Aerospace Polymers are Shaping up

Structural and functional properties can go hand in hand

T. Dingemans, Faculty of Aerospace Engineering

^{13}Al

1933

1960

1969

^{22}Ti

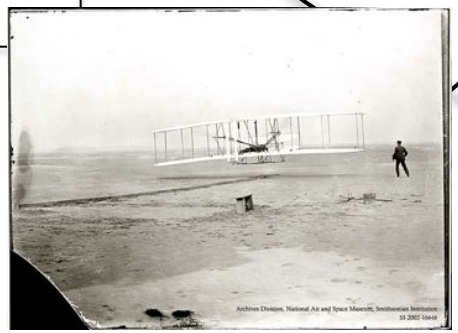
1983

2002

2005

^{13}Al

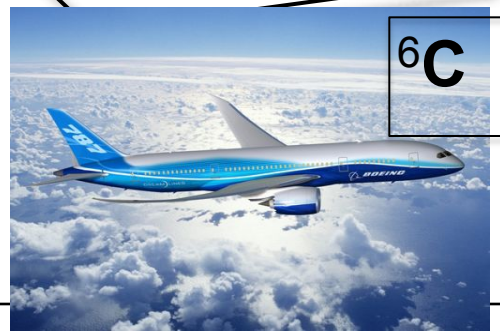
^{6}C



1903

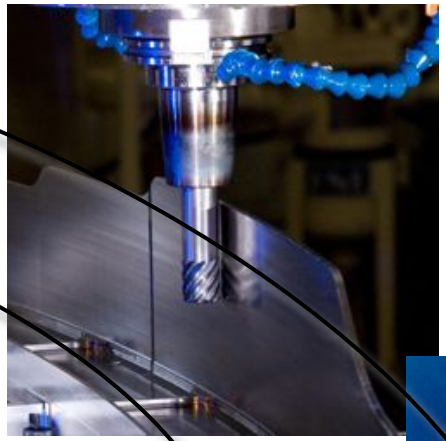
Wood

2009



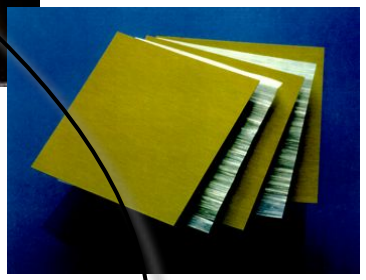
A closer look at the materials in use

