl_3$ solutions. Receptor 1 was dissolved in water-saturated $CDCl_3$ to a concentration of 197 mM. Monitoring the sulfonamide N—H and water 1H NMR resonances following a series of dilutions resulted in data that could be fit to a 1:1 dimerization with the non-linear regression curve fitting software WinEQNMR. In $CDCl_3$ solutions receptor 1 is shown to dimerize with a modest $K_{dim} = 42 M^{-1}$. Supporting evidence of dimerization in $CDCl_3$ solutions resulted from the NOE observed between the protons on the guest water molecules and the sulfonamide protons of the receptor. Receptor 1 exhibits a propensity to crystallize as a dimer with H_2O even in the presence of other potential neutral guest molecules and in solvents dried over 3 Å molecular sieves.

[0087] Receptor molecules 1 and 2 both alter guest selectivity by simple changes in the protonation state of the receptors. By protonating the pyridine nitrogen of receptors 1 and 2, the anion binding capacity of these receptors is activated. The halide binding properties of $H1^+$ have been investigated in the solid state: single crystals of the chloride and bromide complexes are prepared by dissolving receptor 1 or 2 in ethyl acetate and bubbling HCl or HBr gas through the solution.

Crystallization is induced by layering hexanes onto the yellow ethyl acetate solutions. Strikingly, the single crystal structures of the $\text{H2}^+.\text{Cl}^-$ and $\text{H1}^+.\text{Br}^-$ complexes revealed nearly isostructural dimers to those observed for the neutral $(1.\text{H}_2\text{O})_2$ and $(2.\text{H}_2\text{O})_2$ water dimers. In the solid state the $(\text{H2}^+.\text{Cl}^-)_2$ and $(\text{H1}^+.\text{Br}^-)_2$ dimers (FIG. 2) are held together by four sulfonamide hydrogen bonds [3.156(2)-3.229(2) Å, $\text{N}-\text{H} \dots \text{Cl}$ angles 151(2)-171(3)°; 3.338(5)-3.440(6) Å, $\text{N}-\text{H} \dots \text{Br}$ angles 136(4)-168(4)°], two pyridinium $\text{N}-\text{H}$ hydrogen bonds to the anions [3.022(2) Å, 175(3)° for $(\text{H2}^+.\text{Cl}^-)_2$ and 3.127(6) Å, 173(4)° for $(\text{H1}^+.\text{Br}^-)_2$], two $\text{C}_{\text{aryl}}-\text{H} \dots \text{X}$ hydrogen bonds (3.69-3.90 Å), and two π -stacking interactions between receptors (3.49 Å for $(\text{H2}^+.\text{Cl}^-)_2$ and 3.61 Å for $(\text{H1}^+.\text{Br}^-)_2$). The numerous hydrogen bonds and unique dimerization bring the negatively charged halides into close proximity with halide-halide distances of 3.92 Å for $(\text{H2}^+.\text{Cl}^-)_2$ and 4.08 Å for $(\text{H1}^+.\text{Br}^-)_2$.

[0088] CAChe semi-empirical calculations of the 2,6-bis(2-anilino-ethynyl)pyridine receptors suggested that larger polyatomic anions would not fit within the binding pocket of the receptor. As predicted, the single crystal X-ray structure of the HBF_4 salt ($\text{H1}^+.\text{BF}_4^-$) reveals that the binding pocket is too small to accommodate the interaction of the large BF_4^- guest with either sulfonamide proton. Dilution experiments of $\text{H1}^+.\text{BF}_4^-$ revealed minimal change in the ^1H NMR spectrum upon addition with CDCl_3 , indicating negligible dimerization in solution as predicted by the receptor conformation observed in the crystal structure. However, titrations of $\text{H1}^+.\text{BF}_4^-$ with tetra-n-butylammonium halide salts do indicate anion binding occurs in solution between the receptor and halides. Furthermore, the concentration dependence observed in the ^1H NMR spectrum upon dilution of $(\text{H1}^+.\text{Cl}^-)_2$ in CDCl_3 indicates the presence of a receptor/halide dimer in solution. A supersaturated solution of $(\text{H1}^+.\text{Cl}^-)_2$ (60 mM) was obtained by passing HCl gas through a CDCl_3 solution of neutral receptor 1. Plotting the changes in chemical shift upon dilution and subsequent fitting of this data to a 1:1 dimerization model with the non-linear least squares regression program WinEQNMR resulted in a $K_{\text{dim}}=250 \text{ M}^{-1}$ in CDCl_3 .

[0089] Further evidence of dimerization was obtained by mixing a 1:1 ratio of receptor 1 and a p-methoxyphenyl sulfonamide derivative (synthesis described in Example 4 above). In an equimolar mixture of the two receptors, the resulting ^1H NMR signals are shifted from the signals observed for either of the analogous homodimers prepared in the same way at the same concentration. Briefly, the equimolar mixtures of these receptors were prepared at 10 mM in CDCl_3 as follows: $[1.\text{H}_2\text{O}].[\text{pMeO}.\text{H}_2\text{O}].1.\text{H}_2\text{O}$ (3.650 mg, 0.00488 mmol) and $\text{pMeO}.\text{H}_2\text{O}$ (3.740 mg, 0.00480 mmol) were dissolved in separate portions of CDCl_3 with 1% TMS (1 mL) passed through basic alumina and dried with 3 Å molecular sieves. Aliquots (400 μL) from each solution were transferred to an NMR tube via syringe and thoroughly mixed. ^1H NMR spectra were recorded on a Varian 300 MHz spectrometer. Proton signals were referenced to the 1% TMS included in the CDCl_3 . ^1H NMR (300 MHz, CDCl_3): δ 7.81-7.73 (m, 10H), 7.52-7.44 (m, 12H), 7.38-7.33 (m, 8H), 7.18 (d, $J=9$ Hz, 4H), 6.85 (d, $J=9$ Hz, 6H), 7.18 (d, $J=6$ Hz, 3H) 2.29 (s, 6H), 1.26 (s, 18H).

[0090] By comparison, 10 mM stock solutions of $(\text{H1}^+.\text{Cl}^-)_2$ had the data: ^1H NMR (300 MHz, CDCl_3): δ 9.51 (b, 2H), 8.40 (b, 1H), 8.13 (d, $J=6$ Hz, 4H), 8.00-7.75 (b, 4H), 7.48-7.41 (m, 6H), 7.18 (d, $J=6$ Hz, 3H) 2.29 (s, 6H), 1.26 (s,

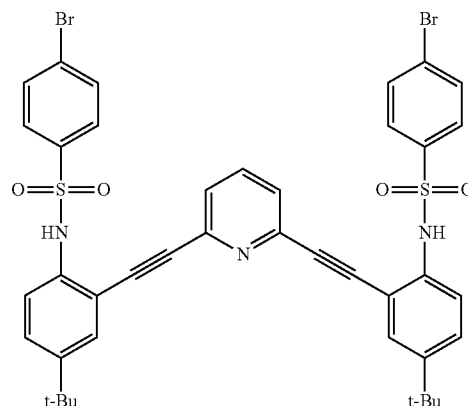
18H). 10 mM stock solutions of $(\text{HpMeO}^+.\text{Cl}^-)_2$ had the data: ^1H NMR (300 MHz, CDCl_3): δ 9.36 (b, 2H), 8.31 (t, 1H), 8.17 (d, $J=9$ Hz, 4H), 7.72 (d, $J=9$ Hz, 4H), 7.40 (m, 6H), 6.86 (d, $J=9$ Hz, 4H) 3.75 (s, 6H), 1.26 (s, 18H).

