Supporting Information

Controllable synthesis of gold nanoparticles in aqueous solution by microwave assisted flow chemistry

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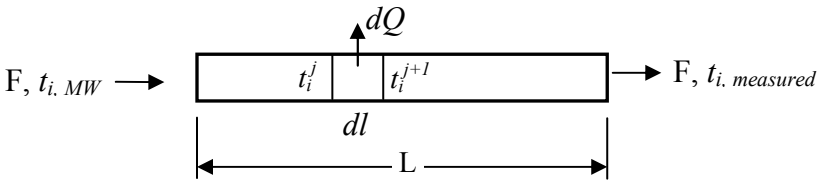
Estimation of fluid temperature outside the microwave heating zone

The temperature of the reaction fluid was measured at the position of 5 cm away from the microwave heating zone. To estimate the fluid temperature outside the microwave heating zone, forced convection heat transfer between the fluid inside the PTFE tubing and the outside surrounding air was considered.



For fully developed internal laminar flow in a circular tube, the Nusselt numbers are constant-valued. The values depend on the tube diameter:

$$Nu = \frac{h_i d_i}{\lambda_f}$$

where:

d_i=Tube inside diameter
λ_f=thermal conductivity of the fluid
h_i=convective heat transfer coefficient

For convection with uniform surface heat flux in circular tubes, Incropera & DeWitt' correlation can be used:[1]

$$Nu_D = \frac{48}{11} \cong 4.36$$

Taking a small section of the tubing (*dl*), the temperature change of the fluid can be calculated by the heat transfer rate through the tubing wall:

$$dQ = K_o \pi d_o \left(t_i^j - t_o\right) dl \quad (1)$$

$$K_o = \left[\frac{1}{h_i}\frac{d_o}{d_i} + \frac{d_o}{2\lambda_f}\ln\frac{d_o}{d_i} + \frac{1}{h_o}\right]^{-1} \quad (2)$$

and the heat balance of the fluid:

$$t_i^{j+1} = \frac{dQ}{mCp} + t_i^j \quad (3)$$

Since the content of the Au nano particles in the reaction fluid was very low (<0.5wt%), the properties of water[2] were used in the calculation. The estimated fluid temperatures outside the microwave heating zone at different microwave power and different ratio of citrate and Au are listed in Table 1.

[1] Incropera, Frank P.; DeWitt, David P. (2002). *Fundamentals of Heat and Mass Transfer* (5th ed.). Hoboken: Wiley. pp. 486, 487.

[2] Incropera, Frank P.; DeWitt, David P. (1996). *Introduction to Heat Transfer* (3rd ed.). John Wiley&Sons, Inc., New York, USA.

Table S1 Estimated fluid temperature at the exit of the microwave zone using the measured temperature data recorded at 5 cm away from the exit of the microwave zone.

Fluid volume flow rate (F)	**F=4 mL/min**				**F=4 mL/min, MW=36 W**				
	MW (W)				**[Cit]/[Au]**				
MW power (MW)	20	25	30	36	1	4	6	10	20
Measured temperature (°C)	80	90	109	116	114	115	116	117	118
MW zone temperature (°C)	86	96	116	123	120	121	122	123	124

Table S2 The mean particle length and width and mean aspect ratio of the produced Au-NPs under constant citrate-to-gold ratio of 6/1 and 4 mL min^{-1} flow rate by using microwave power of 25, 30, 36, 40 and 45 W, and their standard deviations (SD).

Microwave Power (W) / # of counted Au-NPs	Mean particle width / nm	± SD_{width} / nm	Mean particle length / nm	± SD_{length} / nm	Mean aspect ratio	± $SD_{aspect\ ratio}$
25 / 270	4.0	1.4	7.9	4.1	2.16	1.47
30 / 157	6.3	1.6	9.3	4.8	1.45	0.55
36 / 499	6.7	1.5	9.1	2.8	1.40	0.40
40 / 190	8.1	3.4	11.4	5.6	1.39	0.36
45 / 201	6.9	1.3	9.5	3.4	1.38	0.51

Table S3 The mean particle length and mean particle width of the produced Au-NPs under constant microwave power of 36 W, 4 mL min^{-1} flow rate and 20 psi back pressure by using citrate-to-gold molar ratios of 2, 3, 4, 6, 10, 20, 40 and 60, and their standard deviations (SD).