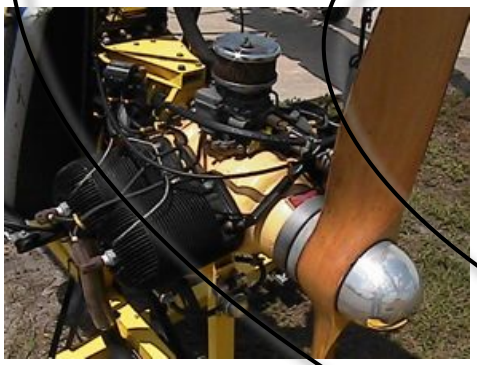
Titanium



Aluminum

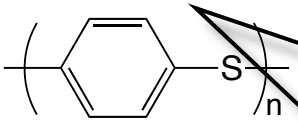
Aluminum glass polymer





Ceramic

Polymers

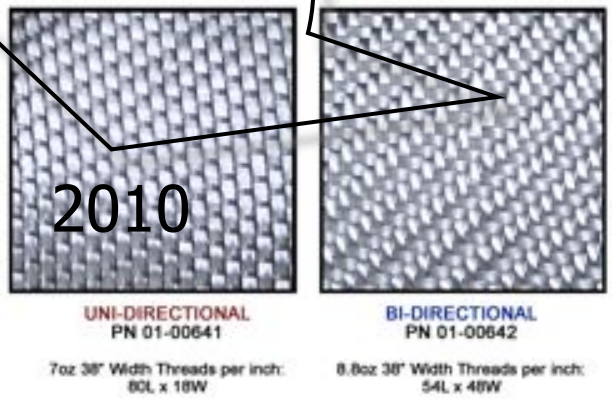


Steel and wood

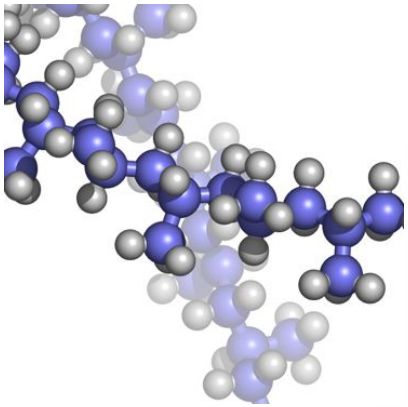
1903

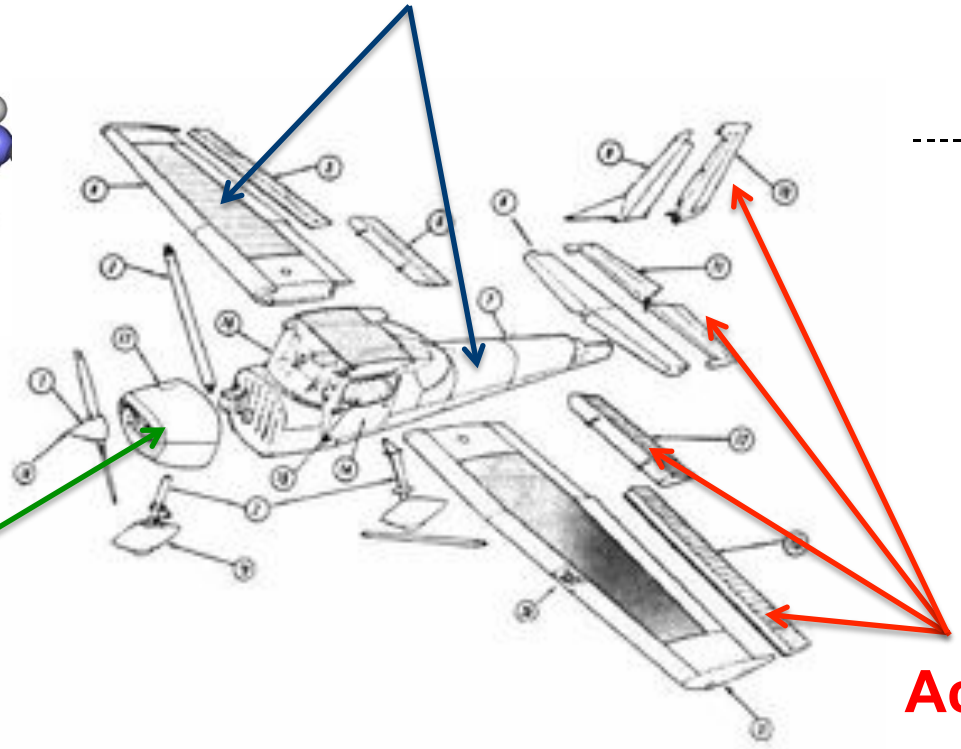
Carbon fiber

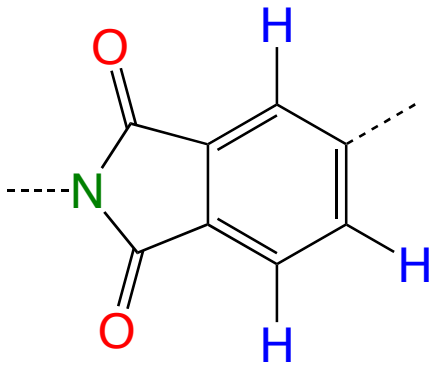
2010

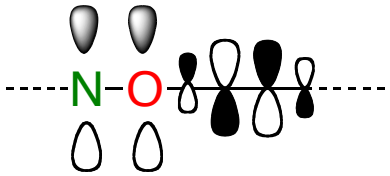


Can structural and functional go hand in hand?



