Electronic Supplementary Information

Multi-Quantum-Well Quantum Dots with Stable Dual Emission

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Experiment

1. Materials

Dimethylzinc (1.0 M solution in toluene) was purchased from J&K Scientific Ltd. (Carboxyalkyl) terminated polydimethylsiloxane cSt15-30 (DMS-B12) and amino-terminated polydimethylsiloxane (NH_2-PDMS) were purchased from Fluorochem Ltd. And silicone resin (KMT-5261s) was from Beijing KMT technology Ltd. All chemicals were used without purification.

2. Synthesis of Zn-PDMS

It is according to literature, under a nitrogen atmosphere, the DMS-B12 was slowly injected into 1M dimethyl zinc-toluene solution with slow stirring until no obvious bubble appears. The prepared Zn-PDMS solution is stored under nitrogen.[S1]

3. Synthesis of NH_2-PDMS & Zn-PDMS Copassivated MQW-QDs

For the surface modification for MOW-QDs was also prepared according to literature.[S1] under a nitrogen atmosphere, 2 ml synthesized ZnSe/CdSe/CdS/CdSe/CdS/ZnS QDs dispersed in DMS-B12 solution and $Cd(DDTC)_2$ were added into a 25 ml three-neck flask together with amino-terminated PDMS (NH_2-PDMS). After stirring well and thoroughly with nitrogen bubbling, the flask was heated to 80°C under a nitrogen flow. Then the flask was heated to 140 °C in 3 min and kept for another 40 min and cooled to about 80 °C. Afterwards, $Zn(DDTC)_2$ and certain amount of Zn-PDMS were added into the flask under nitrogen. Continuously, the flask was heated to 140 °C in 5 min and kept for another 40 min. And then the flask was cooled to room temperature. A certain amount of the resulting solution was dispersed into toluene to get a QDs solution with a uniform concentration.

Characterization

Table S1 A list of samples studied in this work.

Sample ID	Structure	Variable				
		1	**2**	**3**	**4**	**5**
A	ZnSe/**CdSe**	--	--	--	--	--
B	ZnSe/**CdSe**/CdS	--	--	--	--	--
C	ZnSe/CdSe/**CdS**/CdSe/CdS	(C1) 0.09nm CdS	(C2) 0.20nm CdS	(C3) 0.31nm CdS	--	--
D	ZnSe/CdSe/CdS/**CdSe**	(D1) 0.84nm CdSe	(D2) 1.00nm CdSe	(D3) 1.21nm CdSe	(D4) 1.40nm CdSe	(D5) 1.56nm CdSe
E	ZnSe/CdSe/CdS/CdSe/CdS /**ZnS**	--	--	--	--	--
F	ZnSe/CdSe/CdS/CdSe/**ZnS**	--	--	--	--	--
G	ZnSe/CdSe/**ZnS**/CdSe/CdS/ ZnS	--	--	--	--	--

This paper includes five main parts, and we use the different structures of MQW-QDs in the course of this study and defined as A, B, C, D, E, F, G. As well as F1, F2, F3, F4

respectively represent ZnSe/CdSe, ZnSe/CdSe/CdS, ZnSe/CdSe/CdS/CdSe, ZnSe/CdSe/CdS/CdSe/ZnS, and G1, G2, G3, G4, G5 respectively represent the structure of ZnSe/CdSe, ZnSe/CdSe/ZnS, ZnSe/CdSe/ZnS/CdSe, ZnSe/CdSe/ZnS/CdSe/CdS, ZnSe/CdSe/ZnS/CdSe/CdS/ZnS. In the study of the thickness of different samples. For simplicity, we adopt a serious of letters to represent the different structures, such as the ZnSe/CdSe structure is written as Sample A.

