Electronic Supplementary Material (ESI) for RSC Advances.

Non-covalent interaction, adsorption characteristics and solvent effect of procainamide anti-arrhythmias drug on silver and gold loaded silica surfaces: SERS spectroscopy, density functional theory and molecular docking investigations

V. Vetrivelan[a], Sakthivel S[b], S. Muthu[c]*, Abdulaziz A. Al-Saadi[d]*

[a]*Department of Physics, Thanthai Periyar Government Institute of Technology, Vellore 632002, India.*
[b]*Department of Physics, Panimalar Engineering college, Chennai-600 123, Tamilnadu, India*
[c]*Department of Physics, Arignar Anna Govt. Arts College, Cheyyar 604 407, Tamilnadu, India.*
[d]*Department of Chemistry, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia.*
Corresponding author Emails: mutgee@gmail.com (S. Muthu)*;* asaadi.kfupm@gmail.com *(*A. A. Al-Saadi),

Table S1. Mulliken charges of PA and PA+Ag/Au-SiO_2 in gaseous & water phase computed at the B3LYP/LANL2DZ level.

Atom	PA		PA complexes with Ag-SiO_2						PA complexes with Au-SiO_2					
			Complex 1		Complex 2		Complex 3		Complex 1		Complex 2		Complex 3	
	Gas	Water	Gas	Water	Gas	Water	Gas	Water	Gas	Water	Gas	Water	Gas	Water
O1	-0.2876	-0.3521	-0.3142	-0.3765	-0.4181	-0.4353	-0.420	-0.441	-0.3104	-0.3766	-0.4225	-0.4447	-0.2336	-0.2807
N2	-0.0661	-0.0961	-0.1214	-0.1385	-0.1300	-0.1491	-0.126	-0.149	-0.1309	-0.1504	-0.1227	-0.1375	-0.1440	-0.1574
N3	-0.4138	-0.4136	-0.3852	-0.3853	-0.3757	-0.3756	-0.369	-0.372	-0.3912	-0.3903	-0.3769	-0.3747	-0.6121	-0.6201
N4	-0.7103	-0.7217	-0.7633	-0.7575	-0.6876	-0.6970	-0.688	-0.695	-0.8267	-0.8222	-0.6878	-0.6947	-0.6835	-0.6868
C5	-0.2666	-0.2755	-0.3128	-0.3141	-0.2993	-0.3036	-0.290	-0.296	-0.2985	-0.3034	-0.3096	-0.3116	-0.2924	-0.2890
C6	-0.2767	-0.2824	-0.2838	-0.2879	-0.2867	-0.2888	-0.290	-0.291	-0.2849	-0.2873	-0.2899	-0.2911	-0.2931	-0.2954
C7	-0.2645	-0.2723	-0.2820	-0.2861	-0.2800	-0.2835	-0.275	-0.279	-0.2788	-0.2833	-0.2817	-0.2850	-0.2921	-0.2910
C8	-0.3926	-0.3902	-0.3496	-0.3470	-0.3575	-0.3533	-0.360	-0.351	-0.3528	-0.3496	-0.3593	-0.3524	-0.3106	-0.2995
C9	-0.6877	-0.6945	-0.6503	-0.6577	-0.6268	-0.6382	-0.611	-0.626	-0.6295	-0.6394	-0.6368	-0.6478	-0.6233	-0.6320
C10	-0.6912	-0.6959	-0.6262	-0.6391	-0.6259	-0.6405	-0.620	-0.637	-0.6264	-0.6402	-0.6254	-0.6390	-0.6297	-0.6421
C11	0.1438	0.1392	0.1700	0.1620	0.2920	0.2873	0.297	0.288	0.1764	0.1727	0.3245	0.3269	0.1921	0.2045
C12	0.3541	0.3502	0.3032	0.2990	0.2936	0.2810	0.301	0.291	0.3066	0.3060	0.3092	0.2965	0.3238	0.3241
C13	-0.3646	-0.3922	-0.3413	-0.3662	-0.2998	-0.3048	-0.297	-0.322	-0.3413	-0.3632	-0.2556	-0.2721	-0.3218	-0.3403
C14	-0.3726	-0.3788	-0.3442	-0.3515	-0.3537	-0.3536	-0.309	-0.317	-0.3333	-0.3381	-0.3514	-0.3517	-0.2505	-0.2567
C15	-0.4052	-0.4247	-0.3557	-0.3709	-0.4230	-0.4359	-0.406	-0.426	-0.3477	-0.3590	-0.4226	-0.4421	-0.4019	-0.4194
