Electronic Supplementary Information

Facile fabrication of Ag@C@C8 nanoparticles as a SERS substrate and its environmental applications

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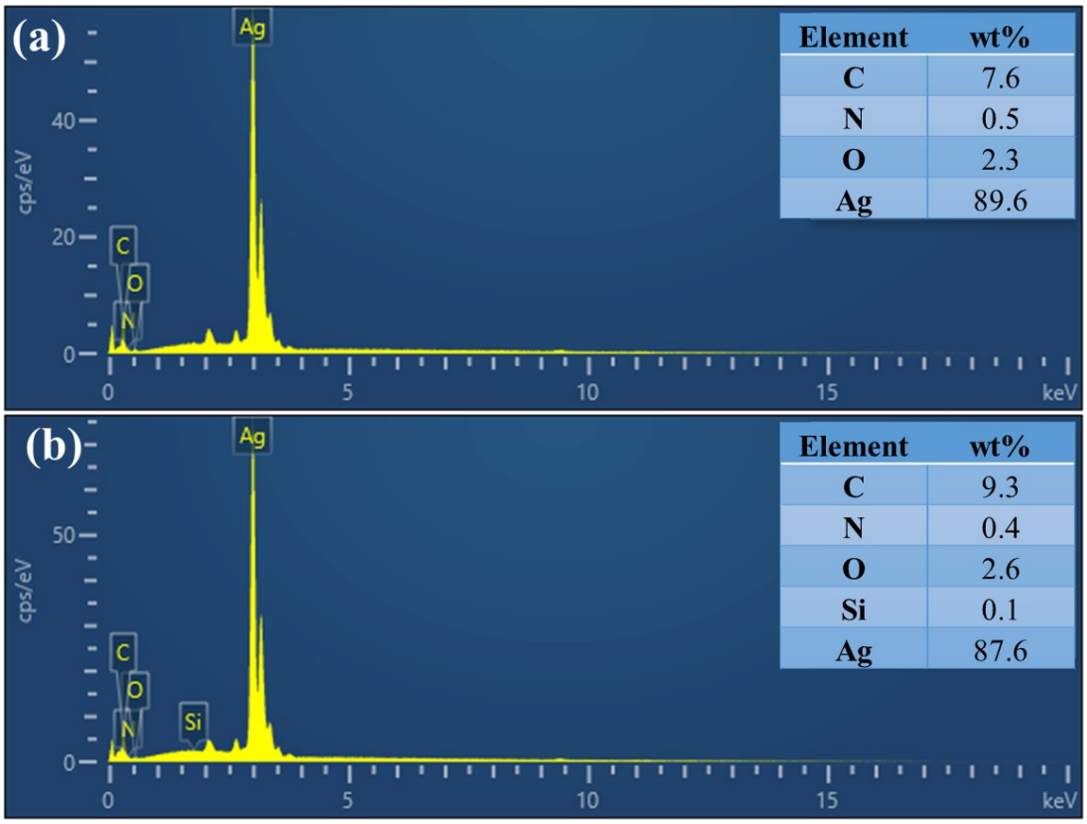

Fig. S1 EDS spectrum of (a) Ag@C nanoparticles and (b) Ag@C@C8 nanoparticles.