1. TEM Images and Characterization of the MQW-QDs

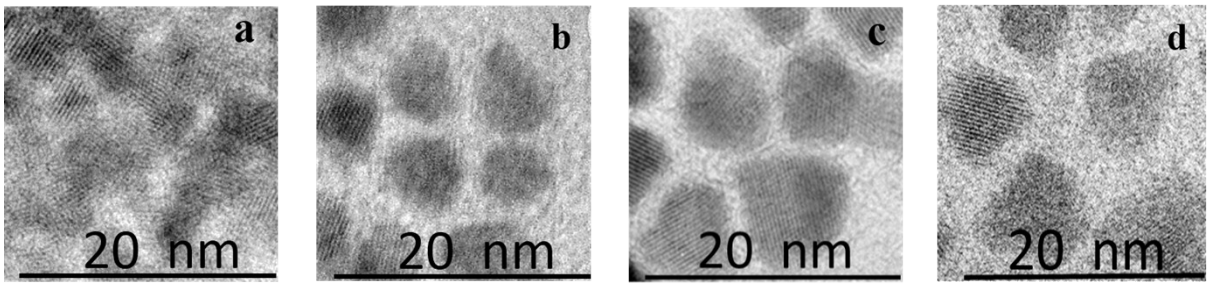

Fig. S1 TEM images of Sample A (a), Sample D (b), Sample C (c), and Sample E (d).

The TEM images clearly illustrate the size variation of the MQW-QDs during the growth, where the CdSe inner-well was first grown on the ZnSe cores with a diameter of about 3.2±0.3 nm, and the Sample D structure with a size of 5.3±0.3 nm in diameter was further grown. After surface passivation with CdS and ZnS, the MQW-QDs with a size of 6.13±0.3 nm and 6.96±0.3 nm in diameter were obtained respectively.