C16	-0.4269	-0.4454	-0.3410	-0.3502	-0.4115	-0.4297	-0.421	-0.439	-0.3490	-0.3548	-0.4120	-0.4290	-0.4427	-0.4582
C17	0.5099	0.4687	0.4429	0.4350	0.4914	0.4488	0.500	0.459	0.4483	0.4394	0.4994	0.4591	0.4956	0.4596
H18	0.1444	0.1729	0.1816	0.2012	0.1780	0.1976	0.176	0.198	0.1743	0.1948	0.1845	0.2073	0.2427	0.2344
H19	0.2476	0.2307	0.2317	0.2204	0.2306	0.2230	0.222	0.217	0.2346	0.2205	0.2357	0.2223	0.2388	0.2307
H20	0.2081	0.2138	0.1866	0.1950	0.1888	0.1963	0.194	0.197	0.1859	0.1955	0.1883	0.1968	0.1871	0.1978
H21	0.1573	0.1726	0.1689	0.1740	0.1756	0.1820	0.170	0.182	0.1734	0.1800	0.1825	0.1794	0.1874	0.1856
H22	0.1975	0.2055	0.1836	0.1992	0.1797	0.1979	0.175	0.197	0.1785	0.1972	0.1807	0.1998	0.2043	0.2041
H23	0.1565	0.1736	0.1692	0.1728	0.1766	0.1813	0.177	0.183	0.1754	0.1806	0.1738	0.1750	0.1800	0.1839
H24	0.2485	0.2221	0.2526	0.2334	0.2537	0.2325	0.254	0.238	0.2506	0.2254	0.2622	0.2444	0.2353	0.2441
H25	0.1998	0.2276	0.2063	0.2203	0.2042	0.2227	0.214	0.229	0.1984	0.2192	0.2113	0.2273	0.2380	0.2399
H26	0.2052	0.2124	0.2389	0.2240	0.2109	0.2091	0.191	0.209	0.2164	0.2045	0.2287	0.2228	0.2144	0.2090
H27	0.2240	0.2069	0.2003	0.1984	0.2118	0.2046	0.241	0.213	0.2076	0.2028	0.1997	0.2016	0.2038	0.2046
H28	0.1962	0.2075	0.1878	0.1957	0.1930	0.1992	0.197	0.199	0.1878	0.1976	0.2010	0.1987	0.1969	0.2005
H29	0.2040	0.2120	0.1967	0.2014	0.1974	0.2013	0.201	0.202	0.1971	0.2009	0.1997	0.2021	0.1959	0.2017
H30	0.2206	0.2073	0.2082	0.2017	0.2105	0.2037	0.219	0.206	0.2097	0.2033	0.2072	0.2025	0.2054	0.2037
H31	0.1942	0.2046	0.1909	0.1992	0.1914	0.1994	0.189	0.200	0.1894	0.1987	0.1919	0.2002	0.1926	0.2001
H32	0.2982	0.3377	0.3003	0.3383	0.3190	0.3508	0.310	0.344	0.2989	0.3404	0.3226	0.3595	0.3526	0.3892
H33	0.2649	0.2676	0.2807	0.2733	0.2494	0.2554	0.262	0.263	0.2847	0.2772	0.2573	0.2587	0.2700	0.2696
H34	0.2172	0.2468	0.2287	0.2505	0.2219	0.2519	0.196	0.229	0.2190	0.2453	0.2266	0.2543	0.2200	0.2375
H35	0.2182	0.2487	0.2303	0.2556	0.3052	0.2860	0.225	0.250	0.2333	0.2592	0.2297	0.2531	0.2248	0.2532
H36	0.2142	0.2485	0.2333	0.2582	0.2178	0.2490	0.220	0.251	0.2375	0.2625	0.2223	0.2526	0.2262	0.2543
H37	0.3002	0.3294	0.3474	0.3663	0.3077	0.3370	0.314	0.340	0.3697	0.3964	0.3143	0.3408	0.3190	0.3453
H38	0.3021	0.3292	0.3528	0.3748	0.3284	0.3393	0.316	0.339	0.3722	0.3996	0.3189	0.3413	0.3179	0.3444
Si39			0.7903	0.7446	0.7465	0.7073	0.788	0.747	0.9523	0.9390	0.9498	0.9394	0.9492	0.9415
O40			-0.9598	-0.9691	-0.9395	-0.9567	-0.963	-0.972	-0.8554	-0.9161	-0.9623	-0.9711	-0.9643	-0.9743
O41			-0.8598	-0.9385	-0.8940	-0.9315	-0.863	-0.938	-0.9635	-0.9745	-0.8588	-0.9147	-0.8560	-0.9142
Si42			0.7921	0.7442	0.7482	0.7139	0.791	0.750	0.9497	0.9383	0.9420	0.9365	0.9551	0.9433
Ag43			-0.4413	-0.3333	-0.3359	-0.2557	-0.465	-0.359						
Ag44			0.4567	0.5308	0.4218	0.4748	0.434	0.488						
Au43									0.4398	0.4687	0.3522	0.3639	0.3544	0.3876
Au44									-0.7471	-0.7170	-0.7407	-0.7036	-0.7715	-0.7373