Cit:Au ratio / # of counted Au-NPs	Mean particle width / nm	± SD_{width} / nm	Mean particle length / nm	± SD_{length} / nm	Mean aspect ratio	± $SD_{aspect\ ratio}$
2 / 243	9.2	3.4	13.7	5.4	1.52	0.39
3 / 245	7.4	1.8	10.6	3.5	1.49	0.55
4 / 208	7.2	2.2	10.3	3.8	1.42	0.42
6 / 499	6.7	1.5	9.1	2.8	1.4	0.4
10 / 548	3.5	1.3	4.3	1.4	1.26	0.19
20 / 168	8.6	1.7	9.9	2.1	1.16	0.16
40 / 117	13.8	3.8	15.7	4.5	1.14	0.15
60 / 50	19.4	5.6	21.5	7.1	1.11	0.12

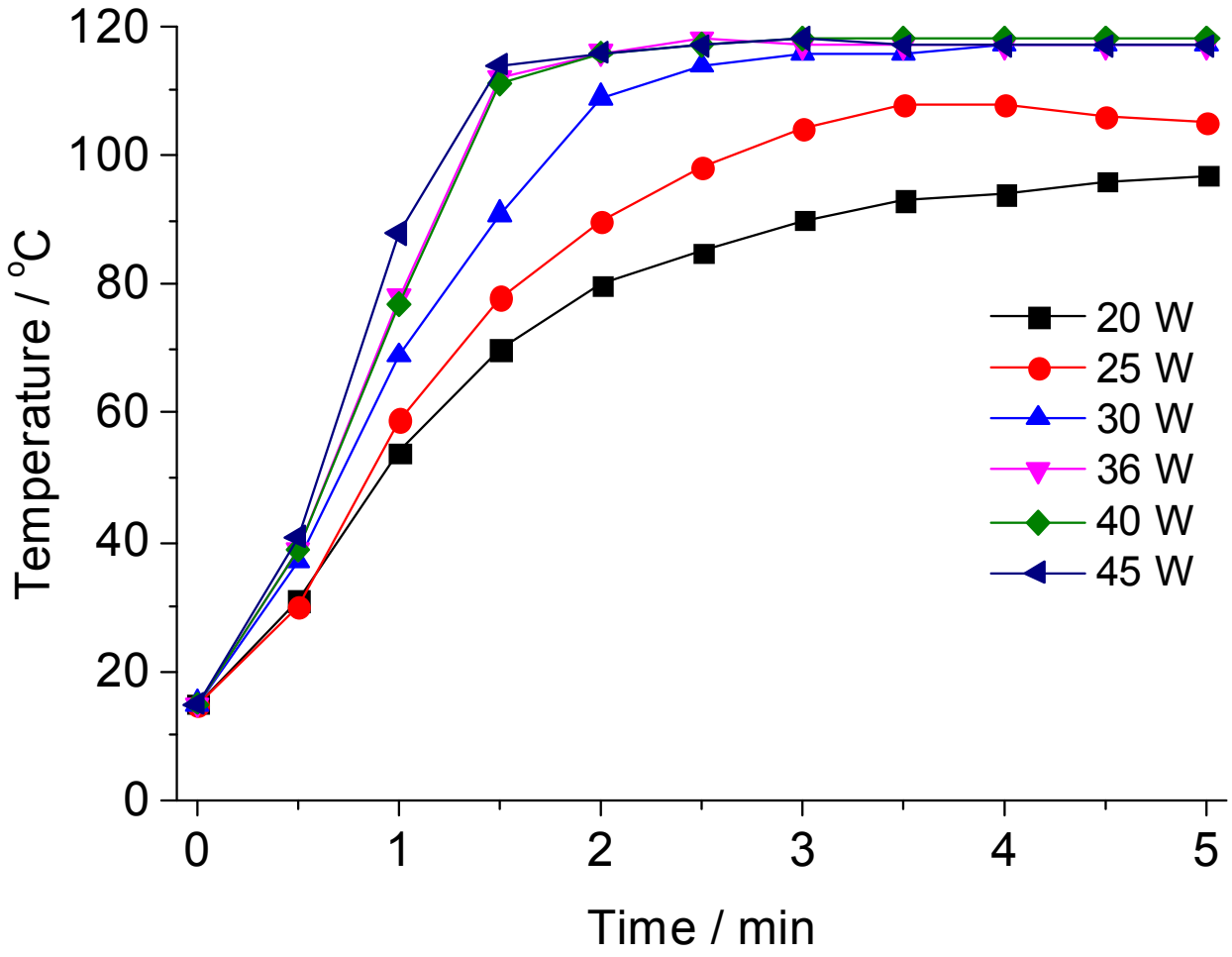


Figure S1 Temperature versus time graphs for the applied microwave power of 20, 25, 30, 36, 40 and 45 W for citrate-to-gold molar ratio of 6/1, 4 mL min^{-1} flow rate and 20 psi back pressure. The reaction fluid temperature outside the flow reactor was recorded at every 30 seconds intervals during 5 min reaction time.

