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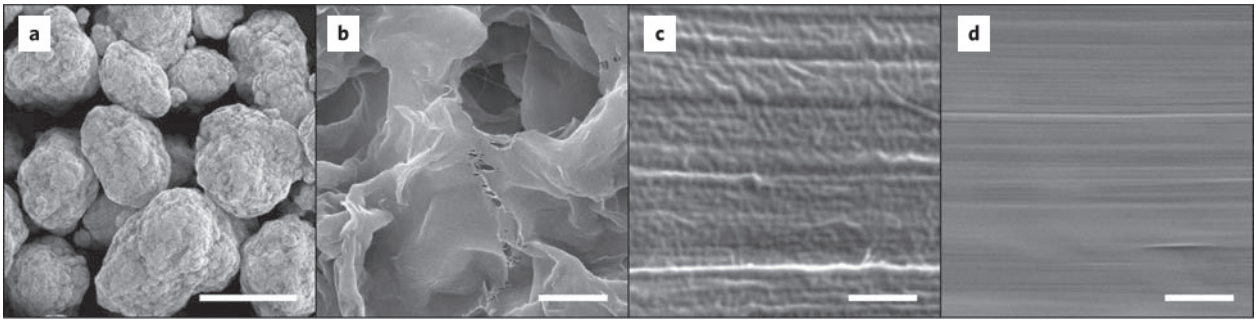
PRESS RELEASE

Continuous fabrication system for highly aligned polymer films provides method for tuning mechanical and thermal properties in bulk polymers

September 1, 2014 — Novel and scalable continuous fabrication process combining Couette flow extrusion and macroscopic plastic deformation results in ability to increase mechanical, thermal, and crystalline properties in bulk polymer films.



Sequence of scanning electron microscopy (SEM) images demonstrate drastic changes in polyethylene surface morphology resulting from the fabrication process. The initial polymer particulate material resembled tightly wound balls of string (a). Comparing this to the extruded sample (b), however, polymer disentanglement as a result of the high shear rate Couette-based extrusion process is evident. SEM images of 50× (c) and 100× (d) drawn films. As shown, film structure is uniform fiberous with minimal defects. Scale bar represents 100 microns (a), and 2 microns (b–d).

A team of researchers from the Massachusetts Institute of Technology (MIT) in Cambridge, MA have demonstrated a novel automated fabrication process consisting of a three-step sol-gel extrusion, structure freezing and drying, and mechanical drawing process which results in production of highly aligned polymer films. Alignment of molecular chains within polymers is a desirable trait for many applications as it results in superior mechanical and thermal properties in the polymeric materials. Although these highly aligned polymer films (HAPFs) are in demand, previous fabrication methods were limited to manual, lab-scale batch processes. This novel, scalable technology can enable deployment of low-cost and energy efficient polymer alternatives to traditionally used materials in heat transfer applications, such as electronic packaging and heat exchangers, with the additional advantages of energy savings, weight reduction, chemical resistance, and electrical insulation. The report appears in the September 2014 issue of the journal TECHNOLOGY.

"By taking advantage of the inherent high thermal conductivity of polymers' C-C bond, and a corresponding reduction in chain entanglements and defects, this process opens the door for transforming materials which are traditionally

considered thermal insulators into something that is ideal for use in heat transfer applications," says Professor Gang Chen, Ph.D., of the Massachusetts Institute of Technology and Principal Investigator on the paper.

While lab-scale fabrication processes have been successfully demonstrated, however, the investigators at MIT were able to solve the significant challenges which exist in terms of scaling and automated handling of the numerous process variables. In this work, improvement, or 'tuning' of the material properties, is achieved through manipulating the polymers' molecular chains first by disentanglement followed by macroscopic plastic deformation-induced alignment. This high throughput platform has three advantages over previous methods: (1) utilization of Couette flow for enhanced chain disentanglement; (2) constant-force adaptive-thickness mechanical drawing system aiding in uniform film production; and (3) an automated scalable platform — thus successfully demonstrating a desktop printer sized fabrication platform for HAPFs in a commercially attractive form factor.

Utilization of Couette flow produces a high degree of molecular chain disentanglement; liquid N_2 cooling freezes the disentangled structure in the extruded polymer gel; and the constant-force mechanical drawing leads to highly crystalline and uniform aligned final films. The platform was demonstrated using ultra-high molecular weight polyethylene, producing HAPFs with crystallinity >99% and lengths exceeding 15 meters. Molecular chain disentanglement has two crucial effects: (1) allows for plastic deformation to high draw ratios without film rupture, and (2) helps in subsequent molecular chain alignment for improved material properties.

While commercial-grade production systems for highly aligned polymer *fibers* are already in use (and address an existing mature commercial market), new opportunities for highly aligned polymers in a *film* form factor must be addressed. "This is a great example of a market-ready technology, which can supplement existing fabrication processes used for producing aligned polymer fibers. While fibers are ideal for textiles, however, for practical applications, such as fins in heat exchangers, casings for electronic systems, and biomedical treatments for improved cooling, a film (vice fibrous) form of these materials is essential. The difficulty lies in translating the remarkable material property enhancements seen in high performance *fibers* into a *film* form factor," says James Loomis, Ph.D., the lead author on this paper. "Furthermore, for widespread commercial implementation of these advanced materials, a scalable, continuous, and robust film manufacturing platform is needed."

The team from MIT is working now to further characterize structural changes in the polymers as a function of the draw ratio (amount of plastic deformation in the films), establishing relationships between varying molecular weights and realized material properties, and investigating orientation effects of highly aligned nanocarbon-polymer composites. Application of this technology towards composites which incorporate electrically conductive nanofillers presents an exciting new direction for commercial deployment of composites with tunable strength, and thermal conductivity, and electrical conductivity.

Additional co-authors of the TECHNOLOGY paper are Hadi Ghasemi, Ph.D., Xiaopeng Huang, Ph.D., Nagarajan Thoppey, Ph.D., Jianjian Wang, Jonathan K. Tong, Yanfei Xu, Ph.D., Xiaobo Li, Ph.D., and Cheng Te Lin, Ph.D., all from the NanoEngineering Group at the Massachusetts Institute of Technology.

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