2. Influence of the Thickness of Outer Well in MQW-QDs

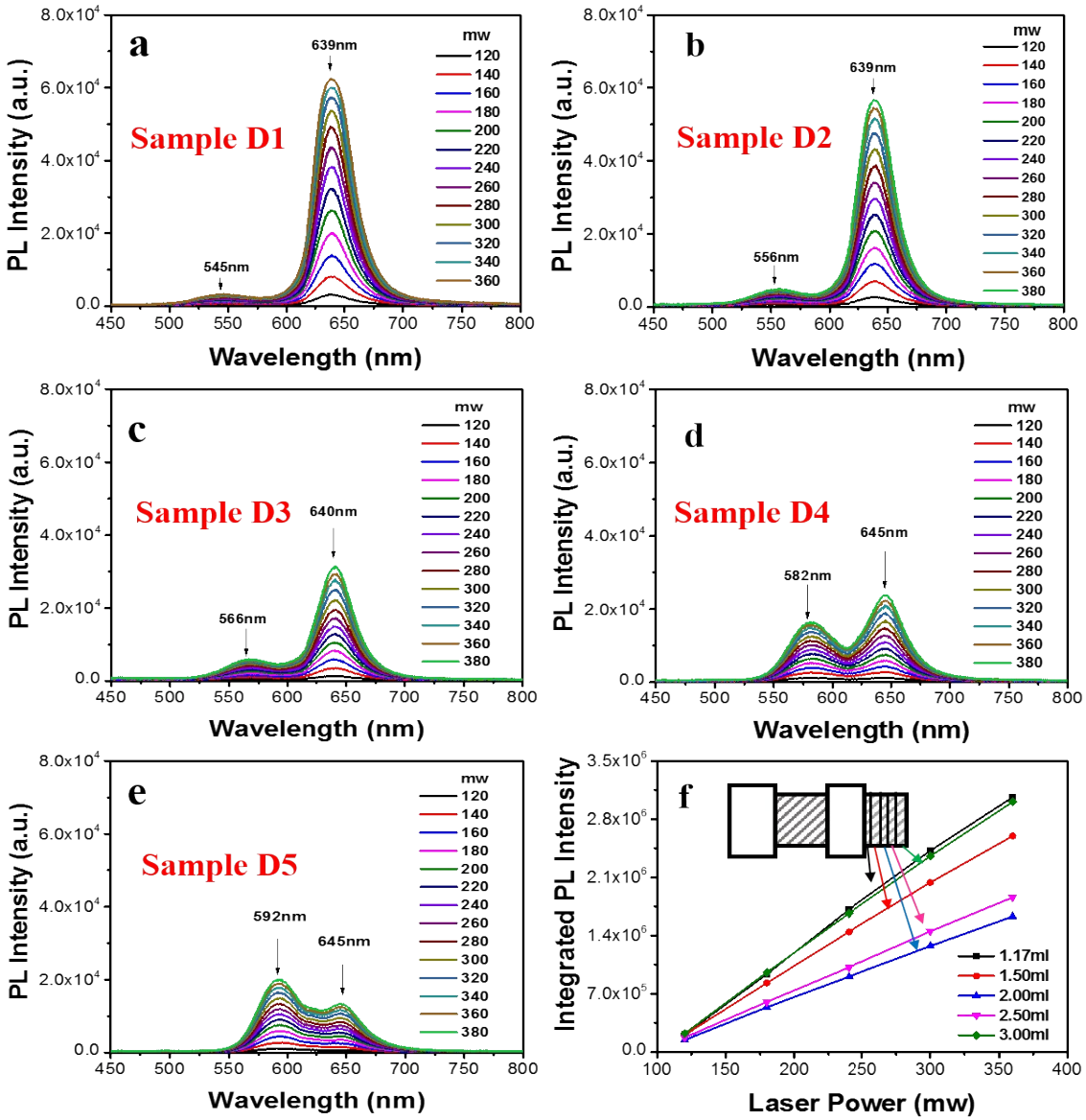

Fig. S2 The laser power dependence of PL spectral of the Sample D structure with different outer-well thickness (a-e) and the double wells PL spectra integral (f).

The results clearly exhibit that the relativity between PL intensity and laser power with different outer-well (CdSe) thickness. With the growth of outer-well, the PL intensity of the outer-well increases obviously due to the number of effective electrons and holes increases, while the PL intensity of the inner-well decreases because the light is preferentially absorbed by the outer-well under the same laser power. Fig. S2f summerizes integrated PL intensity from 500 nm to 750 nm of the double wells with different outer-well thickness. When the

outer-well CdSe grows thick enough, the intermediate CdS are affected by the common tension between the inner-well and the outer-well, and result in the lattice deformation seriously.

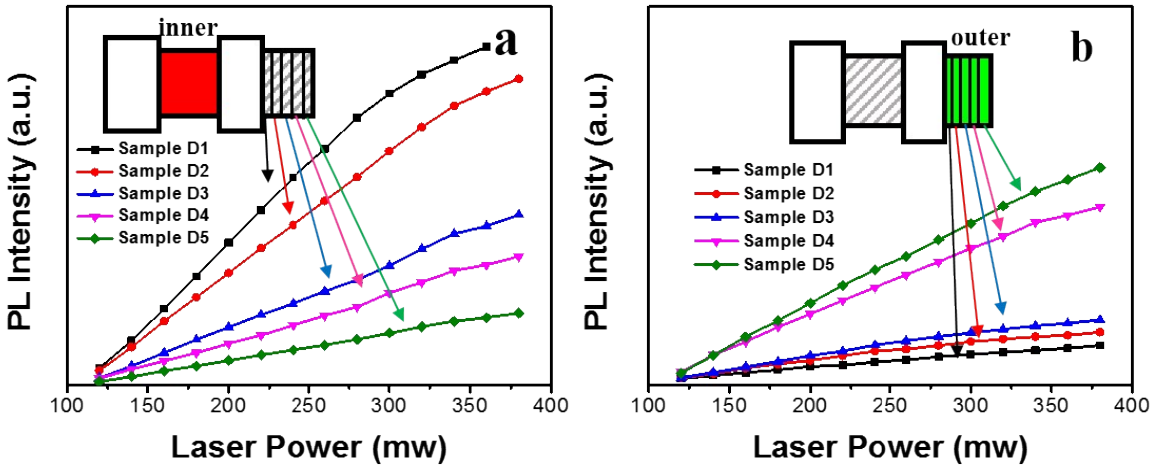

Fig. S3 The laser power dependence of PL intensity of the inner-well (a) and the outer-well (b) of the MQW-QDs with different outer-well thickness.

