Continuous Processing of High Thermal Conductivity Polyethylene Fibers and Sheets

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Project Objective

- Plastics are *less expensive, lighter, and require less energy to process than metals*; however, they have low thermal conductivity values (~0.3 W/mK)

- Thermal conductivity is an important consideration in choosing materials for *energy applications*

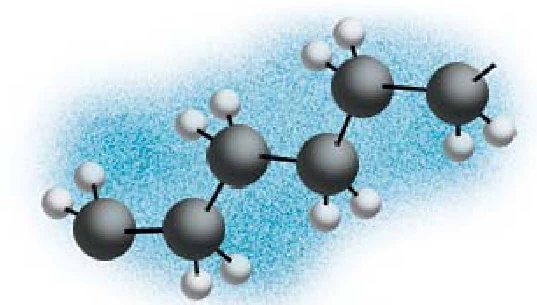
- We are developing a *continuous fabrication process* for high thermal conductivity polyethylene (PE) films

- While high thermal conductivity in (PE) has been shown in isolated nanofibers, real world commercial applications require a different form factor and fabrication process

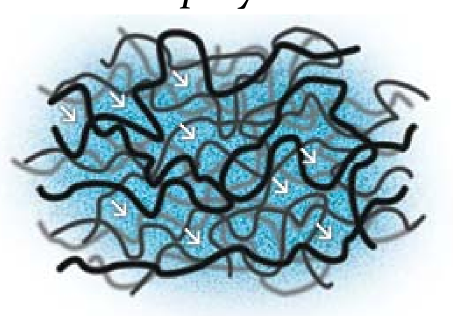
Technical Approach

- Concept:
  - A single extended polymer chain can have high thermal conductivity due to the C-C bond
  - In bulk polymers, however, due to entanglements and defects thermal conductivity drops significantly
  - We aim to fabricate a continuous film with high thermal conductivity by disentangling and aligning polymer chains
  - Successfully demonstrated in 100 nm single fibers (~100 W/mK)[1]

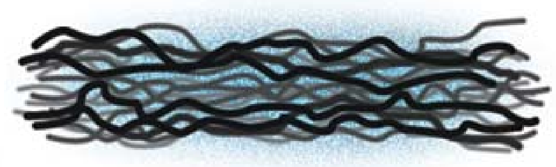
Polymer microstructure



Chain orientation in amorphous polymer



Chain orientation in drawn polymer

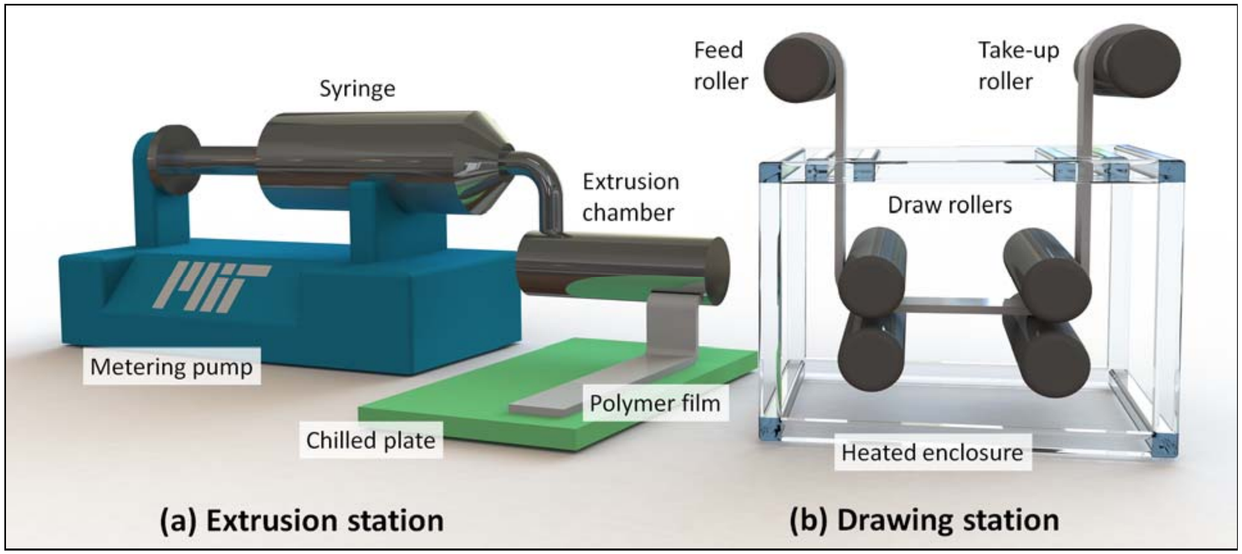


[1] S. Shen, A. Henry, J. Tong, R. Zheng, and G. Chen, Nat Nano **5,** (4), (2010).

