Supporting Information for:

Polymerization-Induced Self-Assembly of Micelles Observed by Liquid Cell Transmission Electron Microscopy

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Other Supporting Information Materials for this manuscript include:
Movies S1 to S4
**Movie S1.** Automated sciTEM sample dispensing and top LCTEM chip placement. The sample solution is loaded into a 384 well microplate. The tip of the LCTEM holder is encased in a humidity chamber with warm water to prevent premature evaporation of dispensed liquid droplets. In this movie, two fluorescent solutions (for visual aid) are deposited onto a bottom LCTEM chip, which is already loaded into the tip of the liquid cell holder. Fiducial recognition for the placement of the top LCTEM chip is performed with a built-in camera system. The top LCTEM chip is picked up with a vacuum tip for placement onto the bottom chip after the sample had been dispensed. See **Figure S1** for more details.

**Movie S2.** Solution of spherical micelles pre-formed outside of the liquid cell under standard polymerization conditions, with an additional 150 equivalents of 2-hydroxypropyl methacrylate (HPMA) added to the solution prior to imaging by LCTEM. The solution was imaged at 200 keV at a 0.25 e/Å² s electron flux and 19,000× magnification. Playback is 3× real time. Total accumulative electron flux = 24 e/Å².

**Movie S3.** Growth of spherical micelles from a monomer solution by PISA. The solution contained HPMA and poly(ethylene glycol) macro-chain transfer agent (macroCTA, referred to herein as the trithiocarbonate macroCTA), and was continuously imaged at 200 keV at a 0.45 e/Å² s flux and 25,000× magnification. Sequential snapshots were taken over a 1 min 20 s period, each with a 1 s exposure time, and stitched together into a movie. Total accumulative electron flux = 36 e/Å².

**Movie S4.** Growth of particles with a “rough” morphology at a higher electron flux. The solution contained HPMA and trithiocarbonate macroCTA which had been polymerized to the micelle phase under standard conditions outside of the liquid cell, with an additional 150 equivalents of HPMA added to the solution prior to imaging by LCTEM. The solution was first imaged at 200 keV at a 0.24 e/Å² s electron flux and 19,000× magnification, then the magnification was increased to 50,000× at a ~7× higher electron flux of 1.7 e/Å² s. Playback is in real time. Total accumulative electron flux = 11 e/Å².

**EXPERIMENTAL SECTION**

**Materials.** Trioxane (> 99.5%, Acros Organics), deionized water ASTM Type II (DI water, Aqua Solutions, Inc.), poly(ethylene glycol) methyl ether (5000 g/mol, Aldrich), N,N-dicyclohexylcarbodiimide (DCC, 99%, Aldrich), 4-dimethylpyridine (DMAP, 99% Acros Organics) were used as received. 4-cyano-4-(dodecylthio)thiocarbonylthiopentanoic acid (CDTPA) chain transfer agent was synthesized according to previously published reports.¹ 2-hydroxypropyl methacrylate (HPMA, 98.8%, Electron
Microscopy Sciences) was filtered through basic alumina prior to use. \(O,O'\)-1,3-Propanediylbis(hydroxyamine•2HCl (crosslinker, > 99%, Sigma-Aldrich) was prepared as a 250 mg/mL deionized (DI) water solution immediately prior to use.

**\(^1\)H NMR spectroscopy.** \(^1\)H NMR spectroscopy was conducted on an Inova 500 MHz, 2 RF channel instrument at 25 °C. DMSO-d6 (Cambridge Isotopes Laboratories, Inc, 99.9%) solvent was used as received.