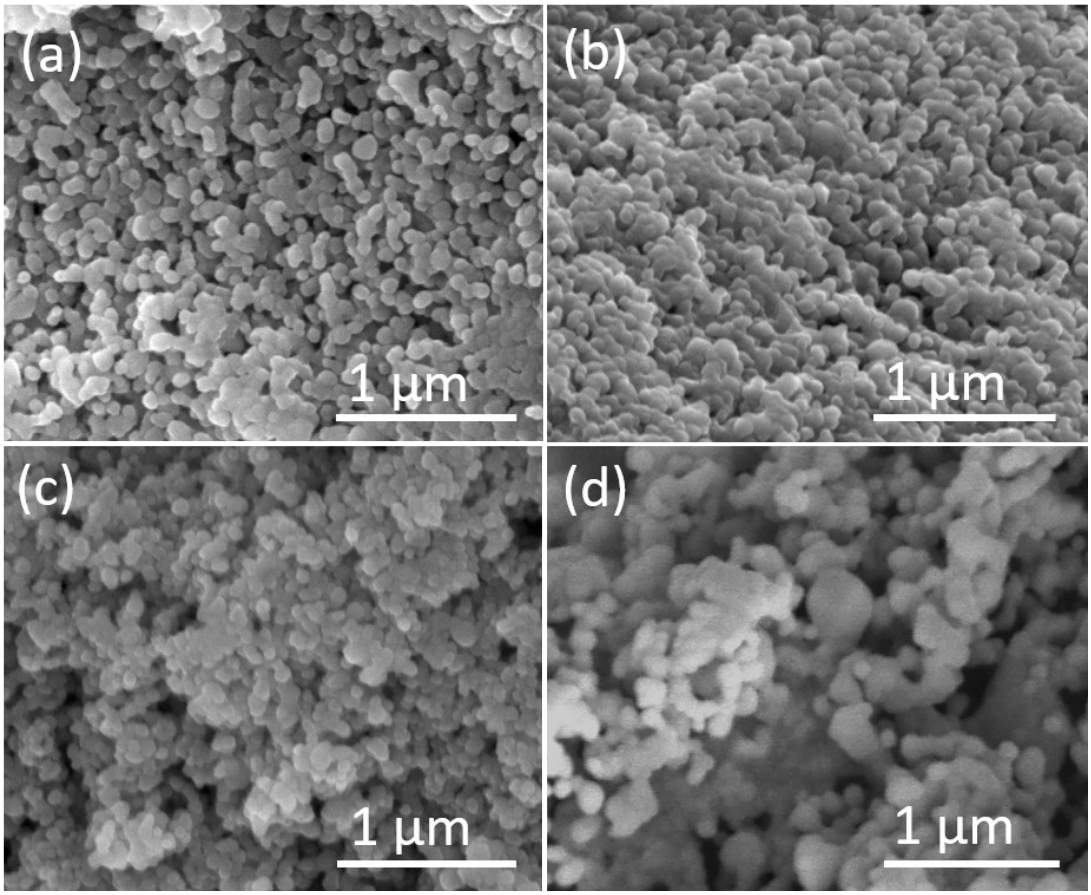

Fig. S2 SEM images of SERS substrates prepared with varying amounts of C8 concentrations (a) 0.25%; (b) 0.5%; (c) 1.5%; and (d) 2.0%.