[0091] This result suggests that both homodimers and a third species—the heterodimer—are present in solution, but equilibrating quickly on the NMR timescale. From all of these experiments it is evident that dimerization of both the neutral and protonated forms of 2,6-bis(2-anilinoethynyl)pyridine receptors occurs both in the solid state and in solution.

[0092] Remarkably, a different type of “heterodimer” ($\text{H1}^+.\text{Cl}^-$).(1. H_2O) was also crystallized in the presence of concentrated HCl with one water and one chloride in the binding pocket. Briefly, the heterodimer $[\text{H1}^+.\text{Cl}^-].[\text{HpMeO}^+.\text{Cl}^-]$ was prepared as follows: The stock solutions from the preparation of $[1.\text{H}_2\text{O}].[\text{pMeO}.\text{H}_2\text{O}]$ (above) were combined and protonated with HCl gas (see above, General salt preparation). ^1H NMR spectra were recorded on a Varian 300 MHz spectrometer. Proton signals were referenced to the 1% TMS included in the CDCl_3 . ^1H NMR (300 MHz, CDCl_3): δ 9.49 (s, 2H), 9.44 (s, 2H), 8.30 (b, 2H), 8.18 (d, $J=9$ Hz, 4H), 8.12 (d, $J=9$ Hz, 4H), 7.71 (d, $J=6$ Hz, 4H) 7.46 (m, 12H), 7.17 (d, $J=6$ Hz, 4H), 6.85 (d, $J=6$ Hz, 4H), 3.73 (s, 6H), 2.27 (s, 6H), 1.25 (s, 36H). The resultant heterodimer contains one protonated receptor that binds a chloride anion while the other receptor in the dimer is neutral and bound to a water molecule. Water and chloride are freely exchangeable in this binding pocket and provide intermediate structural features to the H_2O and halide dimers. Analogous to the other dimers presented, the heterodimer is stabilized by π -stacking interactions between the two receptors (3.43 Å) and a series of seven guest assisted hydrogen bonds. Each guest molecule—water and chloride—accepts two sulfonamide $\text{N}-\text{H}$ hydrogen bonds (3.157(3)-3.181(3) Å, $\text{N}-\text{H} \dots \text{X}$ angles 158(3)-167(3)°) and additionally forms a helical hydrogen bonding pattern running between the pyridinium, chloride, water and pyridine heteroatoms (2.926(3)-3.10 Å, 164(3)-176(4)°). Two $\text{C}_{\text{aryl}}-\text{H} \dots \text{Cl}$ hydrogen bonds (3.76-3.93 Å) also stabilize the dimer.

Example 6

[0093] This example describes the synthesis of the compound

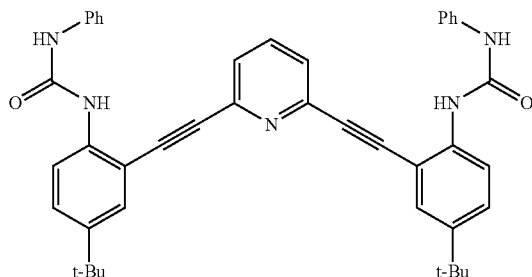


via the General Preparation for Sulfonamides described above. Briefly, arene 3 (100 mg, 0.24 mmol) was reacted with

p-bromobenzenesulfonyl chloride. Purification by chromatography (2.5:1 hexanes:EtOAc) followed by recrystallization by diffusion (hexanes:EtOAc) afforded 10c (183 mg, 89%) as colorless crystals. Mp: 152-154° C. ¹H NMR (300 MHz, CDCl₃): δ 8.00 (br s, 2H), 7.82-7.71 (m, 5H), 7.53-7.37 (m, 10H), 1.29 (s, 18H). ¹³C NMR (75 MHz, CDCl₃): δ 148.25, 142.72, 138.65, 137.16, 135.52, 132.22, 129.59, 128.88, 128.18, 127.96, 126.19, 121.56, 113.46, 92.97, 85.89, 34.43, 31.08. Fluorescence emission ([10c] ≤ 5.7 × 10⁻⁵ M in CHCl₃; 308 nm excitation): λ_{max} 381 nm. MS (CI pos) m/z (%): 863 (M⁺+6, 24), 862 (M⁺+5, 61), 861 (M⁺+4, 42), 860 (M⁺+3, 100), 859 (M⁺+2, 21), 858 (MH⁺); C₄₁H₃₇Br₂N₃O₄S₂ (857.06).

Example 7

[0094] This example describes the synthesis of the compound

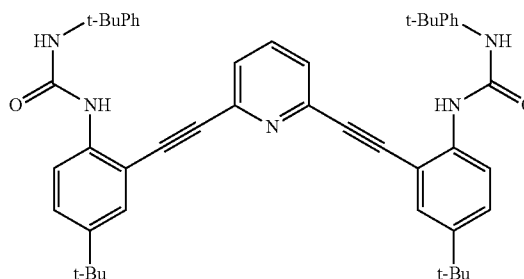


[0095] Phenyl isocyanate (303 mg, 2.5 mmol) was added to a solution of arene 3 (215 mg, 0.5 mmol) in toluene (25 mL). The reaction was stirred for 12 hours under an N₂ environment. Concentration in vacuo afforded a crude oil which was filtered through a 2.5 cm silica plug with 1:1 hexanes:EtOAc. Chromatography on silica gel (3:1 hexanes:EtOAc) followed by precipitation with hexanes or ether afforded the desired product (287 mg, 87%) as a white, fluffy solid. Recrystallization by diffusion (pentane:CHCl₃) afforded white, needle crystals. Mp: 212-215° C. ¹H NMR (300 MHz, CDCl₃): δ

8.32 (br s, 2H), 8.07 (d, J=4.8 Hz, 2H), 7.74 (br s, 2H), 7.47-7.28 (m, 11H), 7.15 (t, J=4.5 Hz, 4H), 6.92 (t, J=4.5 Hz, 2H), 1.29 (s, 18H). ¹³C NMR (125 MHz, THF-d₈): δ 152.95, 145.38, 144.62, 141.17, 140.40, 138.15, 130.11, 129.56, 128.78, 127.65, 122.94, 120.33, 114.49, 110.45, 94.38, 87.33, 35.01, 31.75. Fluorescence emission ([11a] ≤ 5.7 × 10⁻⁵ M in CHCl₃; 371 nm excitation): λ_{max} 411 nm. MS (CI pos) m/z (%): 661 (MH⁺, 49), 660 (M⁺, 100); C₄₃H₄₁N₅O₂ (659.82).