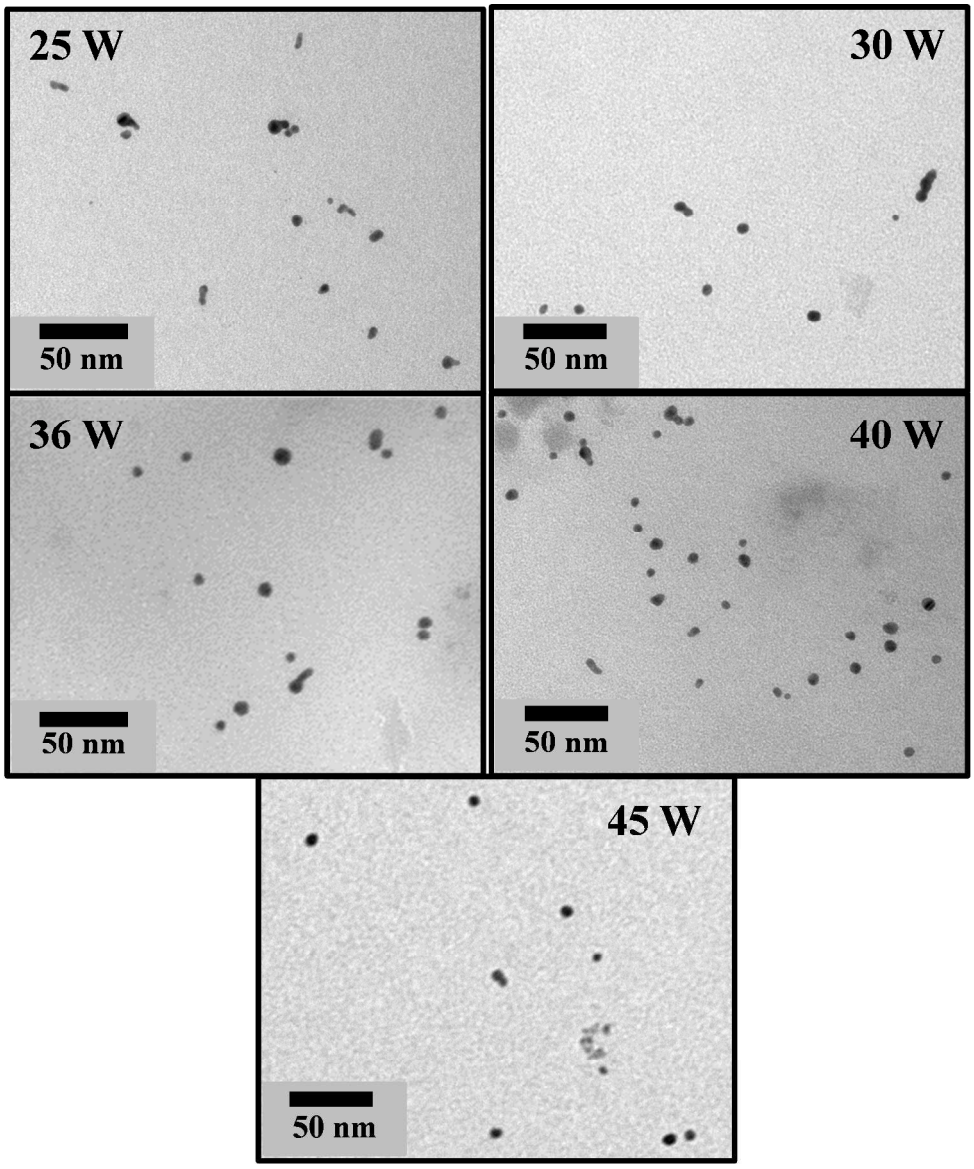


Figure S2 TEM images of the Au-NPs synthesized at constant citrate-to-gold molar ratio of 6/1, 4 mL min^{-1} flow rate and 20 psi back pressure by applying microwave power of 25, 30, 36, 40 and 45 W.