Table S2. Chemical descriptors of PA and PA···Ag- and Au-SiO_2 in gaseous and water phases computed at B3LYP/LANL2DZ.

Atom	PA		Ag-SiO_2	Au-SiO_2	PA···Ag-SiO_2						PA···Au-SiO_2					
					Complex 1		Complex 2		Complex 3		Complex 1		Complex 2		Complex 3	
	Gas	Water			Gas	Water	Gas	Water	Gas	Water	Gas	Water	Gas	Water	Gas	Water
E_{HOMO} (eV)	-5.53	-5.73	-5.23	-6.37	-4.39	-4.65	-4.31	-4.69	-4.05	-4.64	-5.47	-5.43	-5.17	-5.46	-5.39	-5.59
E_{LUMO} (eV)	-0.43	-0.68	-3.69	-4.83	-2.07	-1.85	-1.63	-1.75	-2.00	-1.84	-2.16	-2.18	-2.02	-2.18	-2.42	-2.10
Eg (eV)	5.10	5.05	1.54	1.54	2.32	2.81	2.68	2.94	2.05	2.79	3.32	3.26	3.16	3.29	2.98	3.35
Fermi level (eV)	-2.98	-3.20	-4.46	-5.60	-3.23	-3.25	-2.97	-3.22	-3.03	-3.24	-3.81	-3.81	-3.59	-3.82	-3.91	-3.89
Chemical Potential (eV)	-2.98	-3.20	-4.46	-5.60	-3.23	-3.25	-2.97	-3.22	-3.03	-3.24	-3.81	-3.81	-3.59	-3.82	-3.91	-3.89
Hardness (eV)	2.55	2.52	0.77	0.77	1.16	1.40	1.34	1.47	1.03	1.39	1.66	1.63	1.58	1.64	1.49	1.68
Softness (1/eV)	0.392	0.39	1.30	1.30	0.86	0.71	0.75	0.68	0.97	0.72	0.60	0.61	0.63	0.61	0.67	0.59
Electronegativity	2.981	3.203	4.460	5.601	3.233	3.251	2.974	3.221	3.027	3.242	3.815	3.807	3.595	3.820	3.906	3.89
Electrophilicity index (eV)	1.740	2.032	12.93	20.39	4.506	3.767	3.303	3.524	4.468	3.760	4.389	4.451	4.095	4.440	5.121	4.451
Dipole moment (Debye)	5.67	7.88	4.11	3.77	10.66	11.21	12.02	12.41	18.91	22.65	12.71	14.99	16.19	19.19	13.37	15.65

Table S3. Predicted wavelengths, energies, oscillator strengths, symmetry, and major contributing molecular orbitals of PA…Ag/Au-SiO_2 complexes in comparison with PA in different solvent phase as calculated at the B3LYP/LANL2DZ level of theory.

Compound	Position	Solvent	λ (nm)	Energy (cm^{-1})	Oscillator strength	Symmetry	Major contributions
PA complexes with Ag-SiO2	Complex 1 -H_2N-Ag…SiO_2	Water	561	17826	0.1403	Singlet-A	HOMO->LUMO (98%)
			481	20798	0.0165	Singlet-A	HOMO->L+1 (25%), HOMO->L+2 (66%)
			388	25786	0.3431	Singlet-A	HOMO->L+3 (89%), H-2->LUMO (3%)
		DMSO	565	17688	0.1476	Singlet-A	HOMO->LUMO (98%)
			482	20735	0.0176	Singlet-A	HOMO->L+1 (25%), HOMO->L+2 (66%)
			392	25494	0.3665	Singlet-A	HOMO->L+3 (89%), H-2->LUMO (2%)
		Methanol	559	17886	0.1401	Singlet-A	HOMO->LUMO (98%)
			481	20798	0.0168	Singlet-A	HOMO->L+1 (25%), HOMO->L+2 (64%)
			390	25670	0.3452	Singlet-A	HOMO->L+3 (88%), H-2->LUMO (3%)
		Chloroform	554	18044	0.1518	Singlet-A	HOMO->LUMO (98%)
			488	20491	0.0234	Singlet-A	HOMO->L+1 (28%), HOMO->L+2 (36%), HOMO->L+3 (23%)
			411	24307	0.3956	Singlet-A	HOMO->L+2 (38%), HOMO->L+3 (50%)
	Complex 2 -O-Ag…SiO_2	Water	536	18661	0.1309	Singlet-A	HOMO->LUMO (96%)
			468	21370	0.0192	Singlet-A	HOMO->L+1 (31%), HOMO-