PATENT PENDING

Technical Approach

- There are no commercially available pure polymers with high thermal conductivity
- We developed a 3-stage continuous fabrication process



- Thermal characterization:
  - ❑ We developed and built a custom system (based on the Angstrom method) to measure in-plane thermal conductivity

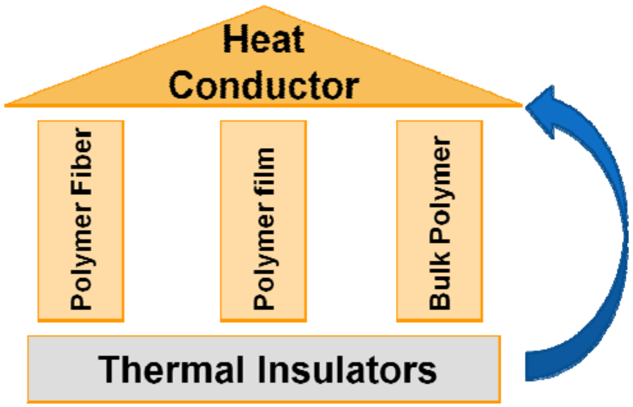
PATENT PENDING

Transition and Deployment

- **End users:**
  - Electronic packaging & thermal management
  - Heat exchangers, HVAC, etc.
  - We have held preliminary discussions with UTRC, and several companies working on various energy efficient devices
- **Mission/capability improvements:** Cost reduction, weight reduction, highly chemical resistant, bio-compatible, electrically isolating, and highly thermal conductive
- **Examples of usage:** Heat exchanger fins, wearable devices, and cases/housing for electronics, and cooling for stroke victims
  - Considering performance-based embodied energy as a FOM, UHMWPE fins in heat exchangers provide 4,126 MJ/KW; current Ti-based fins in seawater treatment are 6,483 MJ/KW (source ORNL)
- **Commercialization approach & technology sustainment model**
  - We are currently in TRL3
  - A technology sustainment study will be conducted in budget period 3

Measure of Success

- If you're successful, what difference will it make?



- What impact will success have: Breakthrough in heat management systems using innovative polymer plastic
- How will it be measured: High thermal conductivity, ease of synthesis, good chemically stability, cost/energy savings, and the potential for scale-up
- What is the potential energy impact? Economic impact?
  - ❑ Significant fabrication energy savings (compared to metal forming/working)
  - ❑ Polyethylene is also cheap and abundant

Project Management & Budget

- Project duration: 3 years
- Tasks and milestones: Quarterly milestone targets and annual go/no-go criteria

Budget Period	Go/no-go description	Verification method	Completion date
1	Development of 1st generation PE processing apparatus	Demonstrate PE sheets (1 × 5 cm^2) fabrication	Completed as of 10/01/13
2*	Development of 2nd generation PE processing apparatus	Achieve 30 W/m·K in the PE films	10/1/2014
3	Development of 3rd generation PE processing apparatus	Achieve 60 W/m·K in the PE films	10/1/2015
* Currently at ~21 W/mK			

Total Project Budget	
DOE Investment	$1M
Cost Share	$0
Project Total	$1M

Results and Accomplishments

- Project status: Developed a continuous platform for fabrication of polyethylene films with thermal conductivity of 21 W $m^{-1}K^{-1}$
- Provisional patent filed
- Completed milestones:
  - Commissioned/optimized an innovative fabrication platform
  - Modeled molecular structure of the films
  - Characterized thermal properties and microstructure of the films
- Results to report:
  - Developed polyethylene films with thermal conductivity of 21 W $m^{-1}K^{-1}$ (commercial films have thermal conductivity of ~0.3 $Wm^{-1}K^{-1}$)
- Future/ongoing work:
  - Achieve final thermal conductivity of 60 W $m^{-1}K^{-1}$
  - Modification/optimization of microstructure/chemistry/fabrication procedure of the films to reach the goal of the project