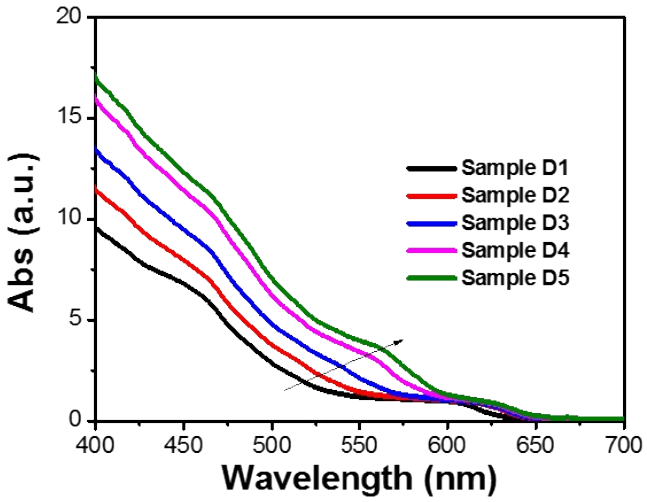

Fig. S4 The absorption spectra of the Sample D structure with different outer-well thickness.

Table S2 The variation of excited state constants and lifetime for Sample D.

Laser	Thickness (outer-well)	λ (nm)	τ 1 (ns)	B1 (%)	τ 2 (ns)	B2 (%)	τ ave (ns)	χ2
380nm	Sample D1	545	1.41	79.53	21.22	20.47	5.47	1.17
		639	2.63	32.77	16.05	67.23	11.65	1.14
	Sample D2	556	1.43	70.26	21.63	29.74	7.44	1.21
		639	2.54	31.19	16.70	68.81	12.23	1.18
	Sample D3	568	1.51	51.19	22.58	48.81	11.79	1.05
		640	2.32	34.44	15.85	65.56	11.19	1.13
	Sample D4	583	1.69	41.15	22.90	58.85	14.17	1.14
		644	1.94	30.52	15.36	69.48	11.26	1.15
	Sample D5	592	1.77	28.50	20.18	71.50	14.93	1.11
		645	1.69	33.62	15.00	66.38	10.53	1.09

[a] (The white represents the inner-well, and the gray represents the outer-well).

3. Influence of the Thickness of the Intermediate Barrier in MQW-QDs.

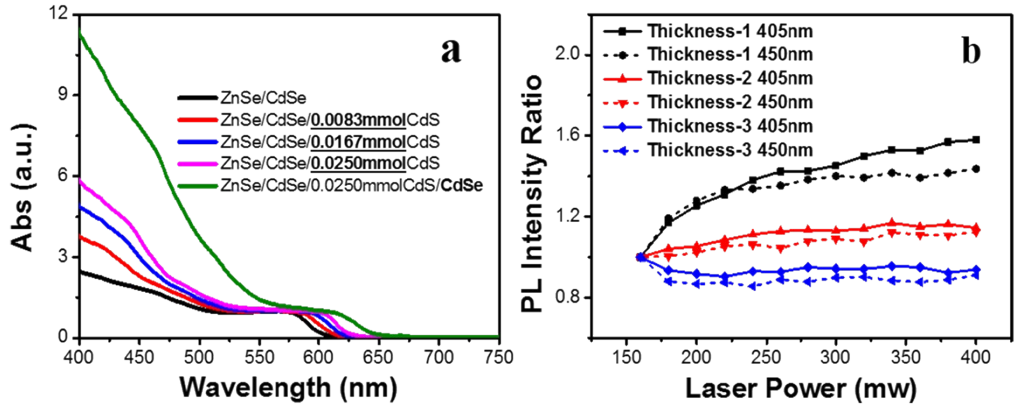

Fig. S5 a) Evolution of absorption and b) PL peak intensity ratio of the inner-well to the outer-well under 405nm and 450nm laser with different thickness of the intermediate barrier CdS.