							>L+2 (51%)
			381	26274	0.3891	Singlet-A	HOMO->L+3 (83%) H-3->LUMO (5%)
		DMSO	540	18523	0.1382	Singlet-A	HOMO->LUMO (96%)
			469	21330	0.0206	Singlet-A	HOMO->L+1 (29%), HOMO->L+2 (52%)
			385	26007	0.4158	Singlet-A	HOMO->L+3 (84%) H-3->LUMO (4%)
		Methanol	535	18690	0.1305	Singlet-A	HOMO->LUMO (96%)
			467	21411	0.0196	Singlet-A	HOMO->L+1 (28%), HOMO->L+2 (52%)
			382	26160	0.3923	Singlet-A	HOMO->L+3 (82%) H-3->LUMO (5%)
		Chloroform	536	18641	0.1393	Singlet-A	HOMO->LUMO (94%)
			464	21566	0.0283	Singlet-A	HOMO->L+1 (17%), HOMO->L+2 (46%)
			403	24813	0.4537	Singlet-A	HOMO->L+2 (23%), HOMO->L+3 (68%)
	Complex 3 -HN-Ag…SiO_2	**Water**	563	17748	0.1349	Singlet-A	HOMO->LUMO (98%)
			482	20766	0.0195	Singlet-A	HOMO->L+2 (86%) HOMO->L+1 (7%)
			392	25523	0.3357	Singlet-A	HOMO->L+3 (89%) H-3->LUMO (3%)
		DMSO	568	17610	0.1421	Singlet-A	HOMO->LUMO (98%)
			483	20717	0.0206	Singlet-A	HOMO->L+2 (86%) HOMO->L+1 (7%)
			396	25233	0.3598	Singlet-A	HOMO->L+3 (90%) H-3->LUMO (2%)
		Methanol	562	17796	0.1347	Singlet-A	HOMO->LUMO (98%)
			481	20785	0.0197	Singlet-A	HOMO->L+2 (86%) HOMO->L+1 (7%)
			394	25410	0.3379	Singlet-A	HOMO->L+3 (89%) H-3->LUMO (3%)
		Chloroform	559	17881	0.1455	Singlet-A	HOMO->LUMO (63%)

			483	20724	0.0234	Singlet-A	HOMO->L+3 (85%) HOMO->L+1 (4%)
			417	23990	0.3924	Singlet-A	HOMO->L+2 (92%)
PA complexes with Au-SiO2	**Complex 1 -H_2N-Au…SiO_2**	**Water**	397	25205	0.142	Singlet-A	HOMO->LUMO (96%)
			330	30280	0.022	Singlet-A	H-2->LUMO (20%), HOMO->L+1 (17%)
			326	30721	0.0184	Singlet-A	H-2->LUMO (34%), HOMO->L+3 (43%)
		DMSO	399	25083	0.151	Singlet-A	HOMO->LUMO (96%)
			331	30218	0.0259	Singlet-A	H-2->LUMO (20%), HOMO->L+1 (17%)
			326	30649	0.0235	Singlet-A	H-2->LUMO (32%), HOMO->L+2 (11%)
		Methanol	396	25231	0.1414	Singlet-A	HOMO->LUMO (96%)
			330	30280	0.0236	Singlet-A	H-2->LUMO (23%), HOMO->L+1 (15%)
			326	30702	0.0197	Singlet-A	H-2->LUMO (30%), HOMO->L+1 (10%)
		Chloroform	397	25173	0.1531	Singlet-A	HOMO->LUMO (96%)
			333	30043	0.0622	Singlet-A	H-2->LUMO (31%), HOMO->L+2 (43%), HOMO->L+3 (16%)
			328	30443	0.031	Singlet-A	HOMO->L+1 (14%), HOMO->L+2 (12%), HOMO->L+3 (58%)
	Complex 2 -O-Au…SiO_2	**Water**	396	25235	0.1381	Singlet-A	HOMO->LUMO (96%)
			332	30127	0.0185	Singlet-A	H-3->LUMO (13%), HOMO->L+1 (11%), HOMO->L+2 (70%)
			326	30632	0.0234	Singlet-A	H-3->LUMO (40%), HOMO->L+3 (50%)
		DMSO	398	25109	0.147	Singlet-A	HOMO->LUMO (96%)
			333	30067	0.0216	Singlet-A	H-3->LUMO (13%), HOMO->L+1 (10%), HOMO->L+2 (70%)
			327	30559	0.0297	Singlet-A	H-3->LUMO (37%), HOMO->L+3 (53%)
		Methanol	396	25251	0.1375	Singlet-A	HOMO->LUMO (96%)