Example 8

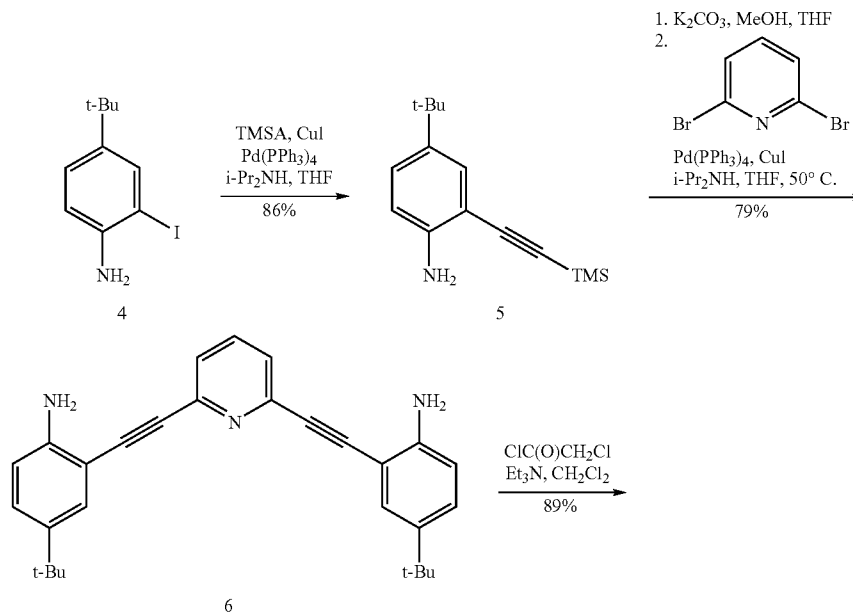
[0096] This example describes the synthesis of the compound

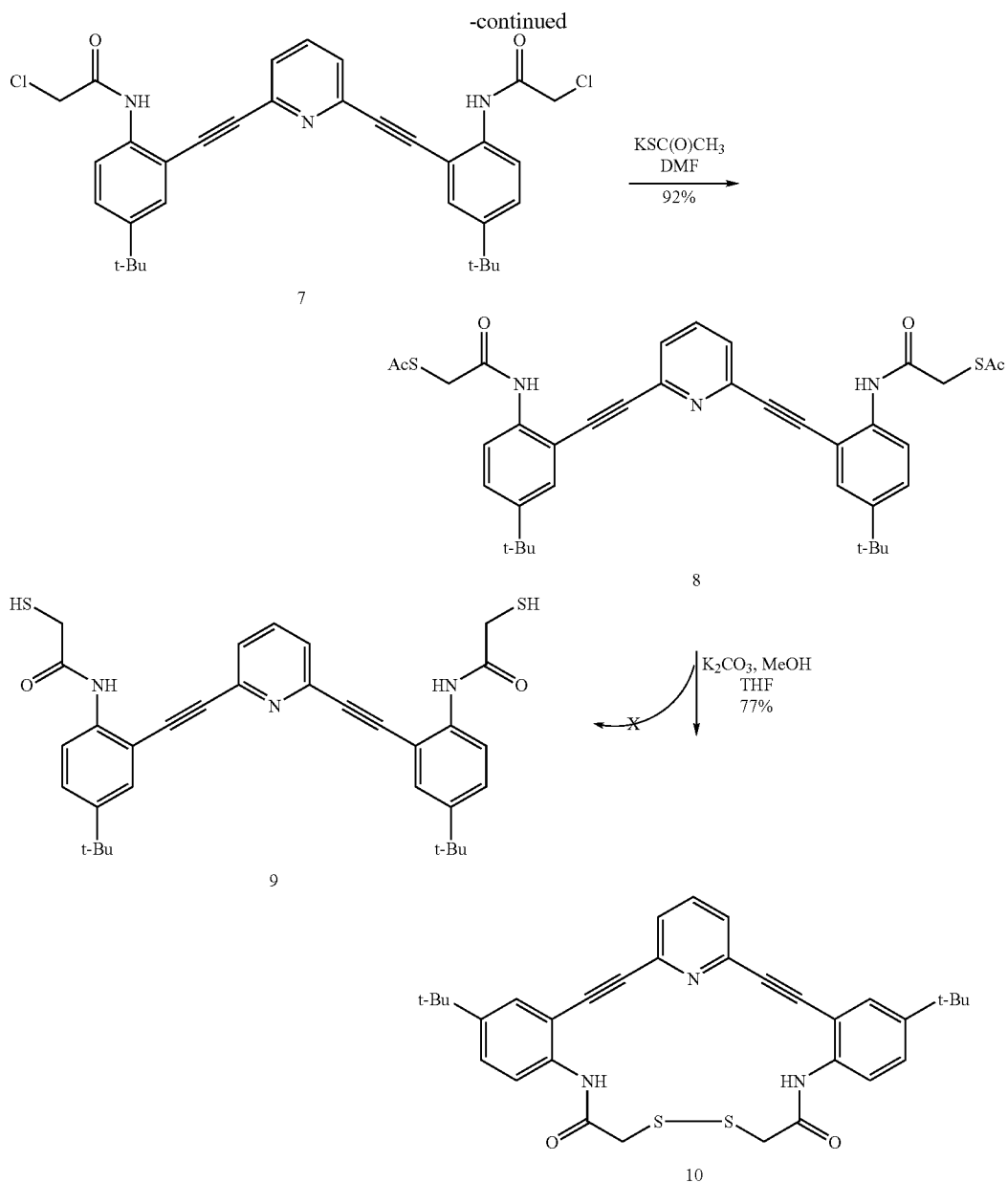


4-(t-Butyl)phenyl isocyanate (124 mg, 0.72 mmol) was added to a solution of arene 3 (100 mg, 0.24 mmol) in toluene (10 mL). The reaction was stirred for 12 hours under an N₂ environment. Concentration in vacuo followed by chromatography on silica gel (CHCl₃) and trituration with acetone or ether afforded 11b (135 mg, 75%) as a white, fluffy solid. Mp: 197-200° C. ¹H NMR (300 MHz, CDCl₃): δ 8.33 (br s, 2H), 8.05 (d, J=8.7 Hz, 2H), 7.66 (s, 2H), 7.38-7.15 (m, 15H), 1.28 (s, 18H), 1.23 (s, 18H). MS (CI pos) m/z (%): 774 (MH⁺+1, 13), 773 (MH⁺, 66), 772 (M⁺, 100); C₅₁H₅₇N₅O₂ (772.03).

Example 9

[0097] This example describes the synthesis of thiol-based receptors via the scheme:

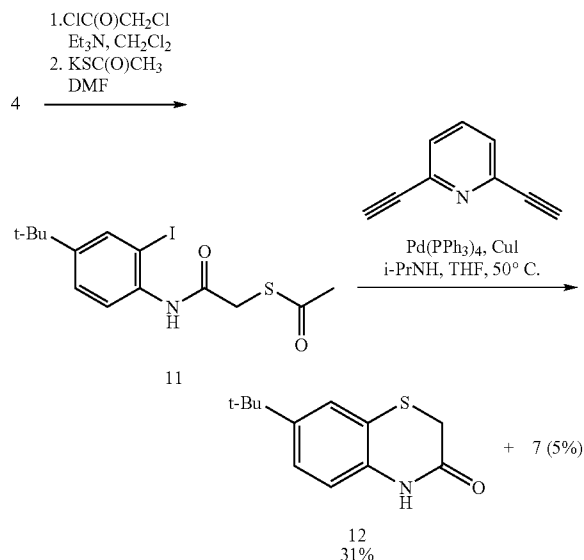




With continued reference to the scheme above, synthesis began with previously reported iodoaniline 4, (Wan, W. B.; Haley, M. M. *J. Org. Chem.* 2001, 66, 3893-3901) available in 73% yield via iodination of tert-butylaniline. Pd-catalyzed cross-coupling (*Metal-Catalyzed Cross-Coupling Reactions*, 2nd ed.; de Meijere, A., Diederich, F., Eds.; Wiley-VCH: Weinheim, 2004) of 4 with TMSA afforded ethynylarene 5 in 86% yield. Arene 6 was obtained in 79% yield by desilylation of 5 with weak base (*Protecting Groups in Organic Synthesis*, 3rd ed.; Greene, T. W.; Wuts, P. G. M., Eds.; Wiley-VCH: New York, 1999; pp 654-657) followed by two-fold cross-coupling to 2,6-dibromopyridine. Treatment of diamine 6 with an excess of chloroacetylchloride in CH_2Cl_2 afforded diamide 7 in very good yield. Reaction of arene 7 with potas-

sium thioacetate in DMF (van Bommel, K. J. C.; de Jong, M. R.; Metselaar, G. A.; Verboom, W.; Huskens, J.; Hulst, R.; Kooijman, H.; Spek, A. L.; Reinhoudt, D. N. *Chem. Eur. J.* 2001, 7, 3603-3615) resulted in acetyl-protected receptor 8. Crystals of arene 8 suitable for single crystal X-ray diffraction, obtained from slow diffusion of hexanes into a concentrated solution of 8 in EtOAc, indicated a dimeric association with intermolecular H-bonding. Treatment of 8 with K_2CO_3 in MeOH and THF under both air-free and ambient conditions afforded the intramolecular disulfide analog 10 in 77% yield instead of the free thiol 9. The disulfide bond of 10 enforces a pre-organization of the phenylacetylene substituents with the amide-N, disulfide linkage, and pyridine-N in a potential binding cavity.