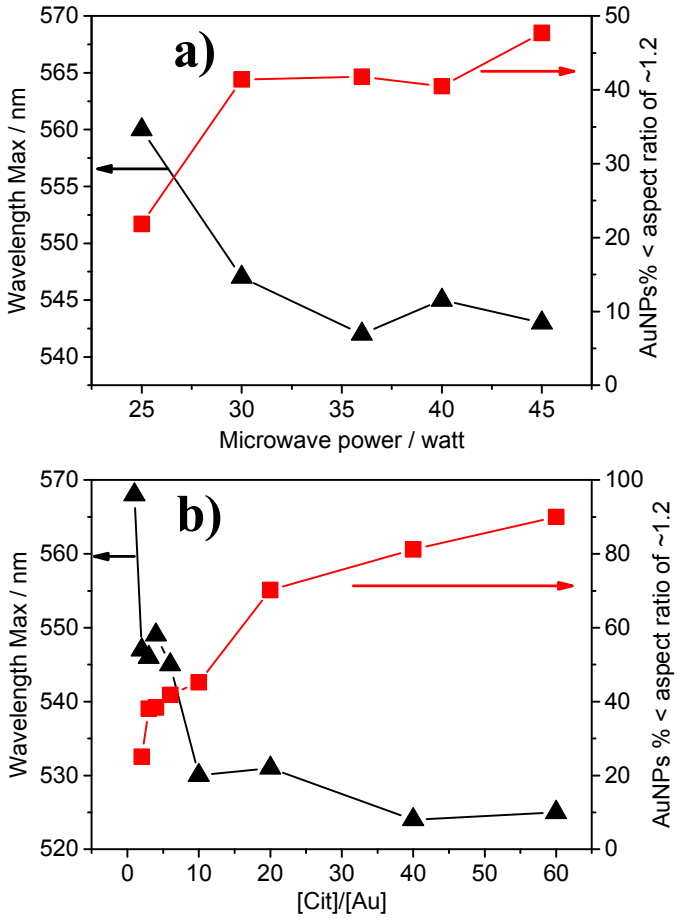


Figure S3 a) Percentage of Au-NPs with aspect ratio smaller than ~1.2 synthesized at constant citrate-to-gold molar ratio of 6/1, 4 mL min^{-1} flow rate and 20 psi back pressure by applying microwave power of 25, 30, 36, 40 and 45 W and their corresponding wavelength max.. **b)** Percentage of Au-NPs with aspect ratio smaller than ~1.2 synthesized under constant microwave power of 36 W, 4 mL min^{-1} flow rate and 20 psi back pressure by using citrate-to-gold molar ratios of 1, 2, 3, 4, 6, 10, 20, 40 and 60 and their corresponding wavelength max..