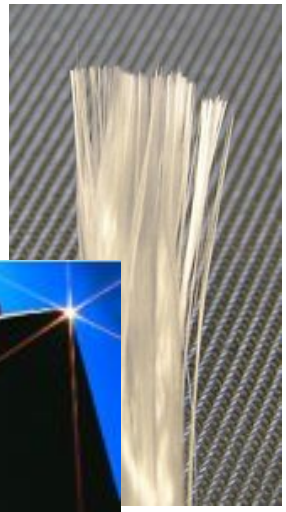


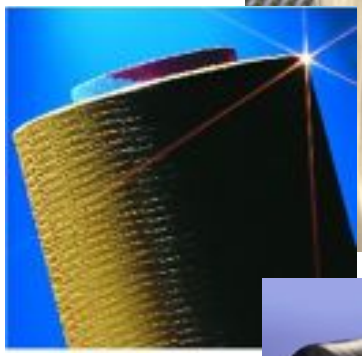


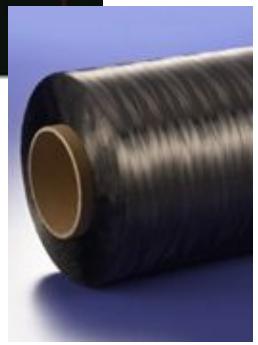


Research

The scientific challenges involved…







1-Structural polymers and composites:

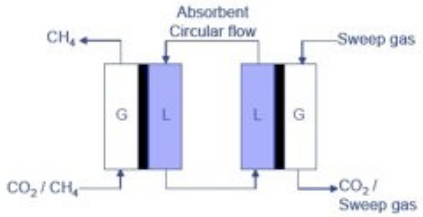
High strength and ***compression stable*** polymer fibers
Tune the ***Fiber-resin interface***
The role of nano reinforcement
In-situ health monitoring
Failure management –self healing

2-Structural polymers for energy generation and storage:

Li-ion batteries
Membranes for fuel-cells
Gas separation and fuel (H_2) storage
Polymer-based solar cells

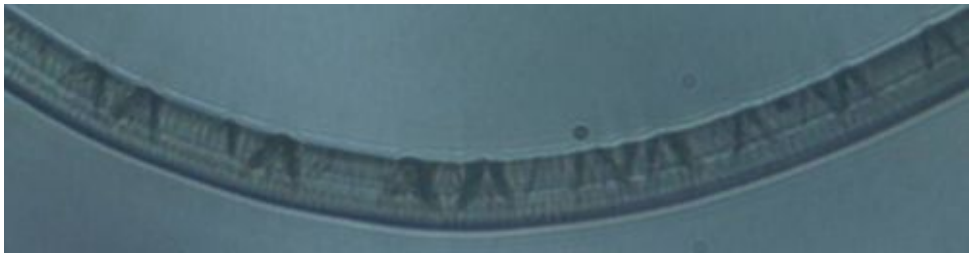
3-Structural polymers with actuating capabilities:

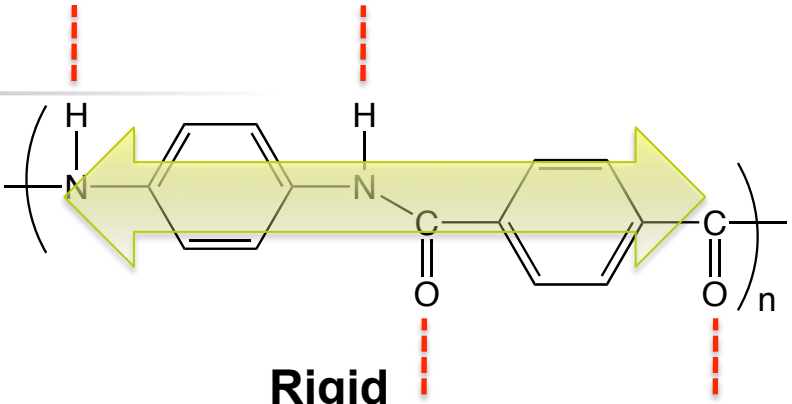
Shape memory polymers
Electro-active polymers
Morphing wing using light sensitive polymers