			332	30134	0.02	Singlet-A	H-3->LUMO (15%), HOMO->L+2 (68%)
			327	30609	0.0246	Singlet-A	H-3->LUMO (36%), HOMO->L+3 (53%)
		Chloroform	398	25127	0.1485	Singlet-A	HOMO->LUMO (96%)
			334	29911	0.0606	Singlet-A	H-3->LUMO (28%), HOMO->L+2 (56%)
			329	30390	0.0308	Singlet-A	HOMO->L+3 (76%) H-3->LUMO (9%)
	Complex 3 -HN-Au…SiO_2	**Water**	397	25213	0.1344	Singlet-A	HOMO->LUMO (94%)
			332	30108	0.021	Singlet-A	H-3->LUMO (14%), HOMO->L+1 (12%), HOMO->L+2 (26%)
			328	30523	0.0277	Singlet-A	H-3->LUMO (37%), HOMO->L+2 (21%), HOMO->L+3 (34%)
		DMSO	399	25092	0.1428	Singlet-A	HOMO->LUMO (94%)
			333	30045	0.0247	Singlet-A	H-3->LUMO (13%), HOMO->L+1 (12%)
			328	30452	0.0341	Singlet-A	H-3->LUMO (34%), HOMO->L+2 (23%)
		Methanol	396	25233	0.1338	Singlet-A	HOMO->LUMO (93%)
			332	30104	0.0225	Singlet-A	H-3->LUMO (15%), HOMO->L+1 (12%)
			328	30503	0.0288	Singlet-A	H-3->LUMO (34%), HOMO->L+2 (23%)
		Chloroform	398	25134	0.1442	Singlet-A	HOMO->L+1 (95%)
			335	29874	0.0525	Singlet-A	HOMO->L+1 (95%), HOMO->L+3 (28%)
			329	30455	0.0339	Singlet-A	H-3->LUMO (32%), HOMO->L+2 (27%)
PA	**DFT**	**Water**	253	39524	0.0434	Singlet-A	HOMO->L+1 (82%) H-3->LUMO (9%)
			244	41026	0.3778	Singlet-A	H-4->LUMO (24%), HOMO->LUMO (60%)
			231	43206	0.2403	Singlet-A	H-4->LUMO (50%), H-4->L+2 (11%)

		DMSO	253	39496	0.0462	Singlet-A	HOMO->L+1 (82%) H-3->LUMO (9%)
			244	40956	0.393	Singlet-A	H-4->LUMO (23%), HOMO->LUMO (61%)
			232	43147	0.2392	Singlet-A	H-4->LUMO (51%), H-4->L+2 (11%)
		Methanol	253	39534	0.0435	Singlet-A	H-3->LUMO (10%), HOMO->L+1 (82%)
			244	41029	0.3594	Singlet-A	H-4->LUMO (26%), HOMO->LUMO (58%)
			232	43181	0.2562	Singlet-A	H-4->LUMO (48%), H-4->L+2 (11%)
		Chloroform	253	39563	0.0501	Singlet-A	H-3->LUMO (11%), HOMO->L+1 (75%)
			245	40858	0.2403	Singlet-A	H-4->LUMO (38%), H-4->L+2 (10%)
			233	43006	0.3818	Singlet-A	H-4->LUMO (33%), HOMO->LUMO (51%)
	Expt.		260				

Table S4. Biological activity of PA as precited using PASS Online software

Pa	Pi	Activity
0,891	0,003	Cardiovascular analeptic
0,887	0,005	Respiratory analeptic
0,886	0,004	Superoxide dismutase inhibitor
0,882	0,009	Phobic disorders treatment
0,835	0,004	Proteasome ATPase inhibitor
0,818	0,005	Analeptic
0,813	0,002	Octopamine antagonist
0,811	0,004	Spasmolytic, urinary
0,811	0,011	Taurine dehydrogenase inhibitor
0,793	0,004	Antihypoxic