[0098] An alternate synthetic route for receptor 9 was investigated following the scheme:

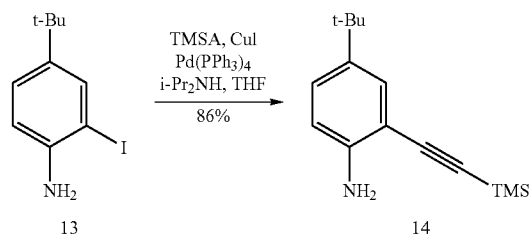


Successive treatment of iodoarene 4 with chloroacetylchloride and potassium thioacetate afforded intermediate 11. Pd-catalyzed cross-coupling of 11 to 2,6-diethynylpyridine (Dana, B. H.; Robinson, B. H.; Simpson, J. J. *Organomet. Chem.* 2002, 648, 251-269) produced penultimate 8 in very low yield (5%) due to competitive formation of benzothiazinone 12 from iodoarene 11. Both slow addition of the diethynylpyridine to a solution of 11 as well as direct combination of the two starting materials resulted in similar product distribution, with 12 as the major product. Benzothiazinone formation can be rationalized by pyridine base or metal catalyst deprotection of the thiol moiety followed by nucleophilic displacement of the iodide, a prearranged and favorable formation of an unsaturated six-membered ring. Conversion of 11 to 12 effectively prevented further cross coupling to the central pyridine core and hence resulted in low yield for arene 8. The remainder of the product distribution could not be discerned but likely included disulfide and/or oligomeric analogs of both 10 and 11.

[0099] Absorption and emission data: Compounds 6-8 and 10 are fluorescent chromophores that exhibit blue or purple fluorescence under UV light (365 nm). The absorption spectra of compounds 6-8 and 10 are dominated by a characteristic pattern consisting of three peaks. There is a lack of significant spectral changes associated with conversion of diamide 8 to disulfide 10, which is not unexpected, as overall conjugation remains limited by the methylene spacer. Upon addition of TFA, 10 displayed enhanced low energy absorption (>100 nm) as well as conversion from a colorless solution with purple fluorescence to a deep yellow solution with yellow fluorescence. Treatment of the acidic solution with aqueous base resulted in return of the original absorption spectrum and fluorescence of 10.

Example 10

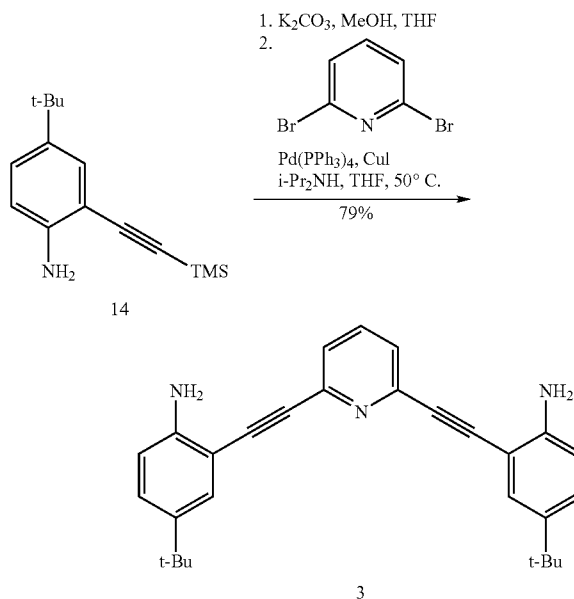
[0100] This example describes the synthesis and characterization of 4-tert-Butyl-2-(2-trimethylsilylethynyl)aniline 14 via the scheme:



A suspension consisting of 4-tert-butyl-2-iodoaniline 13 (800 mg, 2.9 mmol), Pd(PPh₃)₄ (168 mg, 0.15 mmol), and CuI (55 mg, 0.29 mmol) in i-Pr₂NH (50 mL) and THF (50 mL) was degassed by bubbling Ar. TMSA (1.3 mL, 9 mmol) was added and the suspension was stirred at room temperature for 12 hours under N₂. The suspension was filtered and the insoluble salts washed twice with Et₂O. The filtrate was combined with the Et₂O washes, concentrated, and purified by Chromatotron (3:2 hexanes:CH₂Cl₂) to afford 14 (611 mg, 86%) as a red-brown oil. ¹H NMR (300 MHz, CDCl₃): δ 7.32 (d, J=2.1 Hz, 1H), 7.17 (dd, J=8.4, 2.1 Hz, 1H), 6.65 (d, J=8.4 Hz, 1H), 4.13 (br s, 2H), 1.27 (s, 9H), 0.29 (s, 9H). ¹³C NMR (75 MHz, CDCl₃): δ 145.87, 140.55, 128.68, 127.21, 114.09, 107.25, 102.40, 98.99, 33.79, 31.33, 0.16. IR (neat) ν 3476, 3381, 2960, 2868, 2147, 1500 cm⁻¹. MS (CI pos) m/z (%): 316 (M⁺+THF, 38), 279 (M⁺+Na⁺, 35), 247 (M⁺+2, 23), 246 (MH⁺, 100); C₁₅H₂₃NSi (245.44).

Example 11

[0101] This example describes the synthesis and characterization of the compound referred to above as arene 3:

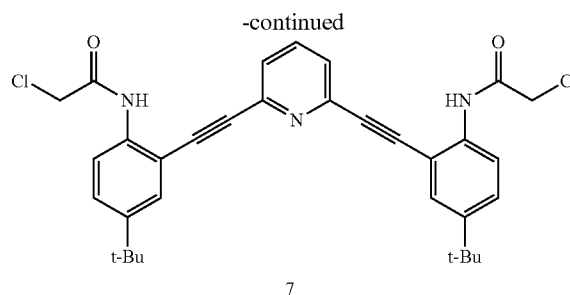
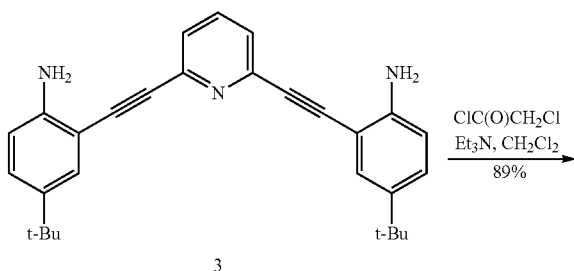