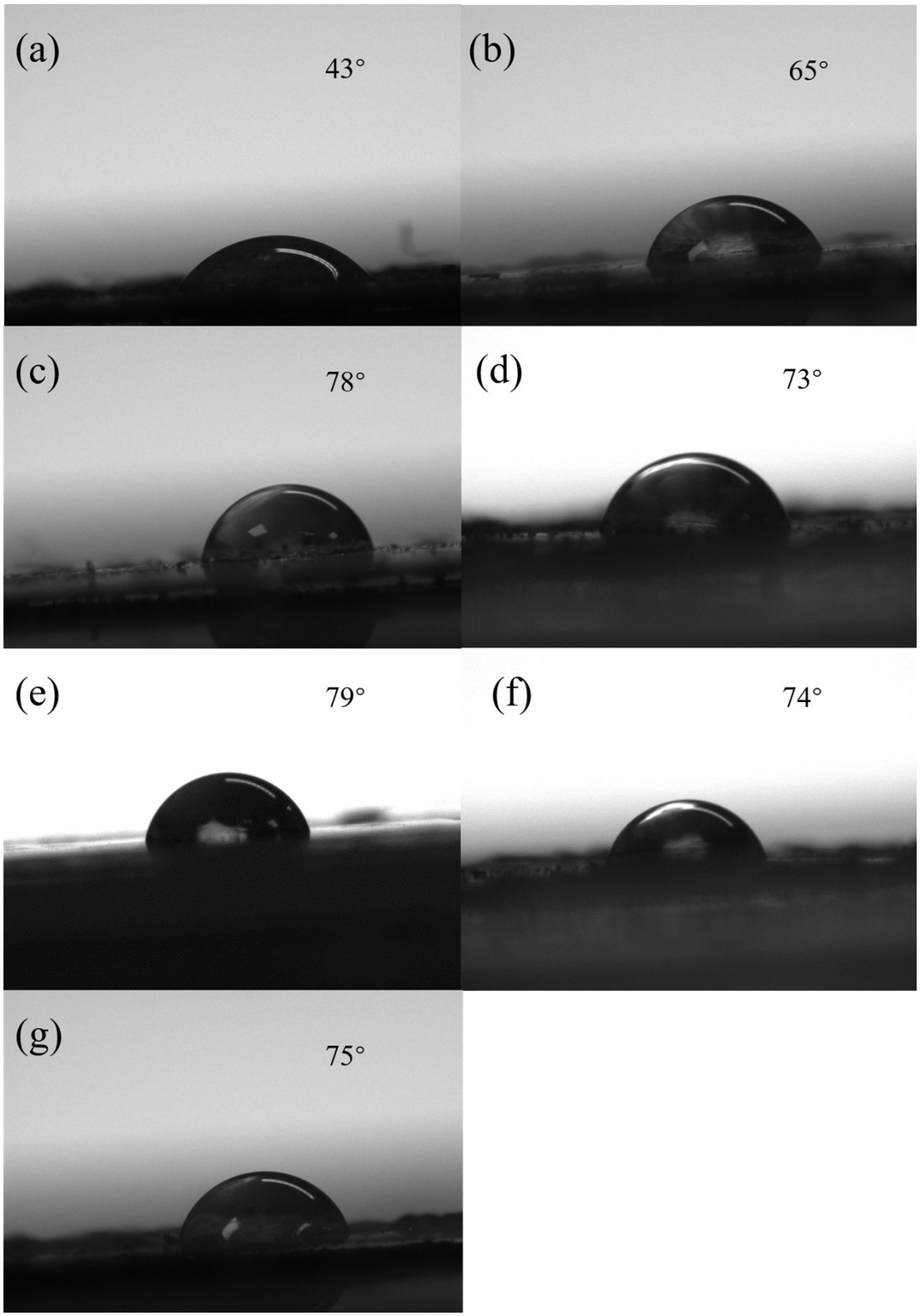

Fig. S3 Contact angles of substrates prepared at different stages of the reaction. (a) before reaction begins (0 h); (b) during the reaction (2 h); (c) while the reaction is stable (8h); (d) after reaction terminates (12 h); (e) after reaction terminates (16 h); (f) after reaction terminates (20 h) and (g) after reaction terminates (24 h).

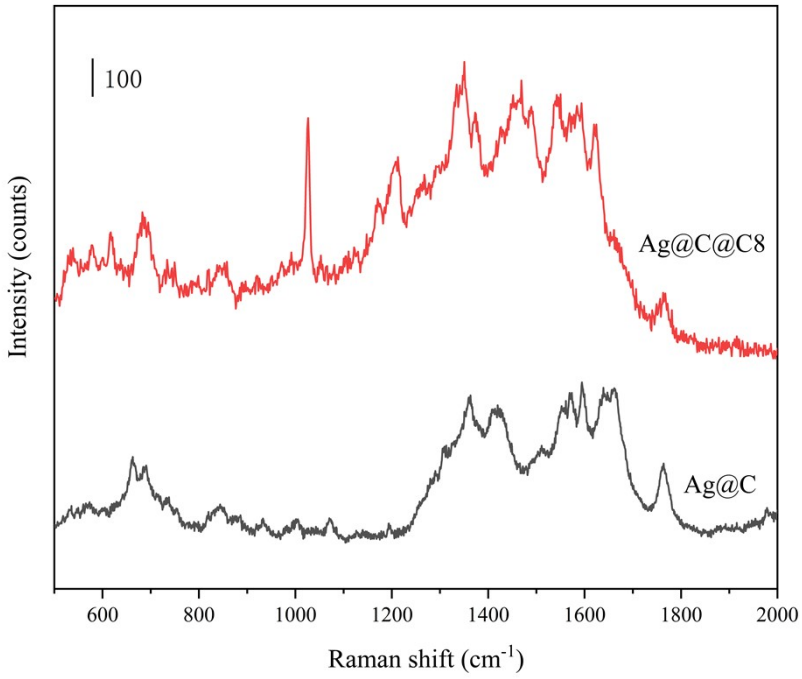

Fig. S4 Raman spectra of Ag@C and Ag@C@C8.

