2023

Fourth Quarter

PTC Newsletter

Polymer Technology Consortia

UPCOMING EVENTS

Mark Your Calendars for the PTC Fall meetings!

Scratch Behavior of Polymers Consortium-SCRATCH

SCRATCH SPRING meeting-March 21st, 2024
Texas A&M University-College Station, TX

Polymer Technology Industrial Consortium-PTIC

PTIC SPRING meeting-March 21st & 22nd, 2024
Texas A&M University-College Station, TX

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PTC, TAMU News & SPE Student Chapter

Single-digit micrometer resolution, and multi-material high-speed 3D printing technologies for soft materials

Hsiao Research Group

Dr. Kaiwen Hsiao is starting as an assistant professor in the Department of Materials Science and Engineering Department at Texas A&M University in January 2024. Her research interests focus on exploring nanoscale molecular arrangement and their impact on soft-material performances for advanced additive manufacturing applications. Recent advances in healthcare and sustainability have accelerated the need to develop transformative manufacturing technologies that transition precise, molecularly assembled materials to scalable 3D architectures with optimal transport properties and molecular selectivity. However, a compromise between pattern resolution and print speed has rendered most high-resolution additive manufacturing technologies unscalable with limited applications. To address this challenge, innovative approaches at the intersection of additive manufacturing (AM), polymer physics, and non-Newtonian fluid dynamics to enable scalable fabrication of micron to nanoscale structures are critical for developing next generation biomedical and soft-electronics applications.

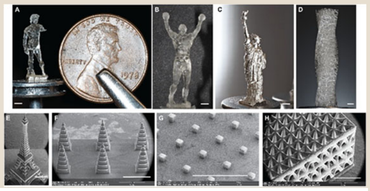

Figure 1. Demonstration prints from the single-digit-micrometer-resolution CLIP-based 3D printer.

The ability to form 3D structures with feature sizes in the microscopic length scale and hierarchical complexity in the macroscopic length scale offers powerful engineering design options for microsystem technologies where conventional planar architectures currently dominate. The three most prominent and common issues that render most AM technologies unscalable and difficult to compete with traditional lithography approaches are the layer artifacts that lead to mechanical anisotropy, reduced resolution, and slow build rates. During Dr. Hsiao postdoctoral research, she developed a high-resolution CLIP technology that allows the fabrication of 3D structures containing single-digit-micrometer features at a print speed that is 10^5 times faster than commercially available high-resolution 3D printers (Fig 1).