A suspension of ethynylarene 14 (206 mg, 0.84 mmol) and K₂CO₃ (5 equiv.) in MeOH (20 mL) and Et₂O (10 mL) was stirred at room temperature and monitored by TLC until completion (15-30 min). The solution was diluted with Et₂O and washed with water and brine. The organic layer was dried

over MgSO_4 and concentrated in vacuo. Without further purification, the residue was dissolved in THF (10 mL) and added dropwise over a period of 12 hours to a stirred, deoxygenated suspension of 2,6-dibromopyridine (50 mg, 0.21 mmol), $\text{Pd}(\text{PPh}_3)_4$ (25 mg, 0.02 mmol), and CuI (8 mg, 0.04 mmol) in THF (50 mL) and $i\text{-Pr}_2\text{NH}$ (50 mL) at 45°C . After an additional 3 hours of stirring, the suspension was filtered and the insoluble salts washed twice with Et_2O . The filtrate was combined with the Et_2O washes, concentrated, and purified by Chromatotron (3:2 hexanes: EtOAc) to afford 3 (70 mg, 79%) as a pale brown, crystalline solid. Mp: 226°C . ^1H NMR (300 MHz, CDCl_3): δ 7.64 (t, $J=8.1$ Hz, 1H), 7.45-7.43 (m, 4H), 7.20 (dd, $J=8.7$, 1.8 Hz, 2H), 6.67 (d, $J=8.7$ Hz, 2H), 4.35 (br s, 4H), 1.27 (s, 18H). ^{13}C NMR (75 MHz, CDCl_3): δ 146.31, 143.84, 140.56, 136.36, 129.24, 128.04, 125.73, 114.34, 105.82, 93.11, 87.59, 33.85, 31.31. IR (neat) ν 3451, 3355, 2957, 2866, 2199, 1500 cm^{-1} . UV/vis (CH_2Cl_2): λ_{max} (ϵ) 249 (44,200), 295 (24,300), 359 (22,500) nm. MS (CI pos) m/z (%): 423 (M^++2 , 100), 422 (MH^+ , 100); $\text{C}_{29}\text{H}_{31}\text{N}_3$ (421.58).

Example 12

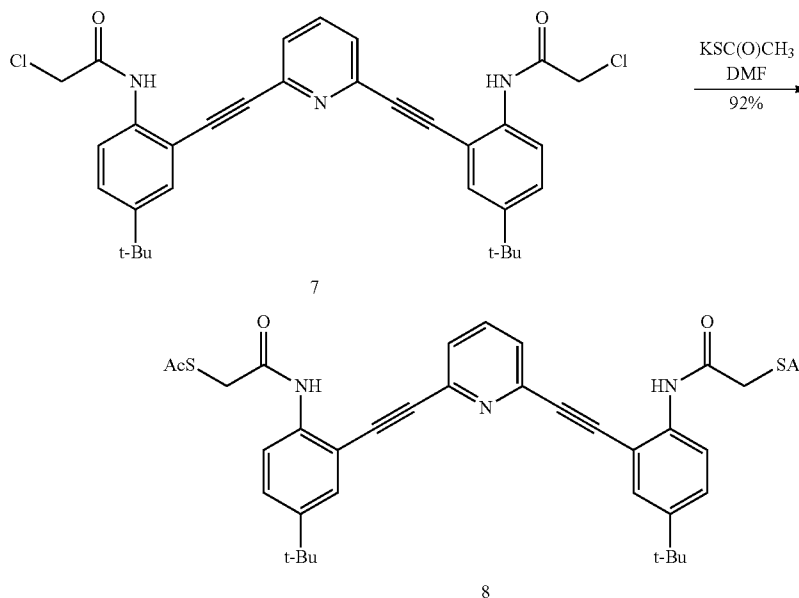
[0102] This example describes the synthesis and characterization of the compound referred to above as arene 7:



[0103] A solution of chloroacetylchloride (571 mg, 5.1 mmol) in CH_2Cl_2 (10 mL) was added to a stirred, deoxygenated solution of arene 3 (395 mg, 0.94 mmol) and Et_3N (379 mg, 3.76 mmol) in CH_2Cl_2 (10 mL). The reaction was stirred for 12 hours at room temperature under N_2 and then concentrated in vacuo. CH_2Cl_2 was added and the organic layer was washed thrice with water, dried over MgSO_4 , and concentrated in vacuo. The crude material was filtered through a 2.5 cm silica plug (1:1 hexanes: EtOAc) and concentrated to afford 4 (476 mg, 89%) as a pale brown solid. Mp: 193°C . ^1H NMR (300 MHz, CDCl_3): δ 9.23 (br s, 2H), 8.30 (d, $J=8.3$ Hz, 2H), 7.72 (t, $J=8.3$ Hz, 1H), 7.64 (d, $J=2.1$ Hz, 2H), 7.52 (d, $J=8.1$ Hz, 2H), 7.43 (dd, $J=8.1$, 2.1 Hz, 2H), 4.27 (s, 4H), 1.31 (s, 18H). ^{13}C NMR (75 MHz, CDCl_3): δ 163.62, 147.46, 143.19, 136.83, 135.83, 129.32, 127.87, 126.20, 119.07, 111.15, 94.78, 84.80, 43.21, 34.41, 31.10. IR (neat) ν 3363, 2962, 2868, 2207, 1691, 1523 cm^{-1} . UV/vis (CH_2Cl_2): λ_{max} (ϵ) 254 (52,600), 293 (27,700), 335 (27,600) nm. MS (CI pos) m/z (%): 578 (M^++ , 15), 577 (M^++3 , 23), 576 (M^++2 , 75), 575 (MH^+ , 38), 574 (M^+ , 100); $\text{C}_{33}\text{H}_{33}\text{Cl}_2\text{N}_3\text{O}_2$ (574.54).

Example 13

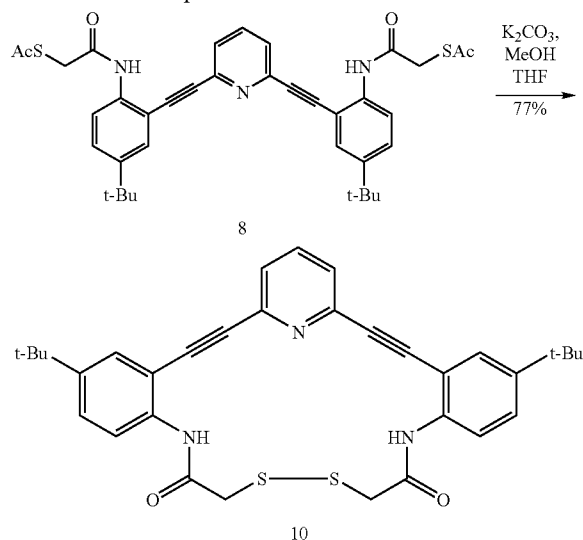
[0104] This example describes the synthesis and characterization of the compound referred to above as arene 8:



Potassium thioacetate (16 mg, 0.14 mmol) was added to a stirred, deoxygenated solution of arene 7 (34 mg, 0.06 mmol) in DMF (3 mL). The reaction was stirred for 12 hours at room temperature under N₂ and then concentrated in vacuo. The crude material was filtered through a 2.5 cm silica plug (1:1 hexanes:EtOAc) and purified via Chromatotron (2:1 hexanes:EtOAc) to afford 8 (35 mg, 92%) as a spongy light yellow solid. Recrystallization by diffusion (hexanes:EtOAc) afforded colorless crystals. Mp: 94° C. ¹H NMR (300 MHz, CDCl₃): δ 8.75 (br s, 2H), 8.28 (d, J=8.7 Hz, 2H), 7.75 (s, 3H), 7.58 (d, J=2.4 Hz, 2H), 7.39 (dd, J=8.7, 2.4 Hz, 2H), 3.76 (s, 4H), 2.34 (s, 6H), 1.28 (s, 18H). ¹³C NMR (75 MHz, CDCl₃): δ 195.20, 166.16, 146.81, 143.31, 136.59, 136.54, 129.38, 127.68, 126.57, 119.45, 110.79, 94.31, 85.15, 34.27, 33.99, 31.05, 30.13. IR (neat) ν 3339, 3058, 2962, 2868, 2208, 1693, 1518 cm⁻¹. UV/vis (CH₂Cl₂): λ_{max} (ε) 253 (48,200), 291 (24,500), 330 (21,600) nm. MS (CI pos) m/z (%): 656 (M⁺+2, 19), 655 (MH⁺, 44), 654 (M⁺, 100); C₃₇H₃₉N₃O₄S₂ (653.85).