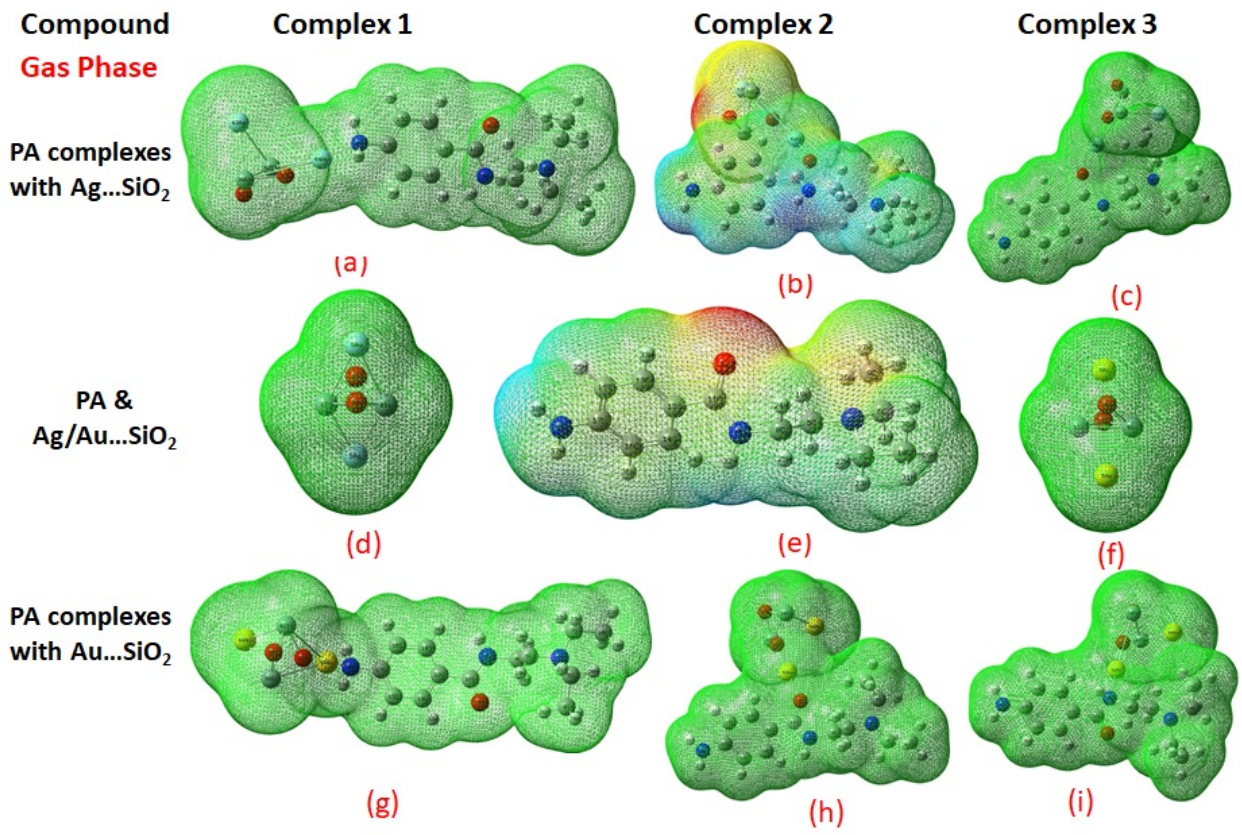

Figure S1. Molecular electrostatic potential (MEP) plots of PA drug with the Ag-SiO_2 (a-c) and Au-SiO_2 (g-i) complexes predicted in the gas medium. The corresponding MEPs of PA, Ag- and Au-SiO_2 substrates are also presented (d-f).