**Size exclusion chromatography.** Size exclusion chromatography (SEC) was performed in N,N-dimethylacetamide (DMAc) with 50 mM LiCl at 50 °C and a flow rate of 1.0 mL min\(^{-1}\) (Agilent isocratic pump, degasser, and autosampler, columns: Plgel 5 μm guard + two ViscoGel I-series G3078 mixed bed columns: molecular weight range 0-20 × 10\(^3\) and 1-100 × 10\(^4\) g mol\(^{-1}\)). Detection consisted of a Wyatt Optilab T-rEX refractive index detector operating at 658 nm and a Wyatt miniDAWN Treos light scattering detector operating at 659 nm. Absolute molecular weights and polydispersities were calculated using the Wyatt ASTRA software and 100% mass recovery methods. Prior to absolute molecular weight determination, unimer samples were purified via dialysis against DI water for 3 days (Spectra/Por 3 Dialysis Membranes (3500 Molecular weight cut-off (MWCO) from Spectrum Laboratories), and nanoparticle samples were purified via dialysis against DI water for 3 days using Spectra/Por Float-A-Lyzer G2 100k MWCO 5 mL tubes from Spectrum Labs before being isolated by freeze-drying.

**Poly(ethylene glycol) macro chain transfer (trithiocarbonate macroCTA) synthesis.** mPEG (2.00 g, 0.400 mmol), CDTPA (806 mg, 2.00 mmol), and DMAP (9.80 mg, 8.00 × 10\(^{-2}\) mmol) were dissolved in dry DCM (15 mL), purged with Ar for 30 min, and cooled to 0 °C. DCC (412 mg, 2.00 mmol) was added to the flask, and the solution was purged with Ar for 30 min. The solution was then allowed to warm to room temperature (ca. 3 h) and stirred for an additional 13 h. Subsequently, the flask was placed in a freezer at -20 °C for 24 h to precipitate the residual DCC salts. The salts were filtered off, and the polymer was precipitated 2× into cold diethyl ether.

**Dynamic light scattering (DLS).** Dynamic light scattering (DLS) analysis was performed with a Malvern Zetasizer Nano ZS (Model No. ZEN 3600, Malvern Instruments Ltd. Samples were diluted to 0.15 mg/mL directly following polymerization.

**Example HPMA PISA procedure.** Trithiocarbonate macroCTA (50.0 mg, 9.25 10\(^{-3}\) mmol) was added to a vial containing HPMA (0.519 mL, 533 mg, 3.70 mmol) and water (3.89 g). The reaction was purged with Ar for 15 min and placed under UV-irradiation. After 1 hour, the reaction was removed from the light source and quenched by exposure to air.

**HPMA PISA Kinetics.** Trithiocarbonate macroCTA (50.0 mg, 9.25 10\(^{-3}\) mmol) was added to a vial containing HPMA (0.519 mL, 533 mg, 3.70 mmol) and water (3.89 g). The solution was then split into 7 vials (0.6 mL each), and each vial was purged with Ar for 10 min. 6 vials were placed under UV
irradiation, with the seventh serving as a time 0 min. Every 10 min, a vial was removed from the light source and exposed to air, then analyzed by $^1$H NMR spectroscopy.

**Monitoring particle growth kinetics by DLS.** Trithiocarbonate macroCTA (100 mg, $1.85 \times 10^{-2}$ mmol) and HPMA (0.524 mL, 0.533 mg, 3.70 mmol) were dissolved in water (4.22 mL). The solution was added to a vial, sealed with a septum, and purged with Ar for 10 min. The reaction vessel was then UV-irradiated. After every 10 min of irradiation, 0.2 mL aliquots were taken from the solution in the vial, diluted 10× in water, and DLS measurements were taken.

**Standard polymerization to the micelle phase, prior to loading into a liquid cell for an LCTEM experiment.** Polymers were prepared as described outside of the liquid cell, under standard polymerization conditions, to a pre-defined degree of polymerization, then quenched by exposure to air. The solution was then purged with Ar for 15 min. An aliquot of this solution was transferred into a liquid cell for imaging.

**Dry-state transmission electron microscopy (TEM).** TEM samples were prepared by depositing small (4 μL) aliquots of sample onto TEM grids (Formvar stabilized with carbon (5–10 nm) on 400 copper mesh, Ted Pella Inc.) that had previously been glow discharged in a PELCO easiGlow glow discharge unit for 90 s. The sample grid was rinsed with three drops of water, then stained with a 1% uranyl acetate solution and rinsed with water. Excess solution was removed by blotting the edge of the grid with filter paper, then the grid was dried. TEM imaging was conducted on an HT-7700 TEM (Hitachi High Technologies America, Inc., Schaumber, IL USA) operated at 100 keV, and micrographs were recorded on an Orius SC1000A CCD camera (Gatan Inc., Pleasanton, CA, USA).