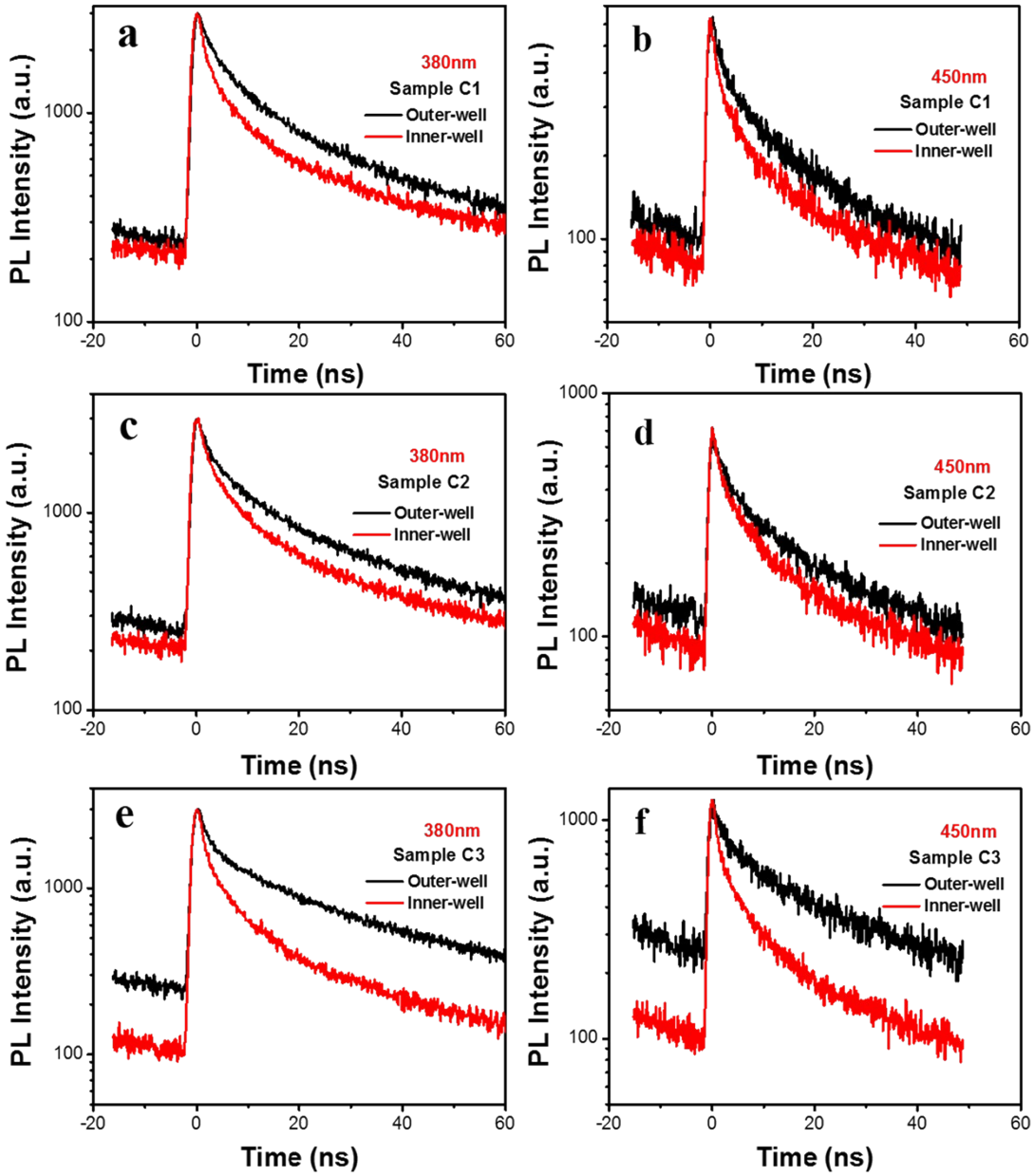

Fig. S6 The PL decay of sample C with 380 nm and 450nm laser as the steady-state excitation source.