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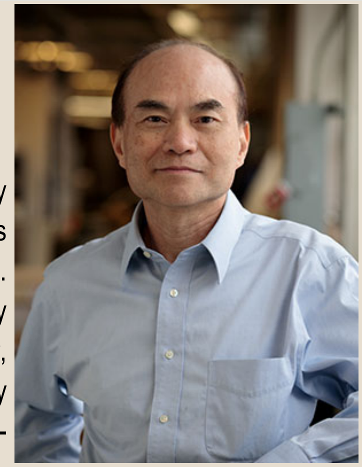
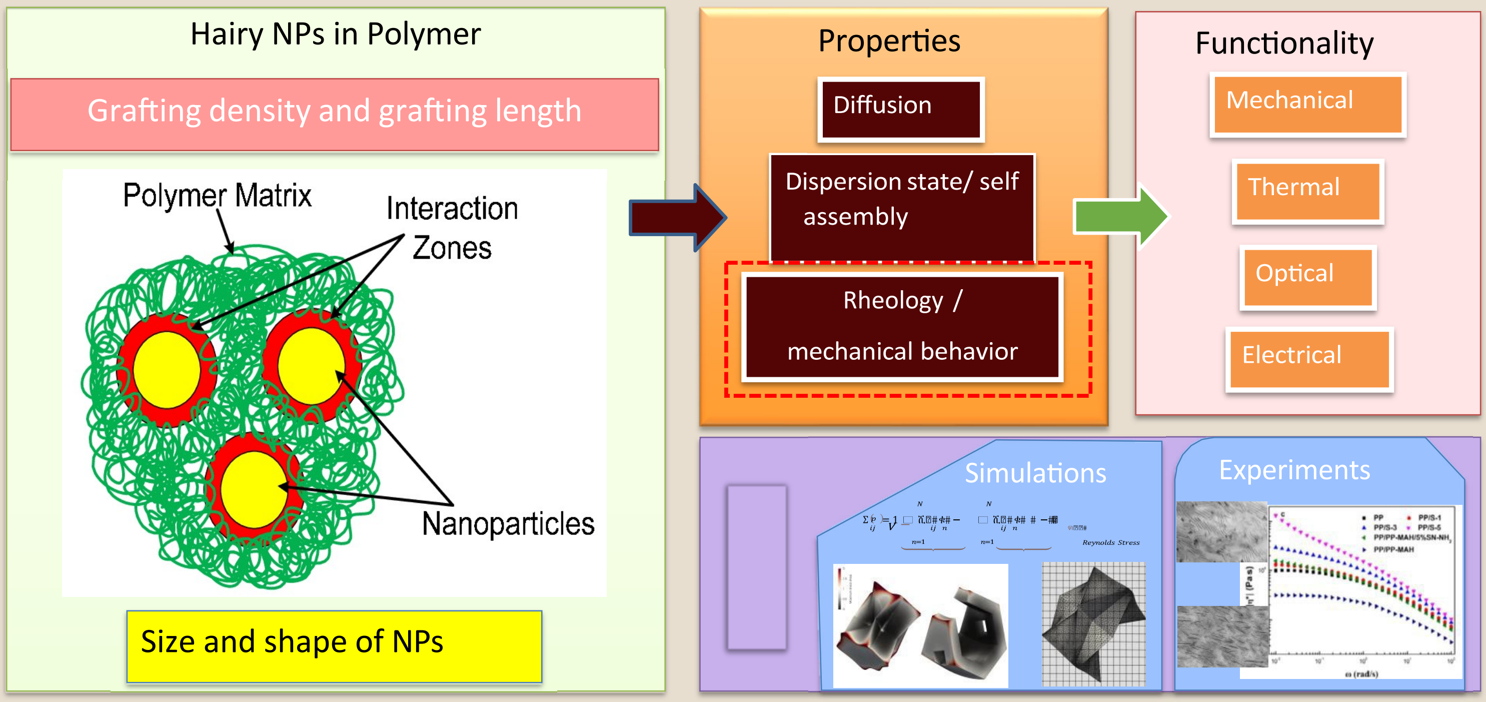
"Rheology of Polymer Melts with Designed Hairy Nanoparticles"

Hung-Jue Sue, MSEN



Professors I. Borazjani (MEEN) and H. -J. Sue (MSEN) have been awarded a grant to study the rheology of "hairy nanoparticles" that have polymer chains covalently bonded to the surface. The polymer chains were added to improve the dispersion of the nanoparticles in the host polymer and prevent aggregation. Such nanoparticles can dramatically improve properties, such as modulus and permeability, at relatively low loadings in comparison to conventional fillers. Hairy nanoparticles exhibit shear-thinning behavior, which is desirable for many applications. Polymer rheology is critical to the efficient production of quality articles, but unfortunately the understanding of the rheology of liquids containing nanoparticles is at a nascent stage.

In the scanning electron microscope (SEM) images below, non-dispersed 2D nanoparticles composed of zirconium phosphate (ZrP) with various aspect ratio are shown.



The objective of this work is to (1) experimentally investigate the rheology of nanocomposites with different hairy NPs; (2) develop and validate computational tools to simulate such suspensions; and (3) investigate the main reasons for the deviation from the theory, thereby pave the way to improve theoretical/simplified models for advanced manufacturing needs.

The working hypothesis is that the increase in graft density and length increases the shear thinning behavior while the non-spherical shape of the hairy nanoparticles (e.g., 2D NPs) increases the viscosity relative to spherical (0D) ones as the non-dimensional moment of inertia (around the vorticity direction of shear flow) and non-dimensional surface-to- volume increases when other conditions (such as volume fraction and Reynolds number) are similar.

Hsiao—Single-digit micrometer resolution, and multi-material high-speed 3D printing technologies for soft materials (Continues from page 1)

This is accomplished by combining the CLIP technology with a custom-designed projection optical lens and an in-line contrast-based focusing system. To maneuver the shallow depth of focus for a high-magnification objective lens, we developed a robust calibration platform to locate the optimal focal plane, thus resolving the fine details of the projected patterns with reproducibility (Fig 2).