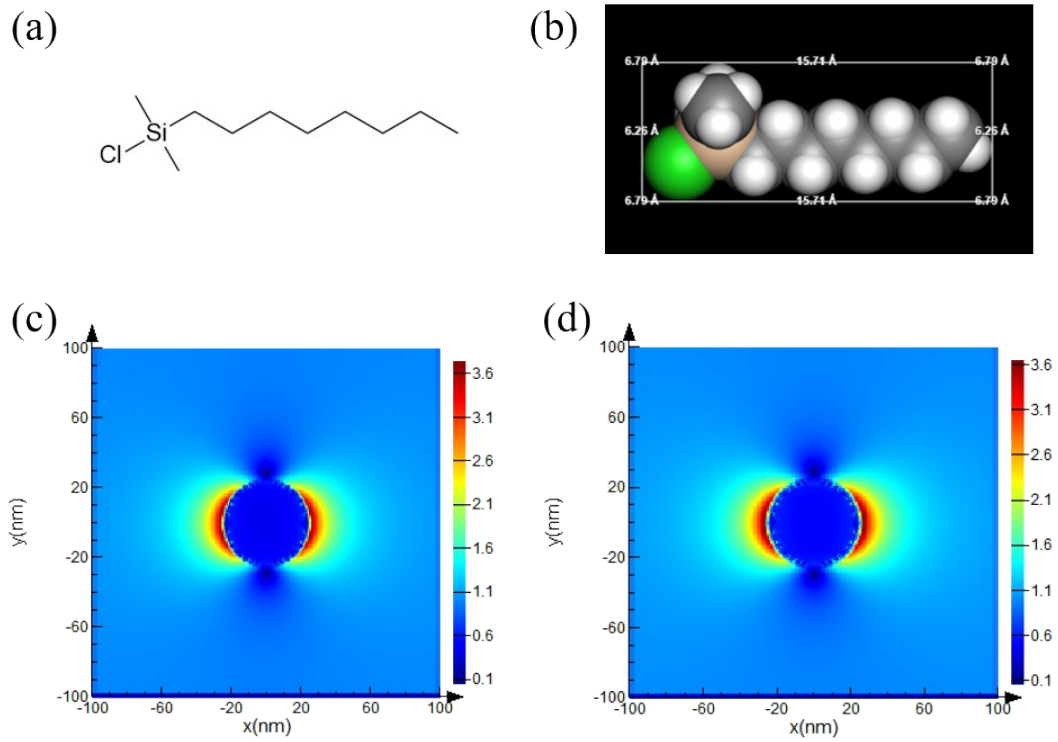

Fig. S5 (a) The structural formula of C8; (b) the physical structure of C8; (c) the electromagnetic field distribution of Ag@C nanoparticle; and (d) the electromagnetic field distribution of Ag@C@C8 nanoparticle.

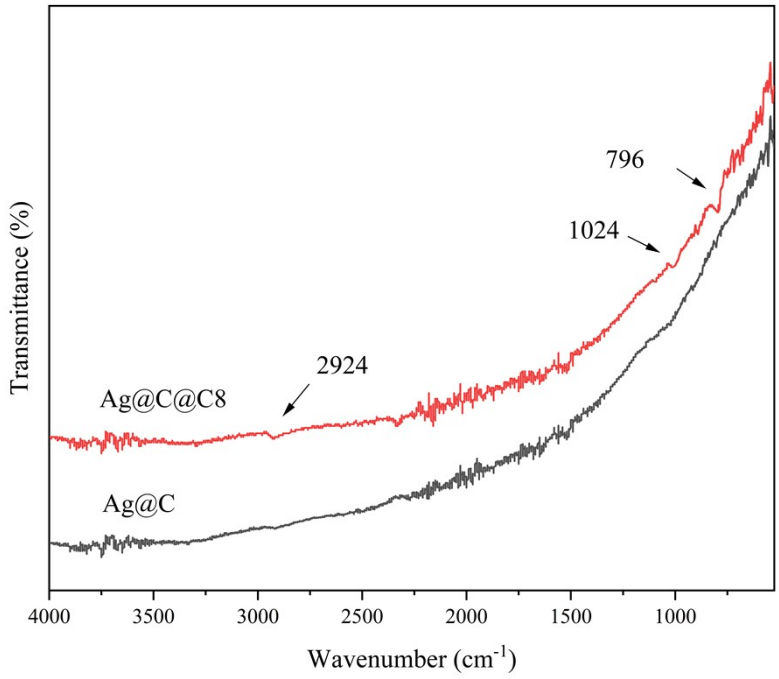

Fig. S6 FTIR spectra of Ag@C and Ag@C@C8.

Table S1 Raman intensities, mean values, error bars and coefficient of variation of different concentrations of R6G at 609cm^{-1}.