The fiber component…

From tension to compression



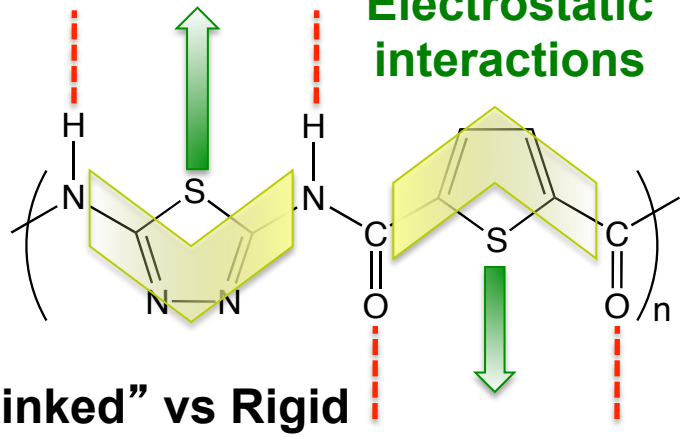


Rigid

H-bonding

H-bonding

Electrostatic interactions



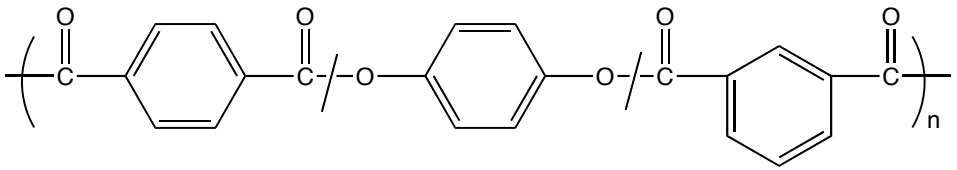
“kinked” vs Rigid

?