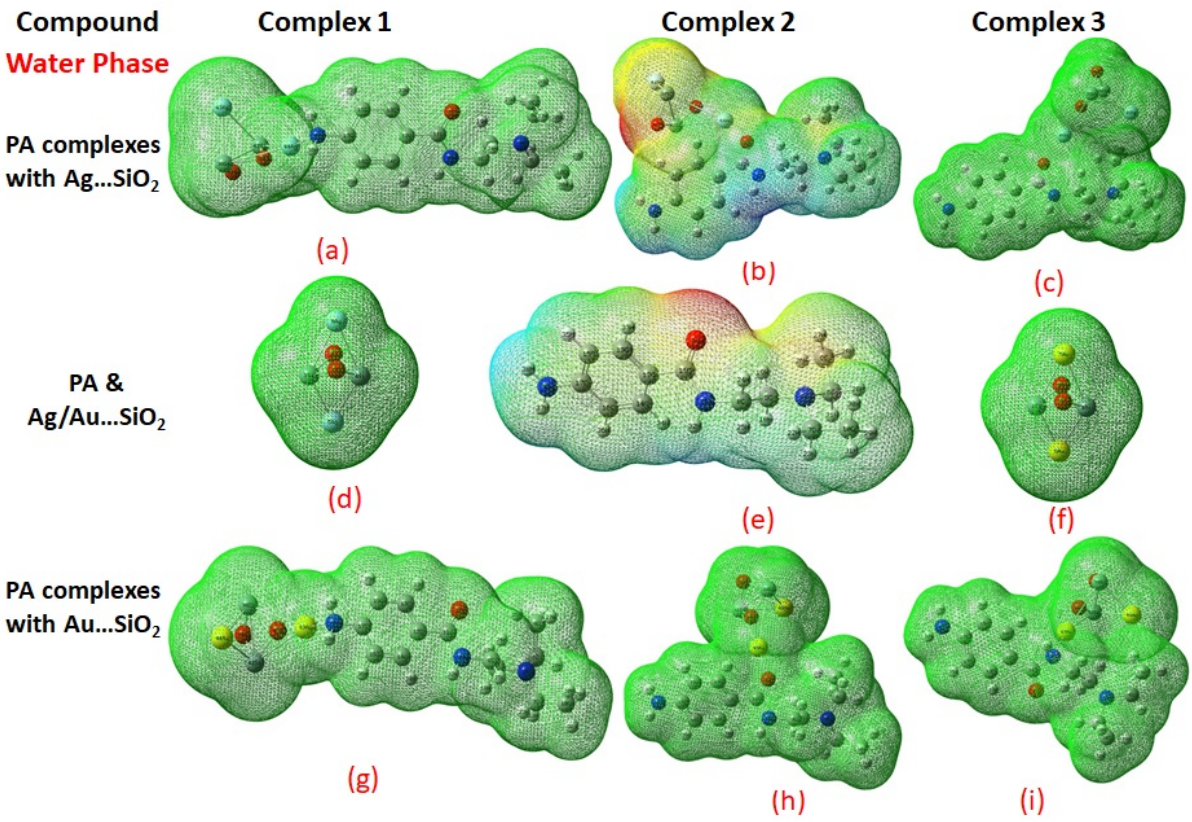

Figure S2. Molecular electrostatic potential (MEP) plots of PA drug with the Ag-SiO_2 (a-c) and Au-SiO_2 (g-i) complexes predicted in water medium. The MEPs of PA, Ag- and Au-SiO_2 substrates are also presented (d-f).