Concentration (M)	Sample		The intensity of the peak at 609 cm^{-1}					Mean value	coefficient of variation (%)	error bars
10^{-7}	Sample 1	Day 1-1	41778.19	41293.68	40557.46	42238.14	41694.52	41512.40	1.52	630.53
		Day 1-2	40497.5	42236.46	42600.63	42397.29	41925.13	41931.40	2.00	838.76
		Day 1-3	42117.75	42503.93	40350.14	42802.45	41502.16	41855.29	2.32	971.71
		Day 2-1	42494.93	40360.93	42949.26	40202.38	42098.87	41621.27	3.03	1260.62
		Day 2-2	40893.55	39031.56	43563.61	41695.87	40998.73	41236.66	3.96	1632.66
		Day 2-3	42744.17	41015.26	40548.74	42235.35	42456.77	41800.06	2.30	960.96
		Day 3-1	42355.81	41539.62	40068.49	41409.23	41571.64	41388.96	2.00	826.88
		Day 3-2	42635.21	41184.29	42051.63	41657.22	41649.26	41835.52	1.30	542.40
		Day 3-3	40846.03	41538.74	41600.68	42791.38	42116.56	41778.68	1.73	724.36
	Sample 2	Day 1-1	42054.96	40913.97	40702.48	41080.03	40968.43	41143.97	1.28	527.40
		Day 1-2	42153.12	42195.07	40251.26	41738.95	42484.39	41764.56	2.12	886.74
		Day 1-3	42686.09	40872.33	42180.65	41079.09	41733.14	41710.26	1.81	754.08
		Day 2-1	41058.63	41340.37	40960.23	41193.38	42438.89	41398.30	1.45	599.05
		Day 2-2	40891.16	42617.34	41514.54	41451.82	40014.28	41297.83	2.31	951.93
		Day 2-3	39814.33	41046.78	42843.82	41957.53	41723.15	41477.12	2.73	1130.18
		Day 3-1	40989.43	42120.36	40976.51	42202.79	42884.23	41834.66	1.99	832.10
		Day 3-2	42243.63	42590.32	42628.32	41233.57	41051.16	41949.40	1.80	754.57
		Day 3-3	42671.46	40582.63	40610.64	42040.65	40571.68	41295.41	2.41	993.69
	Sample 3	Day 1-1	41201.64	41436.23	41709.63	42635.49	42734.84	41943.57	1.67	701.33
		Day 1-2	40667.39	41460.43	41802.16	40631.71	41540.16	41220.37	1.30	536.35
		Day 1-3	39969.66	42511.59	41313.52	40169.04	42053.23	41203.41	2.72	1122.24

		Day 2-1	41777.43	41571.87	41150.66	41873.23	41289.17	41532.47	0.75	309.29
		Day 2-2	41854.53	41705.76	42626.11	40770.73	40653.51	41522.13	1.97	818.85
		Day 2-3	42686.39	42317.81	41387.23	42953.49	40334.73	41935.93	2.56	1073.47
		Day 3-1	39766.61	40957.23	41057.51	41072.39	42815.54	41133.86	2.65	1088.37
		Day 3-2	42576.99	42848.19	40335.57	42049.31	41439.53	41849.92	2.40	1003.32
		Day 3-3	40754.25	42541.68	40423.02	41902.63	40156.81	41155.68	2.48	1021.59
	Sample 1	Day 1-1	4727.03	5035.46	4472.65	4121.08	5513.26	4773.90	11.15	532.49
		Day 1-2	5076.63	4153.41	4951.71	4742.19	5280.46	4840.88	8.91	431.12
		Day 1-3	5120.63	4446.36	5194.85	4489.65	5151.32	4880.56	7.74	377.84
		Day 2-1	5163.29	4605.85	4323.05	5208.16	4385.16	4737.10	8.93	423.10
		Day 2-2	4962.56	4068.15	4026.19	5879.13	4787.44	4744.69	16.02	759.97
		Day 2-3	3865.41	4847.39	5713.58	4567.25	4579.16	4714.56	14.14	666.48
		Day 3-1	4678.52	5064.26	5399.14	3812.96	5762.33	4943.44	15.14	748.50
		Day 3-2	4511.85	5088.46	4978.09	4619.22	4635.15	4766.55	5.27	251.11
		Day 3-3	5016.91	5981.31	3856.62	4648.28	4792.46	4859.12	15.73	764.54
10^{-9}		Day 1-1	4588.25	4592.16	4368.06	4729.11	5389.86	4733.49	8.22	389.05
		Day 1-2	5326.94	4968.46	5281.46	4473.16	4732.54	4956.51	7.32	362.89
		Day 1-3	4882.55	4435.26	4761.29	4956.55	4398.26	4686.78	5.47	256.50
		Day 2-1	4723.96	4865.15	4843.49	4701.46	5166.05	4860.02	3.82	185.48
	Sample 2	Day 2-2	5352.42	4363.25	5098.15	4501.48	5049.23	4872.91	8.64	421.15
		Day 2-3	4531.75	4519.53	5076.51	5496.34	4706.46	4866.12	8.59	417.99
		Day 3-1	5431.84	4531.87	5061.67	4316.56	4206.97	4709.78	11.06	520.65
		Day 3-2	4761.95	4936.52	5163.23	4491.21	4396.17	4749.82	6.64	315.38
		Day 3-3	5143.94	4361.76	5374.16	4961.74	4163.52	4801.02	10.78	517.51
	Sample 3	Day 1-1	4753.26	4865.23	5197.05	4992.06	4715.98	4904.72	3.99	195.71