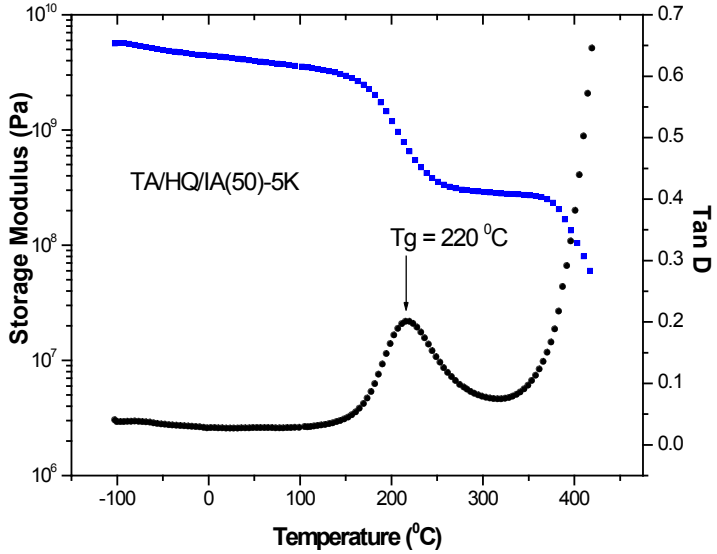
Fiber spinning

The resin component…

- High end-use temperature
- Chemical inert
- Good adhesion



TA/HQ/IA(50) Tm (K-N) = 315 °C

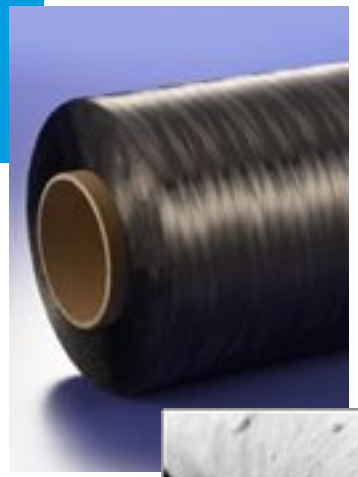


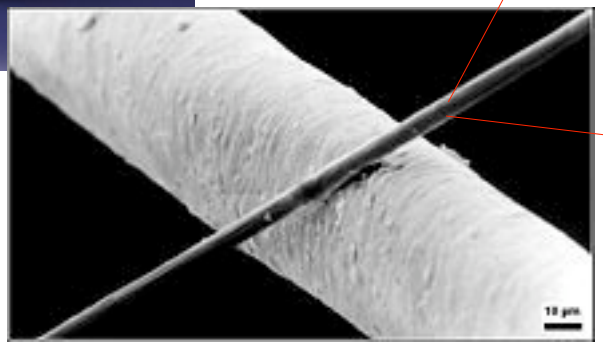
Sample	E′ (GPa) at 24 °C	E′ (GPa) at 100 °C	E′ (GPa) at 200 °C	T_g (°C)
TA/HQ/IA(50)-5K	4.2	3.5	1.2	220
PPS	2.9	-	-	94
Vectra	4.3	1.4	0.3	110

US Patent 6,939,940 (**2005**), US Patent 7,507,784 B2 (**2009**), *Macromolecules*, **2006**, *39(20)*, 6936.