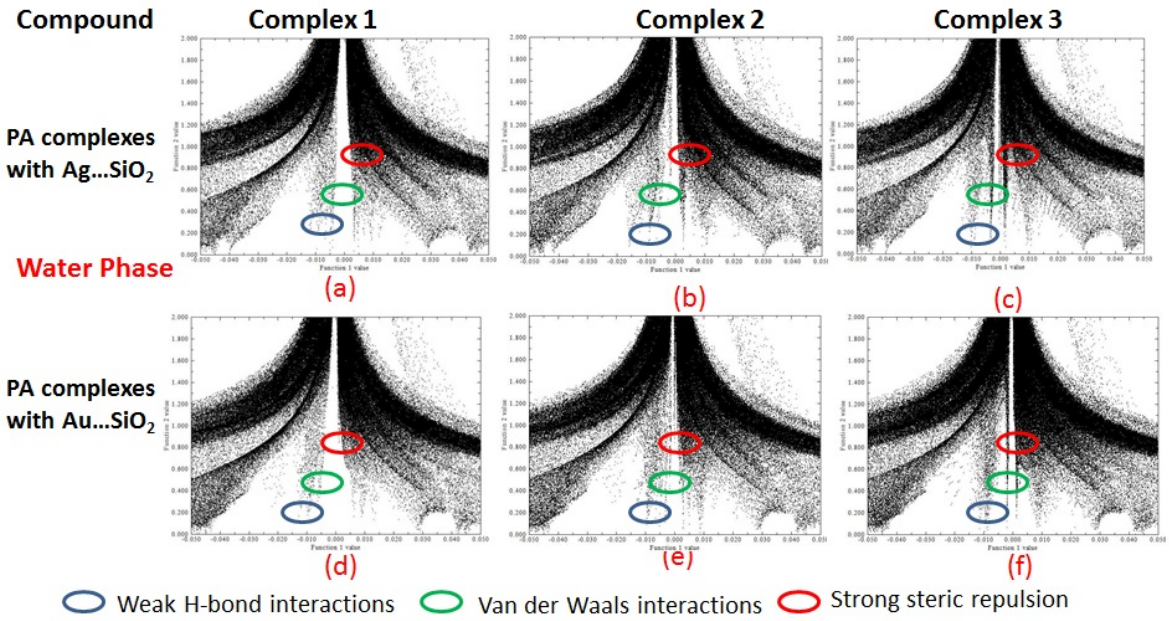

Figure S3. Reduced density gradient (RDG) scattered graphs PA···Ag-SiO_2 (a-c) and PA···Au-SiO_2 (d-f) complexes modeled in water medium. Different possible interaction modes are labeled.

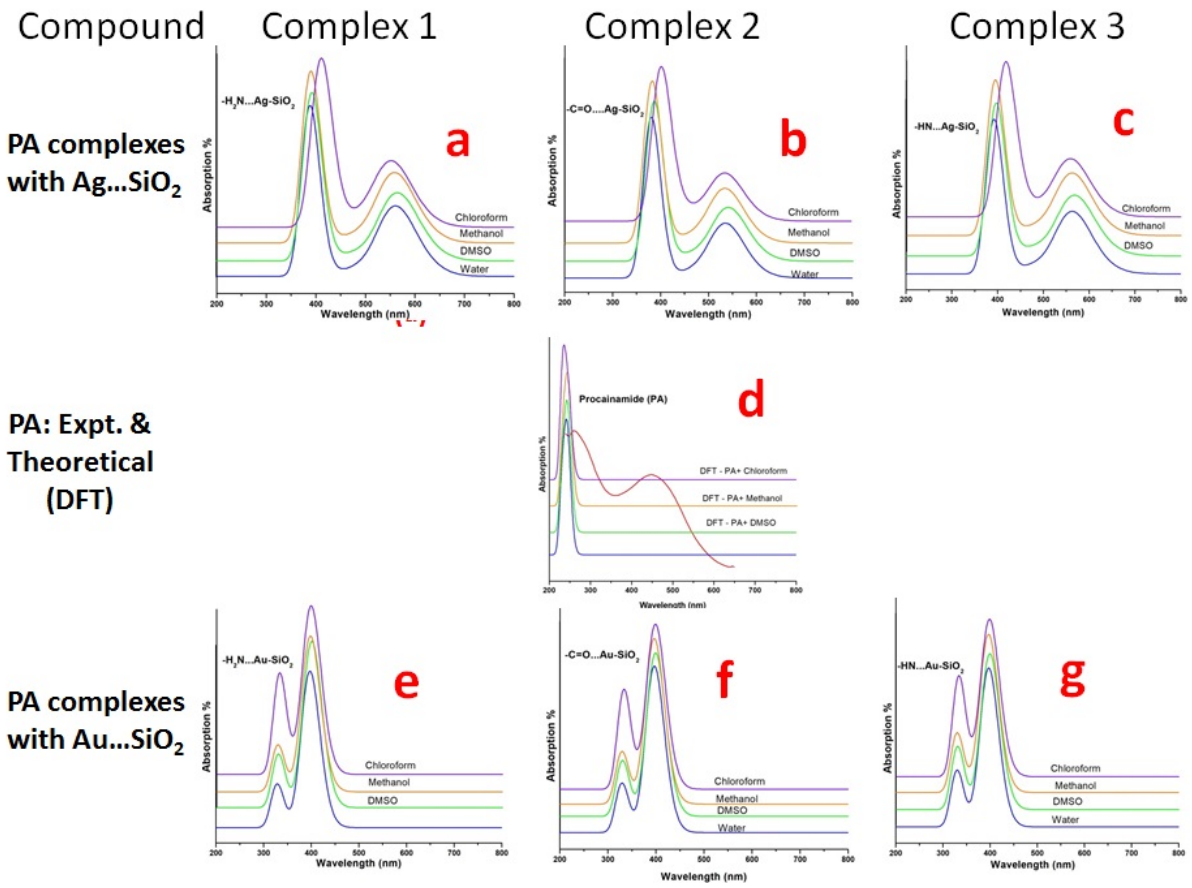

Figure S4. UV-Vis. Spectra of PA, compared with UV-Vis spectra of the PA+ Ag/Au-SiO_2 complexes investigated.