		Day 1-2	4977.25	4784.31	4475.15	4963.45	5266.67	4893.37	5.94	290.73
		Day 1-3	4545.93	5363.56	5454.19	4306.23	4425.79	4819.14	11.33	545.92
		Day 2-1	5273.62	4880.32	4535.05	5213.33	3605.84	4701.63	14.46	679.97
		Day 2-2	4732.16	5442.15	5037.99	3588.16	5438.61	4847.81	15.77	764.62
		Day 2-3	4820.13	4981.31	4755.13	5005.46	5339.88	4980.38	4.56	227.09
		Day 3-1	5403.62	5073.41	5423.08	4187.06	4801.46	4977.73	10.27	511.15
		Day 3-2	4617.95	5584.02	4516.17	5398.66	4355.65	4894.49	11.37	556.68
		Day 3-3	5004.16	5095.64	4295.13	4696.78	4890.62	4796.47	6.62	317.33
	Sample 1	Day 1-1	568.61	551.64	433.85	492.45	532.52	515.81	10.45	53.88
		Day 1-2	563.15	463.92	562.63	578.65	553.15	544.30	8.42	45.85
		Day 1-3	463.15	603.85	516.11	550.04	502.44	527.12	10.05	53.00
		Day 2-1	521.64	543.26	573.52	517.63	599.64	551.14	6.36	35.03
		Day 2-2	632.23	765.42	624.46	800.26	467.73	658.02	20.07	132.07
		Day 2-3	655.65	706.43	664.33	739.04	675.76	688.24	4.98	34.28
		Day 3-1	564.65	506.19	569.74	532.54	503.65	535.35	5.84	31.24
		Day 3-2	484.32	586.45	523.65	629.82	585.69	561.99	10.25	57.58
10^{-11}		Day 3-3	595.32	426.31	599.36	613.11	657.48	578.32	15.30	88.48
	Sample 2	Day 1-1	654.96	496.12	481.06	518.77	558.38	541.86	12.85	69.62
		Day 1-2	452.63	503.22	577.32	680.23	490.03	540.69	16.68	90.19
		Day 1-3	564.65	457.06	533.12	599.26	509.58	532.73	10.16	54.10
		Day 2-1	456.36	550.96	520.53	576.13	502.85	521.37	8.81	45.95
		Day 2-2	556.32	514.27	504.06	515.34	517.59	521.52	3.86	20.14
		Day 2-3	563.64	509.64	509.58	589.22	495.53	533.52	7.61	40.61
		Day 3-1	496.35	563.56	413.62	560.02	505.79	507.87	11.99	60.91
		Day 3-2	503.63	493.52	548.55	620.49	408.32	514.90	15.11	77.82

	Day 3-3	552.36	612.07	515.12	528.85	453.89	532.46	10.80	57.49
	Day 1-1	596.45	561.25	585.32	523.52	520.35	557.38	6.24	34.78
	Day 1-2	648.85	536.01	523.05	511.49	503.76	544.63	10.93	59.52
	Day 1-3	596.32	529.16	618.66	471.66	434.78	530.12	14.83	78.63
	Day 2-1	696.65	605.75	537.28	435.38	509.58	556.93	17.80	99.13
Sample 3	Day 2-2	535.23	555.19	593.08	616.48	530.87	566.17	6.60	37.35
	Day 2-3	535.61	586.31	527.77	516.79	509.57	535.21	5.65	30.26
	Day 3-1	683.21	569.01	501.24	432.68	550.49	547.33	16.90	92.48
	Day 3-2	643.33	656.16	502.01	478.38	559.59	567.89	14.17	80.47
	Day 3-3	453.86	548.66	658.14	525.58	493.37	535.92	14.38	77.06

Table S2 The Raman intensities， mean values, error bars and coefficient of variation of within- and between-days at different concentrations of R6G at 609cm^{-1}.