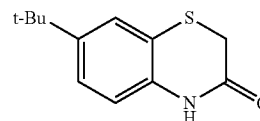
Example 14

[0105] This example describes the synthesis and characterization of the compound referred to above as disulfide 10.



K₂CO₃ (3 equiv) was added to a deoxygenated solution of 8 (23 mg, 0.03 mmol) in MeOH (5 mL) and THF (3 mL). The suspension was stirred at room temperature under N₂ for 30 minutes and completion was monitored by TLC. Et₂O was added and the reaction mixture was washed with water and/or a saturated solution of NH₄Cl. The aqueous layer was further washed with Et₂O twice. The organics were combined and dried over MgSO₄. Concentration and purification via Chromatotron (3:2 hexanes:EtOAc) afforded 10 (17 mg, 77%) as a crystalline, white solid. Mp: 247° C. ¹H NMR (300 MHz, CDCl₃): δ 9.79 (br s, 2H), 8.47 (d, J=9 Hz, 2H), 7.72 (t, J=7.7 Hz, 1H), 7.57 (d, J=2.1 Hz, 2H), 7.51 (d, J=8.1 Hz, 2H), 7.46 (dd, J=8.8, 2.1 Hz, 2H), 3.70 (s, 4H), 1.58 (s, 2H), 1.34 (s, 18H). IR (neat) ν 3318, 2959, 2925, 2855, 2207, 1687, 1515 cm⁻¹. UV/vis (CH₂Cl₂): λ_{max} (ε) 254 (52,200), 296 (24,800), 323 (17,800), 337 (17,500) nm. MS (CI pos) m/z (%): 570 (M⁺+1, 19), 569 (MH⁺, 38), 568 (M⁺, 100); C₃₃H₃₃N₃O₂S₂ (567.76).

[0106] Alternate route product, benzothiazinone 12

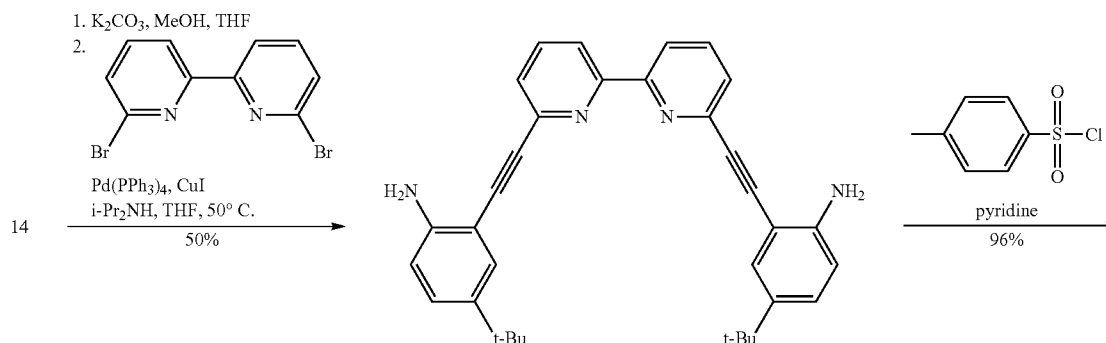


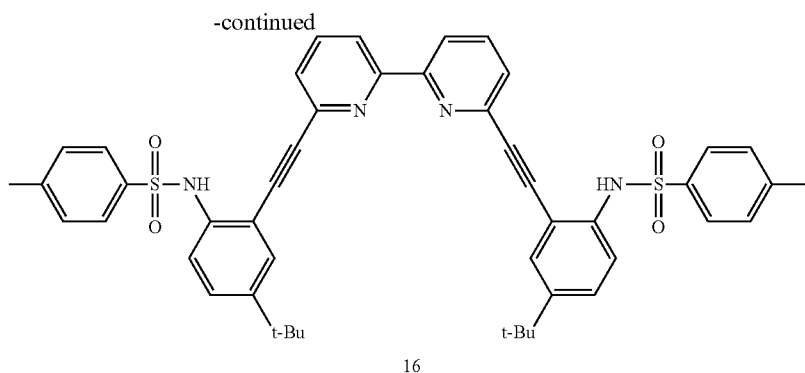
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had the spectral data ¹H NMR (300 MHz, CDCl₃): δ 7.30 (d, J=1.2 Hz, 1H), 7.18 (dd, J=4.8, 1.2 Hz, 1H), 6.82 (d, J=4.8 Hz, 1H), 3.43 (s, 2H), 1.29 (s, 9H). MS (CI pos) m/z (%): 279 (M⁺+H₂O+CH₃CN, 100), 263 (M³⁺+CH₃CN, 73), 218 (M⁺-3, 61); C₁₂H₁₅NOS (221.32).

Example 15

[0107] This example describes the synthesis of host compounds according to the scheme:



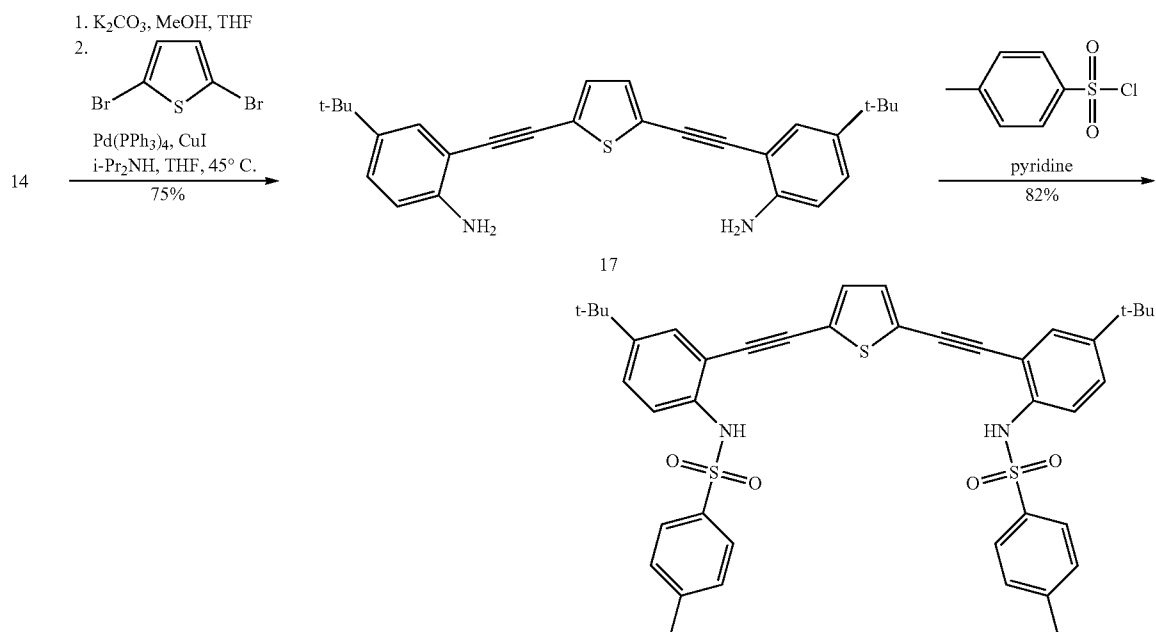


A suspension of ethynylarene 14 (391 mg, 1.6 mmol) and K_2CO_3 (5 equiv.) in MeOH (20 mL) and Et_2O (10 mL) was stirred at room temperature and monitored by TLC until completion (15-30 minutes). The solution was diluted with Et_2O and washed with water and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Without further purification, the residue was dissolved in THF (10 mL) and added dropwise over a period of 12 hours to a stirred, deoxygenated suspension of 6,6'-dibromo-2,2'-dipyridyl (200 mg, 0.64 mmol), $Pd(PPh_3)_4$ (173 mg, 0.2 mmol), and CuI (60 mg, 0.3 mmol) in THF (100 mL) and $i-Pr_2NH$ (100 mL) at $50^\circ C$. After an additional 3 hours of stirring, the suspension was concentrated and filtered through a 2.5 cm silica plug (1:1 hexanes:EtOAc). Purification by column chromatography (CH_2Cl_2) afforded 15 (159 mg, 50%) as a bright yellow, crystalline solid. 1H NMR (300 MHz, $CDCl_3$): δ 8.45 (d, $J=7.2$ Hz, 2H), 7.81 (t, $J=8.1$ Hz, 2H), 7.55 (d, $J=8.1$ Hz, 2H), 7.48 (d, $J=2.3$ Hz, 2H), 7.22 (dd, $J=8.4$, 2.3 Hz, 2H), 6.70 (d, $J=8.4$ Hz, 2H), 4.29 (br s, 4H), 1.30 (s, 18H).

[0108] Arene 15 (25 mg, 0.05 mmol) was reacted with p-toluenesulfonyl chloride according to General Preparation of Sulfonamides. Chromatography on silica gel (3:1 hexanes:EtOAc) afforded 16 (38 mg, 96%) as a pale yellow solid. Recrystallization by diffusion (hexanes:EtOAc) afforded colorless crystals. Mp: $251-252^\circ C$. 1H NMR (300 MHz, $CDCl_3$): δ 8.58 (d, $J=7.8$ Hz, 2H), 7.90 (t, $J=7.8$ Hz, 2H), 7.77 (d, $J=8.4$ Hz, 4H), 7.58-7.42 (m, 8H), 7.37 (dd, $J=8.8$, 2.4 Hz, 2H), 7.14 (d, $J=7.8$ Hz, 4H), 2.32 (s, 6H), 1.29 (s, 18H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 155.86, 147.77, 143.85, 141.95, 137.44, 136.36, 135.74, 129.54, 129.18, 127.75, 127.40, 127.29, 121.15, 120.63, 113.34, 94.77, 84.26, 34.40, 31.13, 21.52. Fluorescence emission ($[16] \leq 5.7 \times 10^{-5}$ M in $CHCl_3$; 343 nm excitation): λ_{max} 390 nm. MS (CI pos) m/z (%): 809 ($M^+ + 2$, 29), 808 (MH^+ , 63), 807 (M^+ , 100); $C_{48}H_{46}N_4O_4S_2$ (807.03).

Example 16

[0109] This example describes the synthesis of host compounds according to the scheme:



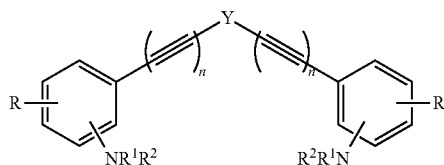
A suspension of ethynylarene 14 (500 mg, 2 mmol) and K_2CO_3 in MeOH (20 mL) and Et_2O (10 mL) was stirred at room temperature and monitored by TLC until completion (15-30 minutes). The solution was diluted with Et_2O and washed with water and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Without further purification, the residue was dissolved in THF (10 mL) and added dropwise over a period of 12 hours to a stirred, deoxygenated suspension of 2,5-dibromothiophene (225 mg, 0.93 mmol), $Pd(PPh_3)_4$ (231 mg, 0.2 mmol), and CuI (76 mg, 0.4 mmol) in THF (50 mL) and $i-Pr_2NH$ (50 mL) at $45^\circ C$. After an additional 3 hours of stirring, the suspension was concentrated and filtered through a 2.5 cm silica plug (CH_2Cl_2). Purification by column chromatography (CH_2Cl_2) afforded 17 (297 mg, 75%) as a bright yellow, crystalline solid. 1H NMR (300 MHz, $CDCl_3$): δ 7.37 (d, $J=2.1$ Hz, 2H), 7.21 (dd, $J=8.5$, 2.1 Hz, 2H), 7.15 (s, 2H), 6.68 (d, $J=8.5$ Hz, 2H), 4.16 (br s, 4H), 1.29 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 145.52, 140.92, 131.49, 128.62, 127.63, 124.52, 114.38, 106.67, 91.25, 86.75, 33.89, 31.33. MS (CI pos) m/z (%): 498 ($M^+ + 2 + THF$, 18), 497 ($MH^+ + THF$, 100), 428 ($M^+ + 2$, 18), 427 (MH^+ , 53); $C_{28}H_{30}N_2S$ (426.21).

[0110] A solution of arene 17 (90 mg, 0.2 mmol) was reacted with *p*-toluenesulfonyl chloride according to General Preparation of Sulfonamides. Chromatography on silica gel (CH_2Cl_2) afforded 18 (123 mg, 82%) as a pale yellow solid. Mp: $89-91^\circ C$. 1H NMR (300 MHz, $CDCl_3$): δ 7.68 (d, $J=8.7$ Hz, 4H), 7.54 (d, $J=8.4$ Hz, 2H), 7.39-7.34 (m, 4H), 7.22 (d, $J=8.7$ Hz, 4H), 7.16 (s, 2H), 7.03 (s, 2H), 2.38 (s, 6H), 1.28 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.99, 144.00, 136.21, 134.96, 132.48, 129.66, 128.98, 127.63, 127.20, 124.09, 120.98, 113.79, 89.54, 87.36, 34.39, 31.10, 21.58. UV/vis (CH_2Cl_2): λ_{max} (ϵ) 234 (58,000), 287 (31,000), 330 (27,600) nm. Fluorescence emission ($[18] \leq 5.7 \times 10^{-5}$ M in $CHCl_3$; 289 nm excitation): λ_{max} 424 nm. MS (CI pos) m/z (%): 807 ($M^+ + 2 + THF$, 16), 806 ($MH^+ + THF$, 38), 805 ($M^+ + THF$, 63), 737 ($M^+ + 2$, 21), 736 (MH^+ , 37), 735 (M^+ , 71), 595 (100), 580 (89); $C_{42}H_{42}N_2O_4S_3$ (734.99).

[0111] In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope and spirit of these claims.

We claim:

1. A compound or salt thereof comprising the formula



wherein Y represents an optionally substituted aromatic group;

n is 1 or 2;

R is H or lower alkyl;

R¹ is H, lower alkyl or aralkyl;

R² is selected from H, acyl aralkyl, phosphonyl, $-SO_2R^3$, $-(R^4)C(O)R^5$, $-N(R^6)C(O)OR^7$, and $-N(R^8)C(O)NR^9R^{10}$;

R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, and R¹⁰ independently are selected from H, lower alkyl, aralkyl, and aryl;

provided that Y is not a pyridyl or bipyridyl.