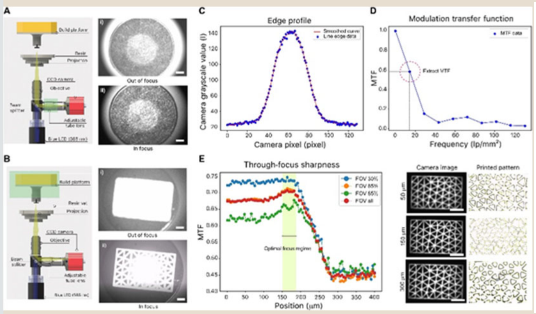
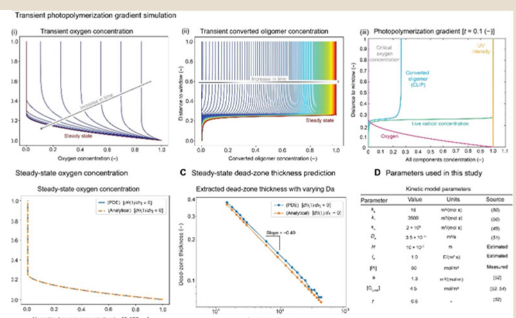


Figure 2. Contrast-based focus algorithm for optimization of the projection focal plane. (A) Focus on the build platform with strobe light by finely adjusting the tube lens (highlighted in green). (i) Build platform is out of focus; (ii) build platform is in focus. Scale bars, 2.5 mm. (B) Focus on a projected pattern by finely adjusting the vertical position of the build platform (highlighted in green). (i) Projected pattern on the build platform is out of focus; (ii) adjusted build platform brings the projected pattern into focus. Scale bars, 2.5 mm. (C) Edge profile of the projected pattern. (D) The calculated MTF of the edge profile. (E) Through-focus sharpness performance obtained from scanning near a rough estimation of the optimal focal plane of 400 μm. Best focal plane with the highest sharpness performance is found and compared with actual prints. The z position with the highest sharpness also has the best resolved 3D print. Scale bars, 1.0 mm.

To achieve an understanding of photopolymerization kinetics on print resolution and the impact of resin transport on print speed for our system, we have introduced a numerical model that considers all fundamental elements in our high-resolution 3D CLIP printing system, including optical projection, photopolymerization reaction kinetics, and resin mass transport. This model allows us to develop a printing strategy that uses the understanding of fundamental transport phenomena and determine print parameters for the printer software control system (Fig. 3). Aside from optimizing the print process, the model also provides fundamental insights into 3D CLIP printing in general, with accurate predictions of the surface finish of a printed part, dead-zone thickness, and resin curing during the 3D printing process.

Figure 3. CLIP printing process: Kinetics modeling. (A)Transient photopolymerization gradient simulation. (i) Transient oxygen concentration profile in the dead-zone regime. (ii) Transient converted oligomer concentration in the dead-zone regime. (iii) Concentration of all components in the dead-zone regime at t = 0.1 (−). (B) Steady-state oxygen concentration in the dead-zone regime for both the analytical expression and numerical solution from PDEs. (C) Dead-zone thickness at various values of the Damköhler number (Da) from both the analytical expression and the numerical solution of the PDEs. (D) Parameters used in this study.



In addition to working on enhancing resolution in high-speed AM technologies, during her postdoctoral research Dr. Hsiao also worked developing iCLIP (injection CLIP) technology. This work further accelerates printing speeds to 10-fold over CLIP printing methods, expands the accessible viscosity range of resin materials, and enables heterogeneous multi-material 3D printing capabilities. Detailed process parameters governing iCLIP are characterized (Fig. 4) and demonstrated with use cases including rapidly printing carbon nanotube–filled composites, multi-material features with length scales spanning several orders of magnitude, and lattices with tunable moduli and energy absorption (Fig. 5).

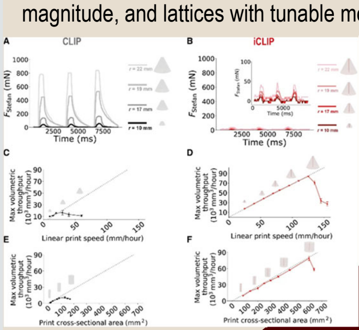


Figure 4. iCLIP accelerates printing of 3D geometries by alleviating suction forces.
(A and B) Experimental load cell force data measured for three consecutive layers, each of 3-s duration, while printing a conical geometry with varying cross-sectional areas by CLIP and iCLIP. (C to F) Quantified maximum print volumetric throughputs for two test geometries with varying cross-sectional areas, cone (C and D) and cylinder (E and F), by CLIP (left) and iCLIP (right). Gray dotted lines indicate delamination-free prints. Error bars denote ±1 SD from three independent print trials.