**Liquid cell transmission electron microscopy (LCTEM).** LCTEM chips (Hummingbird Scientific, Lacey, WA, USA) were freshly glow discharged using an Emitech K350 glow discharge unit and plasma-cleaned in an E.A. Fischione 1020 unit. Bottom LCTEM chips were plasma cleaned for 20 s, while top LCTEM chips were plasma cleaned for 60 s prior to automated sample deposition and liquid cell assembly. Samples were deposited onto the bottom chip ~1 hr after plasma cleaning. LCTEM imaging was performed on an FEI Sphera microscope (FEI, Hillsboro, OR, USA) operated at 200 keV with a Hummingbird Scientific Liquid Flow TEM Holder (Hummingbird Scientific, Lacey, WA, USA). Micrographs were recorded on a 2k x 2k Gatan UltraScan CCD camera (Gatan Inc., Pleasanton, CA, USA) using Gatan Digital Micrograph image acquisition software (Roper Technologies, Sarasota, FL).

The electron flux used in LCTEM experiments was calculated using the beam current measured by the phosphorus screen of the TEM through vacuum and the beam diameter used at each magnification. The TEM camera was operating in continuous imaging mode with a 1 s exposure time.

**Automated sample deposition and chip placement for LCTEM.** The vial of sample solution was briefly opened to air to allow for mild oxygenation, then loaded into a sciTEM (SCIENCE AG,
Berlin, Germany) for dispensing onto a bottom LC TEM chip that had been plasma cleaned ~1 hr beforehand (to promote particle mobility within the liquid cell). Sample deposition was performed with a sciTEM. Automated placement of a freshly plasma-cleaned top chip was performed with a sciTEM. See Figure S4 for schematic of sciTEM setup for automated sample deposition and LC TEM chip placement.

**Automated Particle Tracking.** An automated particle tracking algorithm was developed and applied to the raw LC TEM videos to automatically track individual particles for each video frame. The automated algorithm first detects potential particles per each image frame using our background subtraction (BS) algorithm; see Figure S7 for illustrative outcomes. The detections are associated over time frames based on the spatial proximity and geometrical similarities of the detected particles using our automated multi-object tracking analysis (MOTA) algorithm. During the process, most faulty detections are filtered out, and mis-detected particles are additionally identified to improve the accuracy of analysis. See Figure S8 for an illustrative outcome of the MOTA. Let i denote the index number for denoting the identity of a particle, and let t denote the time index. The main output of the tracking algorithm is the silhouette image of particle i observed at time t in the form of a set of all image pixel locations interior the particle, \( \left\{ (x_n^{(i,t)}, y_n^{(i,t)}) ; n = 1, \ldots, N_{tx} \right\} \). Let \( X_{rt} \) denote the \( N_{tx} \times 2 \) matrix of the pixel locations. We computed the spatial location of the particle by taking the column mean of the matrix, and computed the diameter of the particle by averaging the range of \( X_{rt} \) over different projection angles \( v \).
Figure S1. Experimental setup for sciTEM-enabled automated sample deposition. (a) Picture of nozzles in the sciTEM. The two nozzles on the right contain piezoelectric-actuated glass tips for dispensing liquid samples. The leftmost nozzle contains a vacuum tip for “picking up” an upside-down top LCTEM chip and “placing” it directly onto a bottom LCTEM chip through fiducial recognition. Fiducial recognition (indicated by black arrows) of the top corners of the highly reflective bottom (b) and top (c) chips before liquid cell assembly. The sciTEM uses the fiducials to determine x,y positioning of each chip for perfect overlay of the top and bottom chips, using the vacuum tip, after sample deposition. Blue arrows in (b) and (c) mark the location of the silicon nitride windows of each LCTEM chip. (d) Example picture of top LCTEM chip (blue arrow) and bottom LCTEM chip (white arrow) overlay after automated top chip placement to form a liquid cell.
Figure S2. Dynamic light scattering (DLS) traces for HPMA polymerization under standard conditions, where the increases in hydrodynamic radius ($D_h$) are indicative of a PISA process. The degree of polymerization (DP) shown for each DLS trace was determined through HPMA monomer conversion by $^1$H NMR.
Figure S3. (a) HPMA polymerization kinetics and relative conversion monitored by $^1$H NMR and (b) SEC plots following HPMA polymerization under standard conditions.
**Figure S4.** Particle growth kinetics under standard polymerization conditions monitored by DLS. The extent of HPMA monomer conversion at 50 mins (62%) via $^1$H NMR spectroscopy.
Figure S5. (a) Initiation steps for the RAFT polymerization of HPMA to produce diblock copolymers under 365 nm ultraviolet irradiation and (b) proposed initiation steps for RAFT polymerization of HPMA under electron irradiation within the TEM during an LCTEM experiment.
Discussion on expected concentrations of radicals formed through TEM radiolysis. The electron flux used for imaging in these studies was in the range of 0.5 e/Å²s, corresponding to \(-20 \times 10^5\) Gy/s when the total stopping power of water irradiated at 200 keV is accounted for. The radicals and other molecular species generated from the radiolysis of water can be described as:

\[
\text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ , \text{OH}^* , e^-_{\text{aq}} , \text{H}^* , \text{OH}^- , \text{H}_2\text{O}_2 , \text{H}_2 , \text{HO}_2
\]

in descending order of rate of generation per 100 keV of energy. To control the chemistry occurring within the liquid cell, we wanted to ensure that the concentration of radicals formed through the cleavage of thiocarbonylthio molecules is significantly higher than any radicals formed from water radiolysis, while maintaining our ability to perform PISA. At the electron flux used for the experiments described herein, under a 300 keV accelerating voltage, the expected predominant radiolysis species generated from the solvent, H\(_2\)O\(_2\) and H\(_2\), can be loosely estimated at steady-state concentrations of \(~5\times10^{-5}\) M in the irradiated region of the liquid cell. Similarly, radicals generated from the radiolysis of water can be estimated at orders of magnitude lower steady-state concentrations (e.g., OH\(^*\) at a steady-state concentration of \(~1\times10^{-6}\) M, and e\(_{\text{aq}}\) at a steady-state concentration of \(~5\times10^{-8}\) M). However, the concentration of the thiocarbonylthio molecules in solution, and within the irradiated region of the liquid cell, during LCTEM experiments was \(~2.4\times10^{-3}\) M. If we assume that all thiocarbonylthio molecules within an irradiated region of the liquid cell have equal probability of beam-induced cleavage, and all cleave rapidly upon irradiation, then the concentration of radicals derived from the thiocarbonylthio molecules is also expected to be \(~2.4\times10^{-3}\) M, which is significantly greater than the concentration of any solvent radiolysis product. Additionally, all sample solutions were briefly opened to the air before automated loading into the liquid cell, to both slow down polymerization kinetics and to introduce molecular scavengers to potentially scavenge OH\(^*\) radicals and e\(_{\text{aq}}\). Thus, radical polymerization which occurs should result primarily from cleavage of the thiocarbonylthio molecules.
Automated LCTEM sample deposition and chip placement. It is standard practice that liquid cells for LCTEM experiments are set up by manually pipetting small volumes (e.g. 1 µL) of sample solution onto an LCTEM chip (the bottom chip), followed by assembly into a liquid cell by placing a top chip, or cover chip, and aligning the viewing windows by hand. By this method, we were unable to observe micelle formation due to insufficient contrast against the background—the thick solvent layer. A robotic system, the sciTEM, generates a consistently thin liquid layer between liquid cell chips. A consistent and thin liquid cell is desirable in these experiments to minimize background scattering from the solvent and for reproducibility of the experiment overall. This was accomplished by integrating an automated pick-and-place tool on the picoliter pipetting robot for assembling the liquid cell after dispensing samples such that the viewing windows of each chip are aligned robotically utilizing automated recognition with a mounted camera. This approach minimizes manual manipulation, decreasing the potential for contamination (Movie S1). The design of the dispensed array was empirically optimized so that upon placement of a cover chip, or top chip, no air bubbles were trapped during liquid cell assembly, and liquid cell dehydration is prevented during imaging within the TEM.
Figure S6. (a-d) Sequential images taken during an LCTEM experiment of a solution of micelles that were initially formed outside of the microscope from HPMA and trithiocarbonate macroCTA, with an extra 150 equivalents of HPMA added prior to imaging. The solution was continuously irradiated at 0.25 e⁻/Å²s for 2 min. Insets are zoomed-in images of the particles boxed with the corresponding color. Scale bars of insets = 20 nm.
Figure S7. Control experiment for radical polymerization during an LCTEM experiment of a solution containing HPMA only (no trithiocarbonate macroCTA). The sciTEM was utilized for liquid cell preparation. Solution was continuously irradiated with the electron beam for an extended period of time (>10 min) at relevant electron fluxes, where $t = 0$ is when the irradiated region was first exposed to the electron beam. (a-f) Images taken of the solution when continuously irradiated at 0.57 e/Å², during which no structures were observed to form. We hypothesize that the electron beam at this flux is not of high enough energy to induce radical formation on the vinyl bond of HPMA, whereas the macroCTA is more prone to beam-induced fission resulting in radical formation and therefore polymerization. (g) Image taken of the solution 10 s after the electron flux had been increased to 1.0 e/Å² by increasing the
magnification. Image taken of the solution immediately after (h) and 1 min after (i) the electron flux had been increased to 2.7 e/Å². No structures were observed to form at any time point.