The Fig. S5 clearly displays the evolution absorption with different thickness of the intermediate barrier CdS. It can be seen that the intermediate CdS barrier will increase the absorbance of the MQW-QDs at the wavelength below 500nm and present strong absorption when the wavelength is below 400nm. To identify the influence of the intermediate CdS barrier, we further compared the power dependent PL intensity ratio of the samples with

different barrier thicknesses under the excitation by 405nm and 450nm laser. The tests reveal close variation trend of PL intensity ratio for both 405nm and 450nm lasers, as shown in Fig. S5b. The PL decay tests of samples under the excitation of 405nm and 450nm also provide the similar trends, as shown in Fig. S6.[S2]

4. Influence of the Materials and Thickness of Outer Barriers in MQW-QDs

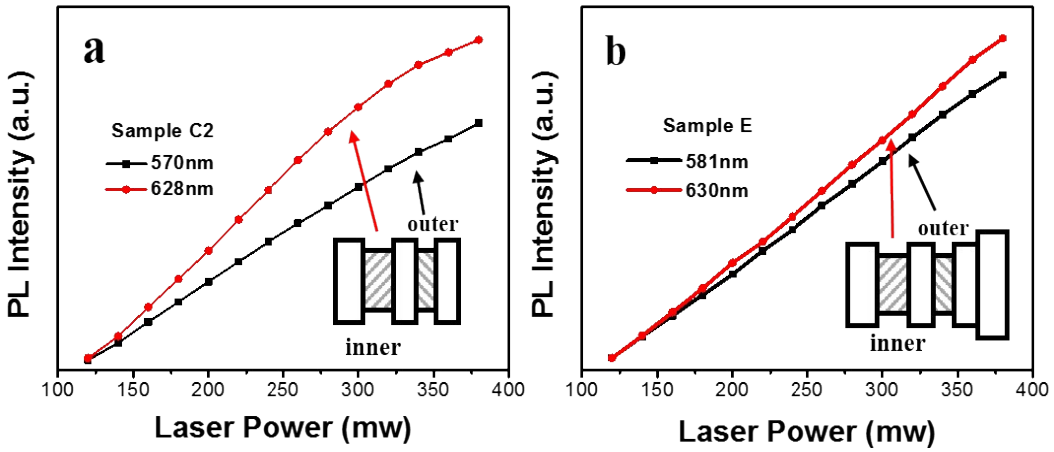

Fig. S7 The laser power dependence of PL intensity of the inner-well (a) and the outer-well (b) of the MQW-QDs with different outer barriers thickness.

Table S3 The variation of excited state constants and lifetime for Sample F.

Laser		λ (nm)	τ 1(ns)	B1(%)	τ 2(ns)	B2(%)	τ ave (ns)	χ2
380nm	**Sample F1**	592	1.97	28.10	14.85	71.90	11.23	1.10
	Sample F2	618	3.36	26.28	16.28	73.72	12.88	1,18
		545	1.53	71.24	20.12	28.76	6.88	1.30
	Sample F3	625	2.23	25.61	14.54	74.39	11.39	1.13
		570	1.80	30.42	18.45	69.58	13.39	1.15
	Sample F4	632	2.24	29.42	15.05	70.58	11.28	1.12

a) (The white represents the inner-well, and the gray represents the outer-well).

Table S4 The variation of excited state constants and lifetime for Sample G.