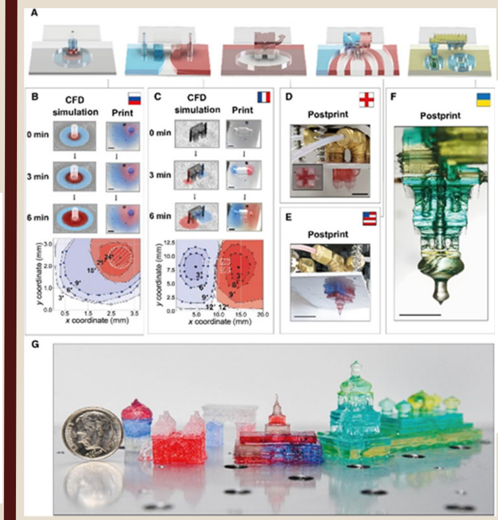
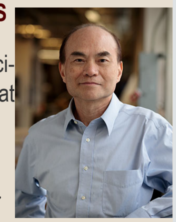


Figure 5. Experimental validation of multimaterial iCLIP print strategies.
(A) Vat resin distribution goals for multimaterial iCLIP printing flow control strategies. (B and C) For the St. Basil's Cathedral and Arc de Triomphe prints, respectively, CFD simulations of flow boundaries induced by injection (left) and images of the resin vat from beneath the window (right), with corresponding digitally extracted flow boundaries at varying time points following the onset of injection (bottom). (D to F) Multimaterial gradients in Westminster Abbey, Independence Hall, and St. Sophia's Cathedral prints, and (G) all tested models following iCLIP printing. Scale bars, 1 cm.

Materials Science & Engineering professor recognized by ACS



Dr. Hung-Jue Sue will be honored by the American Chemical Society for his collaborative research with industry professionals that improves the toughness of epoxy applications.

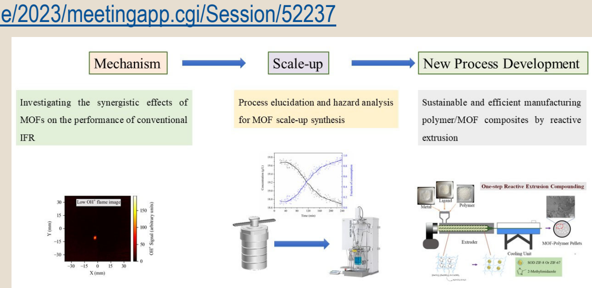
Collaboration between academia and industry researchers has many benefits, explained Dr. Mike Mullins, a retired senior research scientist from The Dow Chemical Company, and a nominator of the team.

"This is an excellent example of how universities and companies can work together to bring new products to market," Mullins said. "Successful partnerships are ones where each partner brings a skill the other needs. Academia needs market knowledge and manufacturing skills while companies need new ideas and technology."

Full story: **https://bitly.ws/WFda**

AICHE 8A Excellence in Graduate Research

Congratulations to Yufeng Quan, who has been selected for the AICHE 8A's Excellence in Graduate Student Research. He will present his research, *Efficient and Sustainable Manufacture of Polymeric Composites and Their Applications in Flame Retardancy*, at this November's AICHE national meeting in Orlando! This is for graduate students who demonstrate excellence in chemical engineering research in polymer science and engineering. https://aiche.confex.com/aiche/2023/meetingapp.cgi/Session/52237