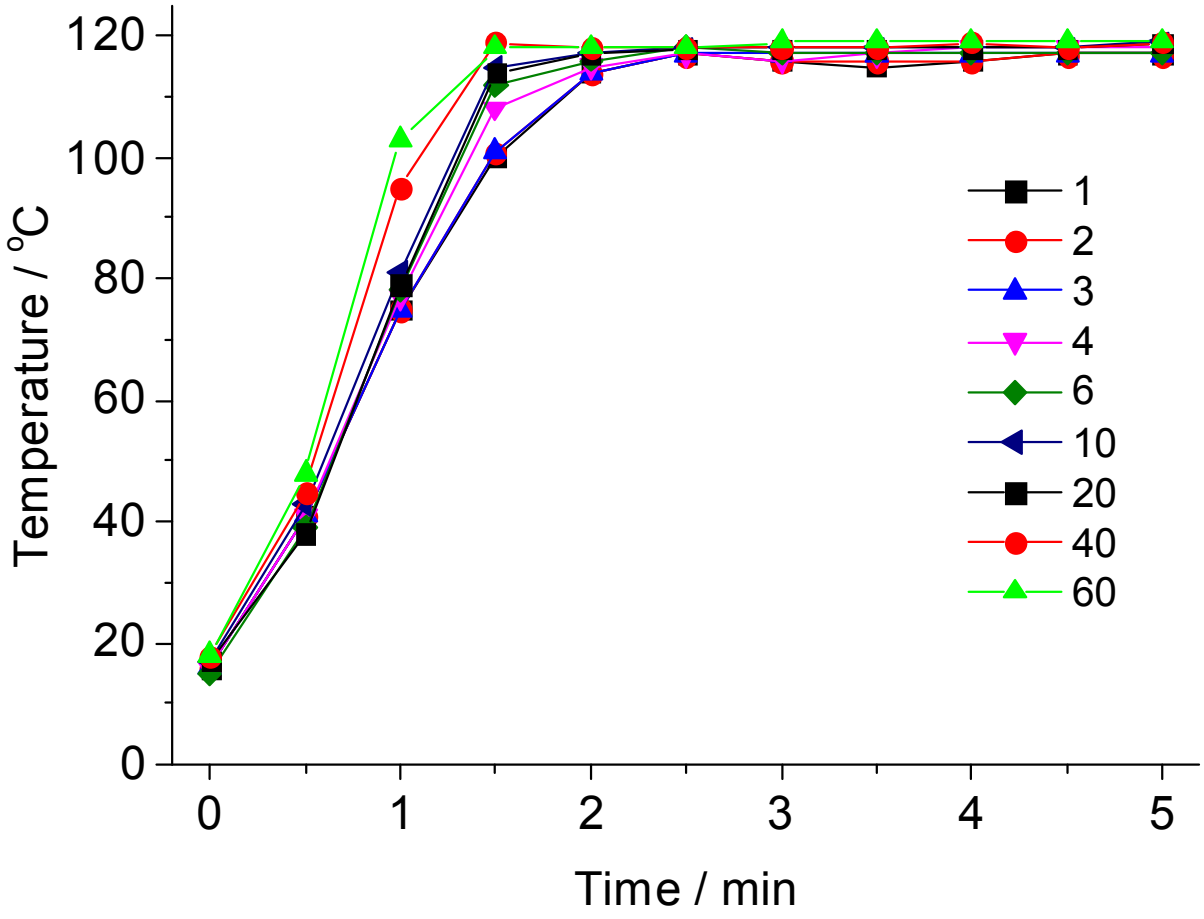


Figure S4 Temperature versus time graphs for citrate-to-gold molar ratios of 1, 2, 3, 4, 6, 10, 20, 40 and 60 under 36 W applied MW power and 4 mL min^{-1} flow rate. The reaction fluid temperature outside the flow reactor was recorded at every 30 seconds intervals during 5 min reaction time.

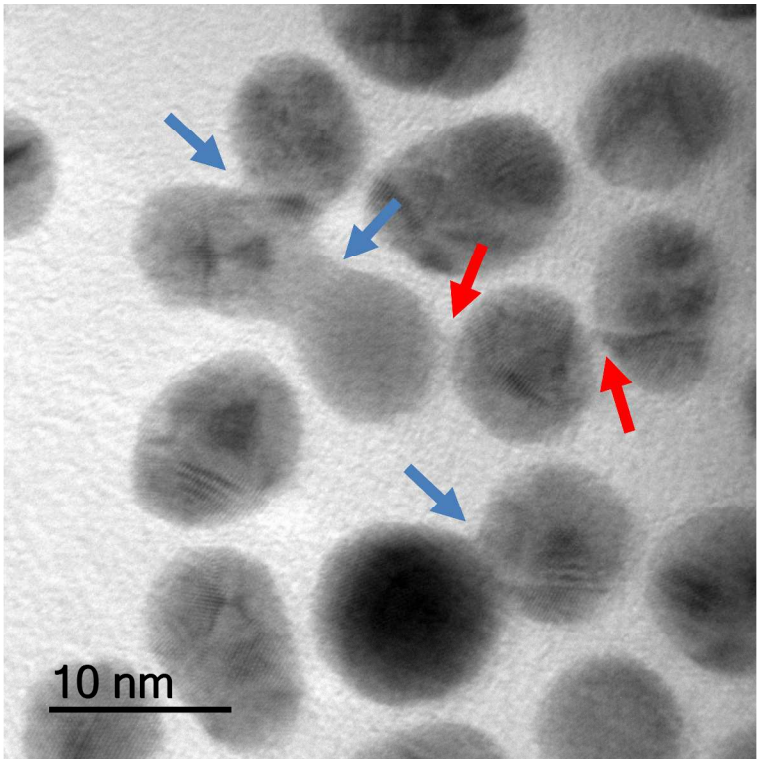


Figure S5 HRTEM image of the Au-NPs produced using citrate-to-gold molar ratio of 6/1, 4 mL min^{-1} flow rate and 20 psi back pressure by applying microwave power of 36. Blue arrows show strong particle-particle interconnection and red arrows show weak particle-particle interconnection. Non-spherical Au-NP formation can be clearly observed from the electron microscopy image.

