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

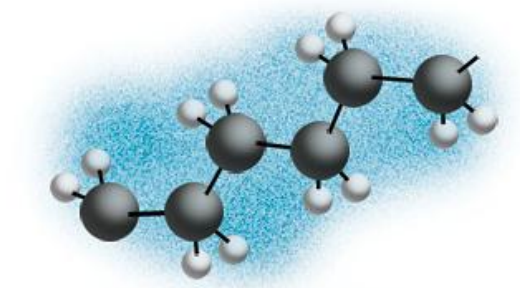
Technical Approach

No commercially available pure polymers with high thermal conductivity

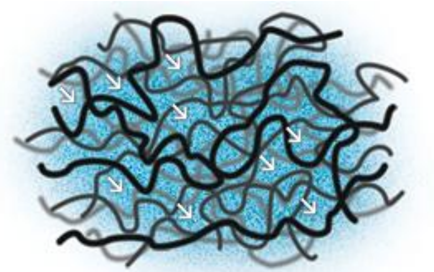
Concept:

- 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



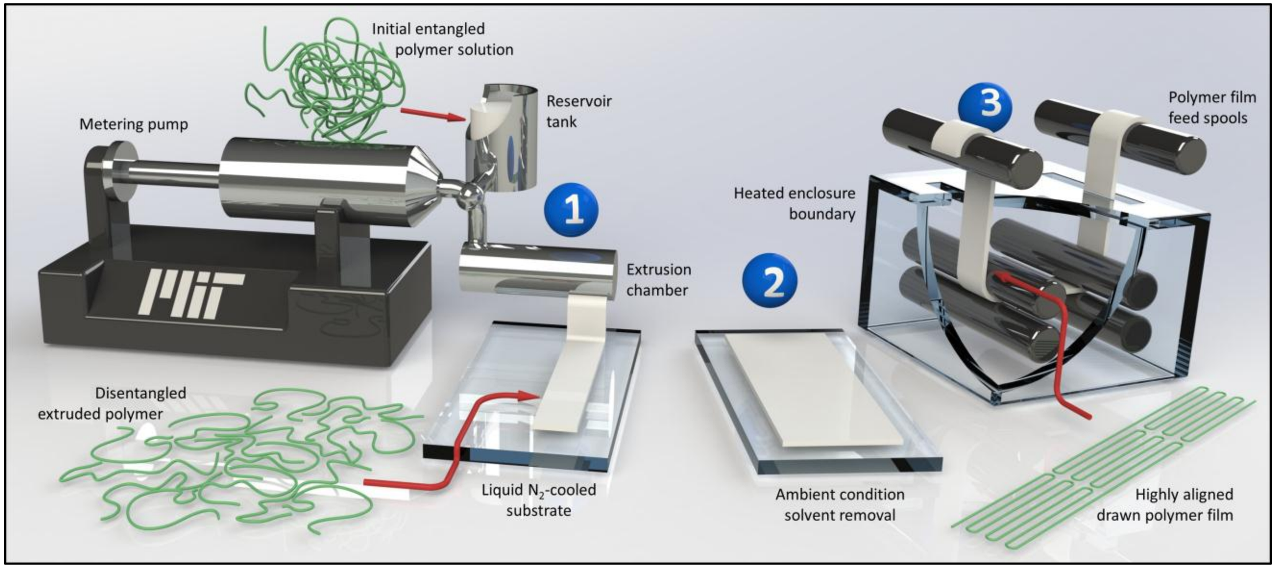
Chain orientation in drawn polymer

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

PATENT PENDING

Technical Approach

- We developed a 3-stage continuous fabrication process
- In BP2 incorporated mixed solvents, mixed PE polymers, 2nd generation fabrication platform to achieve higher draw ratios



- Thermal characterization:
  - ❑ Built custom systems (based on the Angstrom and steady-state methods) to measure in-plane thermal conductivity
  - ❑ Tested single layer films as well as instrumented laminated samples

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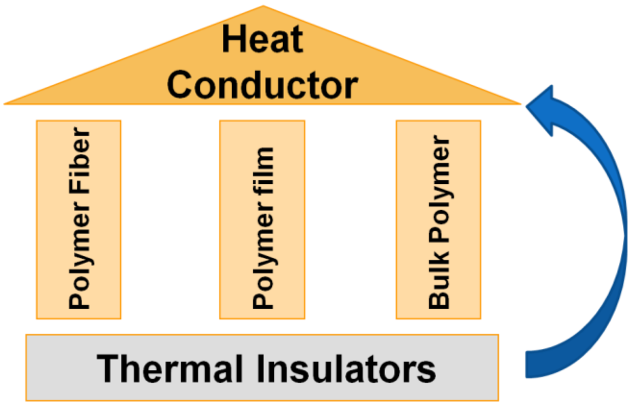
Transition and Deployment

- **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 thermally 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 sheet (1 × 5 cm^2) fabrication	Completed as of 10/1/13
2	Development of 2nd generation PE processing apparatus	Achieve 30 W/mK in the PE films	Completed as of 12/1/14
3*	Development of 3rd generation PE processing apparatus	Achieve 60 W/mK in the PE films	
*Currently at >40 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 (k) of >40 W $m^{-1}K^{-1}$
- Patent filed on fabrication system
- Completed milestones:
  - Commissioned/optimized 2nd generation innovative fabrication platform
  - Developed effective media model to predict the k of the ultradrawn films
  - Characterized thermal properties and microstructure of single layer and laminated films
- Results to report:
  - Demonstrated polyethylene films with thermal conductivity of >40 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