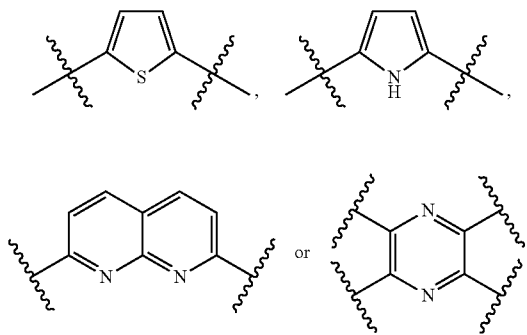
2. The compound of claim 1 wherein Y comprises a heteroaromatic group.

3. The compound of claim 1, wherein Y is a 5- or 6-membered ring.

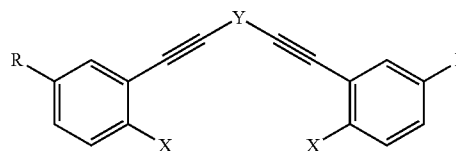
4. The compound of claim 1, wherein Y comprises a polycyclic group.

5. The compound of claim 1, wherein Y comprises a group selected from pyrazinyl, pyrimidinyl, pyrrole, imidazole, triazole, thiophene, thiazole, furyl, and oxazolyl.

6. The compound of claim 1, wherein Y is



7. The compound of claim 1, according to the formula

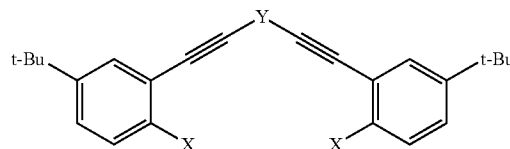


wherein R is selected from H and lower alkyl; and

X is selected from $-N(H)SO_2R^3$, $-N(R^4)C(O)R^5$, $-N(R^6)C(O)OR^7$, and $-N(R^8)C(O)NR^9R^{10}$;

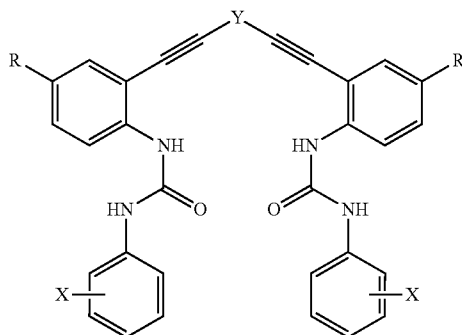
R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, and R¹⁰ independently are selected from H, lower alkyl, aralkyl, and aryl.

8. The compound of claim 1, according to the formula



wherein X is selected from $-N(H)SO_2R^3$, $-N(R^4)C(O)R^5$, $-N(R^6)C(O)OR^7$, and $-N(R^8)C(O)NR^9R^{10}$; and R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, and R¹⁰ independently are selected from H, lower alkyl, aralkyl, and aryl.

9. The compound of claim 1, according to the formula



wherein R is lower alkyl;

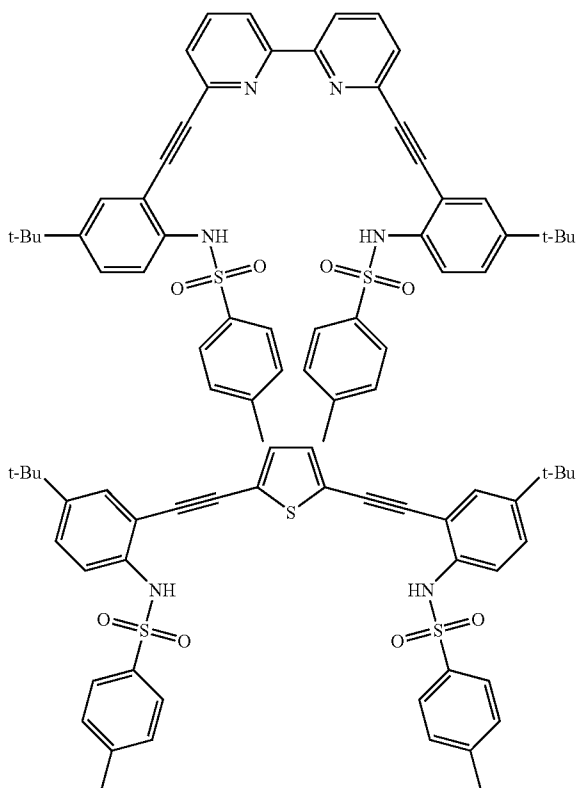
X is halogen, —OR¹¹, alkyl sulfide, nitro, sulfonyl, phosphonyl, phosphate, sulfate, or lower alkyl;

and R¹¹ is H, acyl, or optionally substituted lower alkyl.

10. The compound of claim 9, wherein X comprises an alkoxy or alkyl sulfide moiety.

11. The compound of claim 10, wherein X has the formula —OR¹¹ or —SR¹¹ and R is optionally substituted lower alkyl.

12. The compound claim 1, having the formula



or

13. The compound of claim 1, wherein the compound is macrocyclic.

14. A method for binding a ligand, comprising providing a host compound according to claim 1 and exposing the compound to the ligand, thereby binding the ligand.

15. The method of claim 14, wherein the ligand is an ionic ligand.

16. The method of claim 14, wherein the ligand is an anionic ligand.

17. The method of claim 16, wherein the host is protonated.

18. The method of claim 16, wherein the ligand is chloride, sulfate, hydrogen sulfate, perchlorate, pertechnetate, or nitrate.

19. The method of claim 14, wherein the ligand is an inorganic ligand.

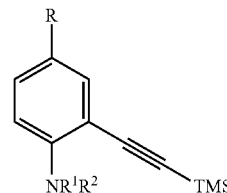
20. The method of claim 14, wherein the ligand comprises a metal selected from the group consisting of Pb, As, Zn, U, Ca, Cd, Hg, and combinations thereof.

21. The method of claim 14, wherein binding the ligand induces a change in the fluorescence emission spectrum of the host compound.

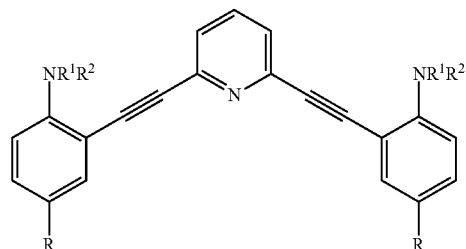
22. The method of claim 14, wherein binding the ligand occurs in a stoichiometry of about two host compound molecules per ligand.

23. A crystalline complex comprising a compound of claim 1.

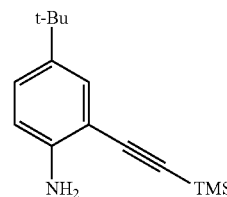
24. A method for preparing a host compound, comprising: providing a compound of the formula



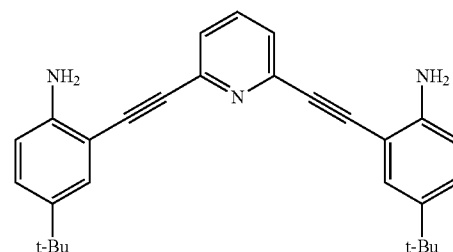
and converting it to a compound of the formula



25. The method of claim 24, comprising providing a compound of the formula



and converting it to a compound of the formula



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