Concentration (M)	Sample	Time	Mean value of within-day	Mean value of between-days	error bars of within-day	error bars of between-days	coefficient of variation (%) of within-day	coefficient of variation (%) of between-days
10^{-7}	Sample 1	Day 1	41766.36	41662.25	813.67	932.10	1.95%	2.24%
		Day 2	41552.67		1284.75		3.10%	
		Day 3	41667.72		697.88		1.68%	
	Sample 2	Day 1	41539.60	41541.28	722.74	825.53	1.74%	1.99%
		Day 2	41391.08		893.72		2.16%	
		Day 3	41693.16		860.12		2.07%	
	Sample 3	Day 1	41455.78	41499.70	786.64	852.76	1.90%	2.06%
		Day 2	41663.51		733.87		1.76%	
		Day 3	41379.82		1037.76		2.51%	
10^{-9}	Sample 1	Day 1	4831.78	4806.76	447.15	550.57	9.27%	11.45%
		Day 2	4732.12		616.52		13.03%	
		Day 3	4856.37		588.05		12.05%	
	Sample 2	Day 1	4792.26	4804.05	336.14	376.29	7.00%	7.84%
		Day 2	4866.35		341.54		7.02%	
		Day 3	4753.54		451.18		9.49%	
	Sample 3	Day 1	4872.41	41693.16	344.12	454.36	7.09%	9.37%
		Day 2	4843.28		557.23		11.60%	

		Day 3	4889.56		461.72	9.42%	
10^{-11}	Sample 1	Day 1	529.08	573.37	50.91	59.05	9.64%	10.19%
		Day 2	632.47		67.13		10.47%	
		Day 3	558.55		59.10		10.46%	
	Sample 2	Day 1	538.43	527.43	71.30	57.43	13.23%	10.19%
		Day 2	525.47		35.56		6.76%	
		Day 3	518.41		65.41		12.64%	
	Sample 3	Day 1	544.04	549.06	57.64	65.52	10.67%	11.94%
		Day 2	552.77		55.58		10.02%	
		Day 3	550.38		83.34		15.15%	

Table S3 The comparisons of our synthesized Ag@C@C8 nanoparticles and other SERS substrates.

Substrate type	Target molecule	LOD	Ref
Au@Ag	Rhodamine 6G	10^{-12} M	1
Ag@Fe_3O_4	Rhodamine 6G	10^{-11} M	2
SiO_2@Ag	Rhodamine 6G	9×10^{-9} M	3
Au@4-ATP@Ag	Crystal violet	1.9×10^{-9} M	4
Ag/PVA@Ag	Crystal violet	10^{-10} M	5
Ag/PAOCG	Crystal violet	10^{-10} M	6
3D porous Ag fiber	Malachite green	8.48×10^{-9} M	7
the paper-based Au/Ag	Malachite green	4.3×10^{-9} M	8
Ag/graphene@Au	Malachite green	10^{-11} M	9
Ag nanorod arrays	Malachite green	10^{-9} M	10
Ag@C@C8	Rhodamine 6G	3×10^{-12} M	this work
	Crystal violet	2.2×10^{-10} M	this work
	Malachite green	1×10^{-9} M	this work

Table S4 Standard recovery experiments with malachite green in different aqueous solution.

Sample	The amount of malachite green added	Detection amount of malachite green	Recovery rate (%)
Fish water 1	1 μM	0.927 μM	92.7%
	0.5 μM	0.509 μM	101.8%
	0.1 μM	0.098 μM	98.0%
	0 μM	—	—
Fish water 2	1 μM	0.939 μM	93.9%
	0.5 μM	0.534 μM	106.8%
	0.1 μM	0.1083 μM	108.3%
	0 μM	—	—
Laboratory tap water	1 μM	0.949 μM	94.9%
	0.5 μM	0.482 μM	96.4%
	0.1 μM	0.0988 μM	98.8%
	0 μM	—	—

Note: "—" means not detected.

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