PTC FACULTY		
Name	**E-mail Address**	**Office #**
Mustafa Akbulut, CHEN	makbulut@tamu.edu	979-847-8766
Amir Asadi, ENTC	amir.asadi@tamu.edu	979-458-7841
Perla Balbuena, CHEN	balbuena@tamu.edu	979-845-3375
Sarbajit Banerjee, CHEM	banerjee@@chem.tamu.edu	979-862-3102
Dave Bergbreiter, CHEM	bergbreiter@tamu.edu	979-845-3437
Janet Bluemel, CHEM	bluemel@tamu.edu	979-845-7749
Iman Borazjani, MEEN	iman@tamu.edu	979-458-5787
Tahir Cagin, MSEN	cagin@tamu.edu	979-862-1449
Homero Castaneda, MSEN	hcastaneda@tamu.edu	979-458-9844
Elena Castell-Perez, BAEN	ecastell@tamu.edu	979-862-7645
Terry Creasy, MSEN	tcreasy@tamu.edu	979-458-0118
Donald Darensbourg, CHEM	d-darensbourg@tamu.edu	979-845-5417
Yossef Elabd, CHEN	elabd@tamu.edu	979-845-7506
Lei Fang, CHEM	fang@chem.tamu.edu	979-845-3186
Micah Green, CHEN	micah.green@tamu.edu	979-862-1588
Melissa A. Grunlan, BMEN	mgrunlan@tamu.edu	979-845-2406
Pavan Kolluru, MSEN	pavan.kolluru@tamu.edu	979-458-6669
Helen Liang, MEEN	hliang@tamu.edu	979-862-2623
Jodie Lutkenhaus, CHEN	jodie.lutkenhaus@tamu.edu	979-845-3361
Anastasia Muliana, MEEN	amuliana@tamu.edu	979-458-3579
Mohammad Naraghi, AERO	naraghi@aero.tamu.edu	979-862-3323
Albert Patterson, ETID	Aepatterson5@tamu.edu	979-845-4953
Emily Pentzer, MSEN	emilypentzer@tamu.edu	979-458-6688
Matt Pharr, MEEN	mpharr85@tamu.edu	979-458-3114
Hung-Jue Sue, MSEN	hjsue@tamu.edu	979-845-5024
Svetlana A. Sukhishvili, MSEN	svetlana@tamu.edu	979-458-9840
Qing Tu, MSEN	qing.tu@tamu.edu	979-458-9353
Qingsheng Wang, CHEN	qwang@tamu.edu	979-845-9803
Shiren (Edward) Wang, INEN	s.wang@tamu.edu	979-458-2357
Taylor Ware, BMEN	Taylor.ware@tamu.edu	979-845-9374
John Whitcomb, AERO	whit@aero.tamu.edu	979-845-4006
Karen L. Wooley, CHEM	wooley@tamu.edu	979-845-4077
Joshua S. Yuan, PLPA	syuan@tamu.edu	979-845-3016

Texas A&M Ranked No. 1 University In The State By Wall Street Journal

Texas A&M University is one of the top institutions of higher education in the country, according to rankings recently published by *The Wall Street Journal.*

Texas A&M was ranked first in the Lone Star State and sixth in the nation among all public universities in the 2024 Best Colleges in the U.S. rankings published by *The Journal* in collaboration with College Pulse and Statista. Overall, Texas A&M was ranked 38th in the nation. All but one university in the top 20 are private colleges.

In Texas, A&M was followed by Rice University, which ranked 64th nationally; The University of Texas at Austin, which finished at 118 nationally; University of St. Thomas, at 158 nationally; and Southern Methodist University, at 175 on the national list.

Full story: **https://bitly.ws/UIPf**

SPE STUDENT CHAPTER officers for 2023-24		
President	**Cassidy Tibbetts, CHEM**	Cassidy.tibbetts@tamu.edu
VP Science	**Nicholas Starvaggi, CHEM**	n.c.starvaggi@tamu.edu
VP Engineering	**Christopher Evan Van Pelt, MSEN**	cvanpel@tamu.edu
Treasurer	**Shi-Guo Li, CHEM**	a860815a@tamu.edu
Secretary	**Ethan Iverson, CHEM**	eiverson@tamu.edu
Activity Coordinator	**Ashley Braaksma, CHEM**	abraaksma@tamu.edu
Publicity coordinator	**An Tran, CHEM**	hoaian_030498@tamu.edu
Webmaster	**Hsien Liang Cho, CHEM**	hlcho1001@tamu.edu

Polymer Specialty Certificate Updates	
Students that have applied for the Polymer Specialty Certificate	**87**
Students that have received the Polymer Specialty Certificate	**75**

For more information, please visit: http://ptc.tamu.edu/polymer-specialty-certificate/

Have Questions?

Dr. Hung-Jue Sue
PTC Director
E-mail: hjsue@tamu.edu

Isabel Cantu
E-mail: icantu@tamu.edu
Phone: 979-458-0918

PTC newsletter prepared by: Isabel Cantu

Edited by: Dr. Michael Mullins