Laser		λ (nm)	τ 1(ns)	B1(%)	τ 2(ns)	B2(%)	τ ave (ns)	χ2
380nm	**Sample G1**	592	1.97	28.10	14.85	71.90	11.23	1.10
	Sample G2	617	3.82	25.77	17.98	74.23	14.33	1,10
		522	1.45	49.58	24.69	50.42	13.17	1.10
	Sample G3	624	2.65	26.63	14.87	73.37	11.62	1.06
		527	2.07	14.49	16.91	85.51	16.61	0.97
	Sample G4	630	3.16	31.85	16.97	68.15	15.86	1.16
		530	2.24	14.50	16.60	85.50	16.28	1.07
	Sample G5	632	2.87	27.25	25.56	72.75	14.74	1.24

a) (The white represents the inner-well, and the gray represents the outer-well).

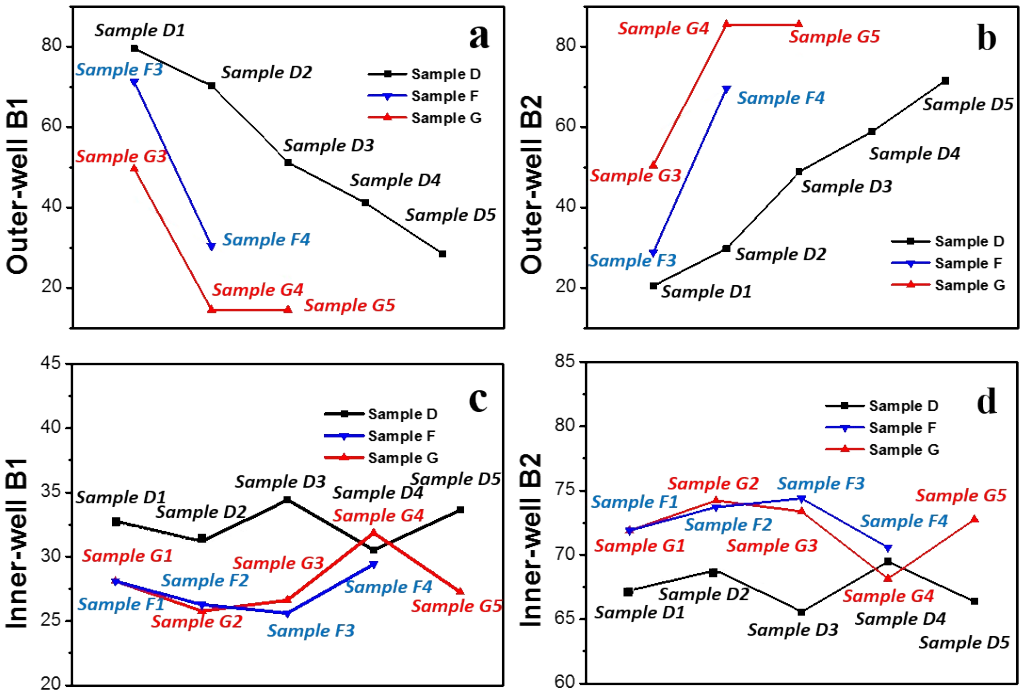

Fig.S8 The variation of B1 and B2 of different structure from Table S2 to Table S4.

This diagram clearly shown the variation of B1 and B2 from Table S2 to Table S4. For inner-well, the fastest (B1) and the slowest component (B2) remain near constant, while the fastest component of the outer-well decreases and the slowest component increases obviously.

Notes and References

S1 Y. Xie, C. Geng, X. Liu, S. Xu, W. Xing, X. Zhang, Z.-H. Zhang, Y. Zhang, W. Bi, *Nanoscale,* 2017, **9**, 16836-16842.

S2 C. K. De, T. Routh, D. Roy, S. Mandal, P, K. Mandal, *J. Phys. Chem. C* 2018, **122**, 964-973.