Figure S8. Control experiment for radical polymerization during an LCTEM experiment of a solution containing trithiocarbonate macroCTA only (no HPMA). The sciTEM was utilized for liquid cell preparation. Solution was continuously irradiated with the electron beam for an extended period of time (>10 min) at relevant electron fluxes. (a) Image taken of the solution 15 s after the region began to be continuously irradiated at 0.57 e/Å². (b) Image taken of the solution after the electron flux had been increased to 0.7 e/Å² by increasing the magnification. Image taken of the solution (c) 15 s after and (d) 1 min, 30 s after the electron flux had been increased to 1.7 e/Å². No structures were observed to form at any time point.
Figure S9. Example of background subtraction (BS) algorithm applied to a raw image (a) taken during an LCTEM experiment of a solution of HPMA and trithiocarbonate macroCTA that had been continuously irradiated with the electron beam, when particle contrast against the solvent background is minimal. (b) BS background estimate, (c) BS foreground estimate, and (d) BS particle detection.
Figure S10. Tracking micelle growth during polymerization-induced self-assembly (PISA) by Multi-Object Tracking Analysis (MOTA) when a solution of HPMA and macroCTA is continuously irradiated with the electron beam for 1 min. (a-g) Image time series from Movie S2 of a solution of HPMA and macroCTA. The solution was continuously imaged at a 0.45 e/Å²s flux and 25,000× magnification. A multi-object tracking algorithm was applied to the LCTEM images for particle detection and growth. Particles are circled and numbered in each frame. (h) Growth profile of micelle diameters, where each time point represents when an image of the sample was acquired.
Figure S11. Full image sequence for Figure 3 micelle growth tracking analysis, with additional images taken at intermediate time points. (a-g) A series of images acquired over 5 min during the irradiation of a monomer solution of HPMA and macroCTA. For LCTEM imaging, the solution was “pulsed” with the electron beam for a 2 s exposure, then the beam was turned off for 30 s. This process was repeated for 5 min. The solution was imaged at a 0.45 e/Å² s flux and 25,000× magnification. A multi-object tracking algorithm was applied to the images to detect particle locations and diameters.
Determining the beam tolerance of formed micelles. A solution of HPMA and PEG macro-CTA micelles which had been pre-polymerized ex situ was initially imaged at low electron fluxes (0.16 e/Å² s; 6,500× magnification), then the magnification was increased to 50,000× (1.7 e/Å² s) to see if higher flux conditions affect micelle nucleation and growth, or perhaps damages fully-formed structures. At lower electron fluxes, micelles were observed in solution (Figure S12 a). When the flux was increased ~10× by increasing the magnification, micelles which had been previously attached to the window began growing quickly in size, gained significant contrast, and developed a rough morphology, as compared to smooth surfaces of typical spherical micelles (Figure S12 c-e). Other particles with the same roughness, which had previously been floating in the solution of the liquid cell, adhered to the surface during imaging. As the magnification was lowered, the particles remained adhered to the surface (Figure S12 f). When the beam was relocated to a fresh, non-irradiated region of the liquid cell, the process was repeated with the same result. From this, we hypothesize that micelle growth under high dose conditions forms particles with rough morphology either due to (1) induced beam damage or (2) the formation of pathway-dependent structures. Because the rate of particle growth increased during high-dose imaging, it appears that particle formation rates are affected by the dose rate, and, with fast polymerization kinetics, structures cannot equilibrate and instead form altered morphologies.
Figure S12. Additional LCTEM imaging of a solution of HPMA and macroCTA which had been polymerized to the spherical micelle phase under standard PISA conditions, outside of the liquid cell, with an additional 150 equivalents of HPMA monomer added to the solution prior to imaging by LCTEM. A liquid cell containing this solution was placed in the TEM and imaged at an electron flux of 0.2 e/Å²s (a) and 0.5 e/Å²s (b). At these electron fluxes, particles were observed to attach to and detach from the window of the liquid cell. (c-e) Images of the region boxed in (b) acquired after the magnification was increased to 50,000× (electron flux = 1.7 e/Å²s). Particles with “rough” morphologies appeared to grow at a rate faster than observed for the systems irradiated under low electron flux conditions. (f) Zoomed-out image of the region after high flux irradiation. Particles stopped increasing in size once the electron flux was decreased.
**Figure S13.** Snapshots from Movie S4 of a solution of HPMA and macroCTA which was polymerized to the spherical micelle phase under standard conditions, outside of the liquid cell, with an additional 150 equivalents of HPMA added to the solution prior to imaging. (a) and (b) Images taken of the monomer solution at a low electron flux (0.24 e/Å²s electron flux, 19,000× magnification). (c) and (d) Rapid growth of colloidal structures with “rough” morphologies in the same region of the liquid cell after the electron flux was increased to 1.7 e/Å²s by increasing the magnification to 50,000×.
REFERENCES