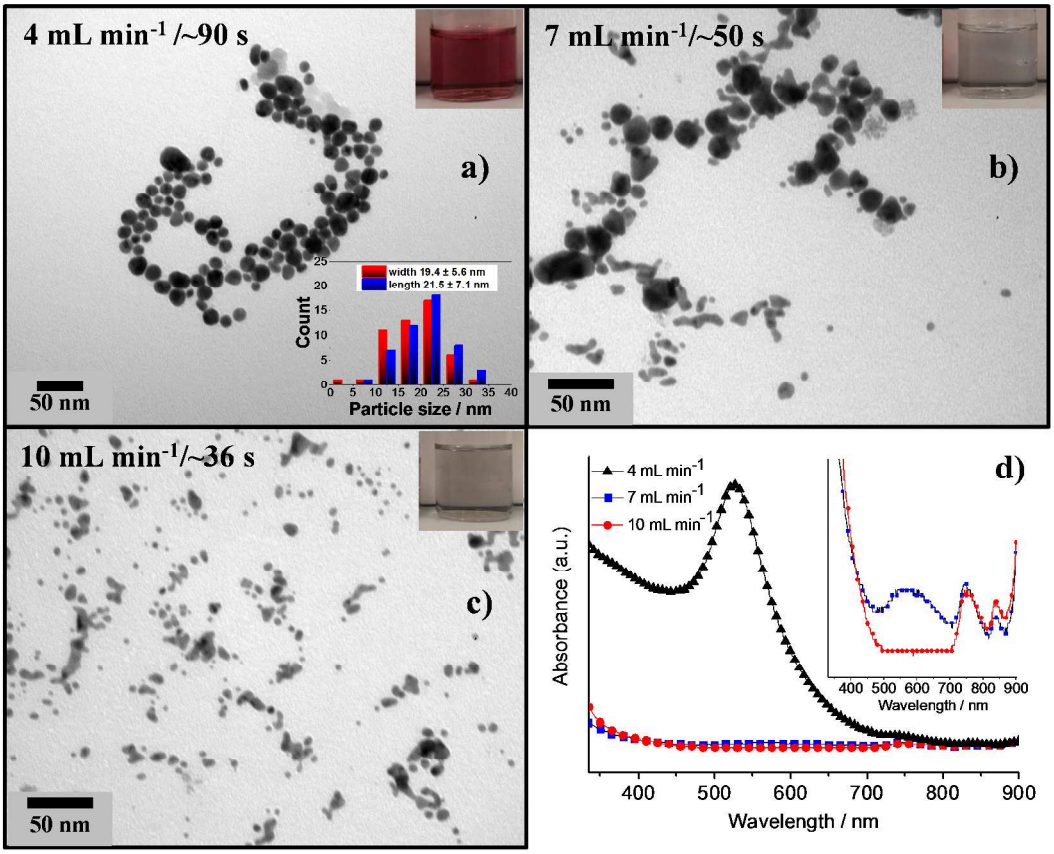


Figure S6 TEM images of the Au-NPs synthesized under constant MWP of 36 W, [60Cit]/[1Au] and 20 psi back pressure by using **a**) 4 **b**) 7 and **c**) 10 mL min^{-1} flow rates. **d)** UV-vis spectra of the Au-NPs synthesized under the given conditions above. Insets: Photographs of the Au-NPs synthesized under **a**) 4 **b**) 7 and **c**) 10 mL min^{-1} flow rates. Photograph in **a** clearly shows the formation of Au-NPs ruby-red in colour. Photographs in **b** and **c** show a grey solution although TEM analysis displays some Au-NP formation. Inset in **a** shows the mean particle length/width and the standard deviations in size of the Au-NPs synthesized using 4 mL min^{-1} flow rate. Inset in **d** shows the enlarged UV-vis spectra of particles produced under the given conditions above. 90, 50 and 36 s correspond to the residence time at the given flow rates. It is worth noting that TEM samples for 7 and 10 mL min^{-1} were prepared by dropping fresh solution of obtained mixture (4×20 μL) on carbon coated TEM grids due to the low concentration of the produced Au-NPs.