1. Lai, J. T.; Filla, D.; Shea, R. *Macromolecules*. **2002**, *35*, 6754–6756.

2. Patterson, J. P.; Abellan, P.; Denny, M. S.; Park, C.; Browning, N. D.; Cohen, S. M.; Evans, J. E.; Gianneschi, N. C. Observing the Growth of Metal–Organic Frameworks by in Situ Liquid Cell Transmission Electron Microscopy. *J. Am. Chem. Soc.* **2015**, *137*, 7322–7328.

3. Vo, G.; Park, C. Robust Regression For Image Binarization Under Heavy Noises and Nonuniform Background. *http://arxiv.org/abs/1609.08078* 2017, 1–32.

4. Park, C., Woehl, T. J., Evans, J. E., and Browning, N. D. IEEE Transactions on Pattern Analysis and Machine Intelligence. **2015**, 37 (3), 611-624.

5. Berger, M. J.; Coursey, J. S.; Zucker, M. A.; Chang, J. Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions | NIST https://www.nist.gov/pml/stopping-power-range-tables-electrons-protons-and-helium-ions (accessed Jan 14, 2016).

6. Allen, A.O. The Radiation Chemistry of Water and Aqueous Solutions. VanNostrand, New York, 1961.

7. Woehl, T. J., Abellan, P. Defining the radiation chemistry during liquid cell electron microscopy to enable visualization of nanomaterial growth and degradation dynamics. *J. Microscopy*. **2017**, 265 (2), 135-147.

8. Schneider, N. M.; Norton, M. M.; Mendel, B. J.; Grogan, J. M.; Ross, F. M.; Bau, H. H. Electron-Water Interactions and Implications for Liquid Cell Electron Microscopy. *J. Phys. Chem. C*. **2014**, *118*, 22373–22382.