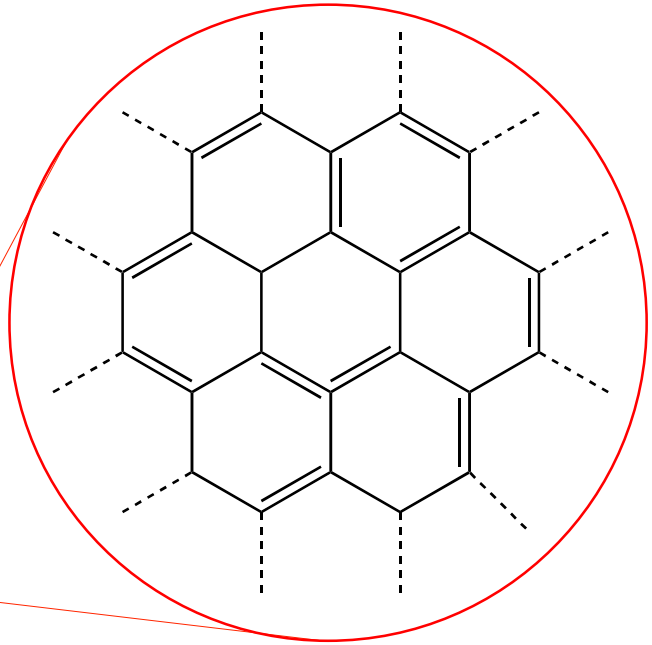
The resin fiber interface

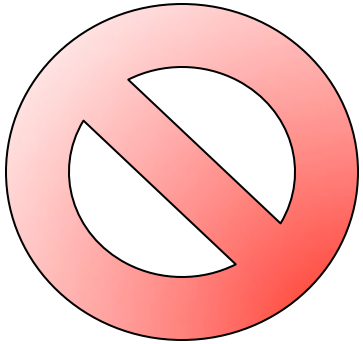
Finding matching chemistries…



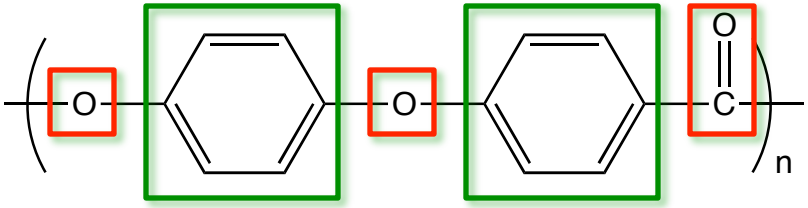


Carbon fiber on a human hair





~ 1 nm



The resin fiber interface

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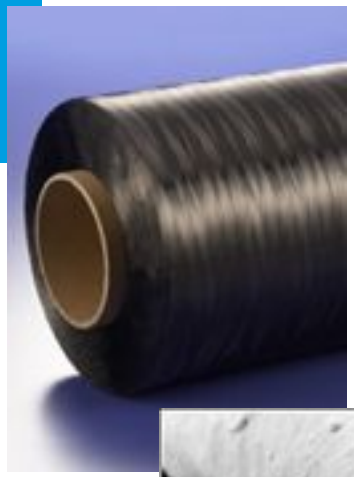
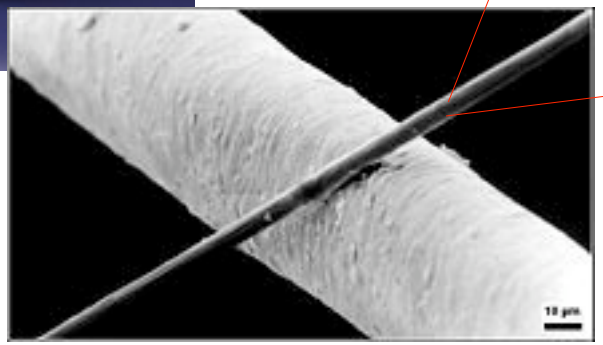
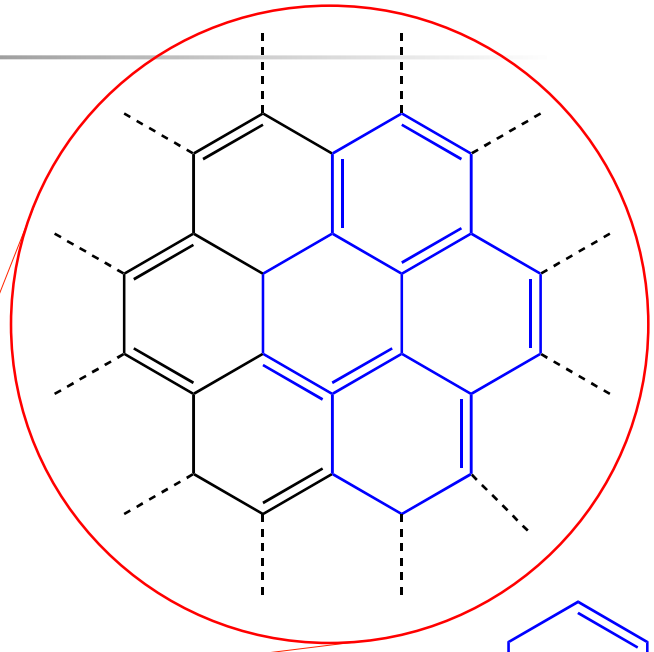
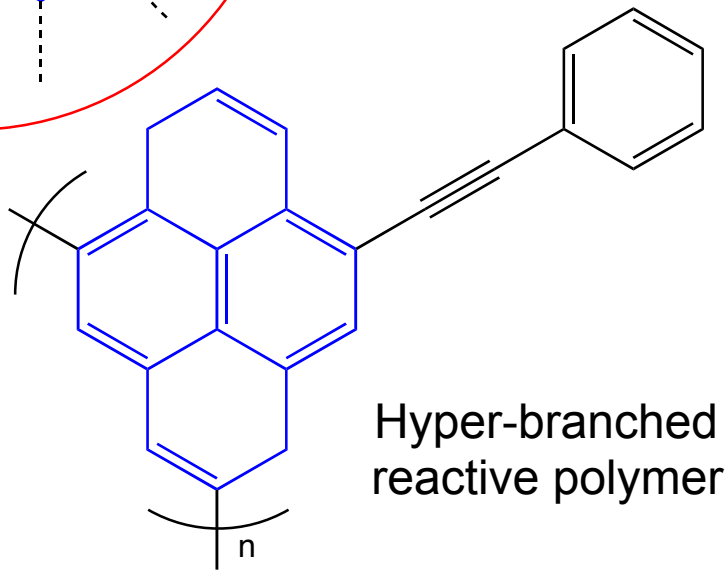




Carbon fiber on a human hair

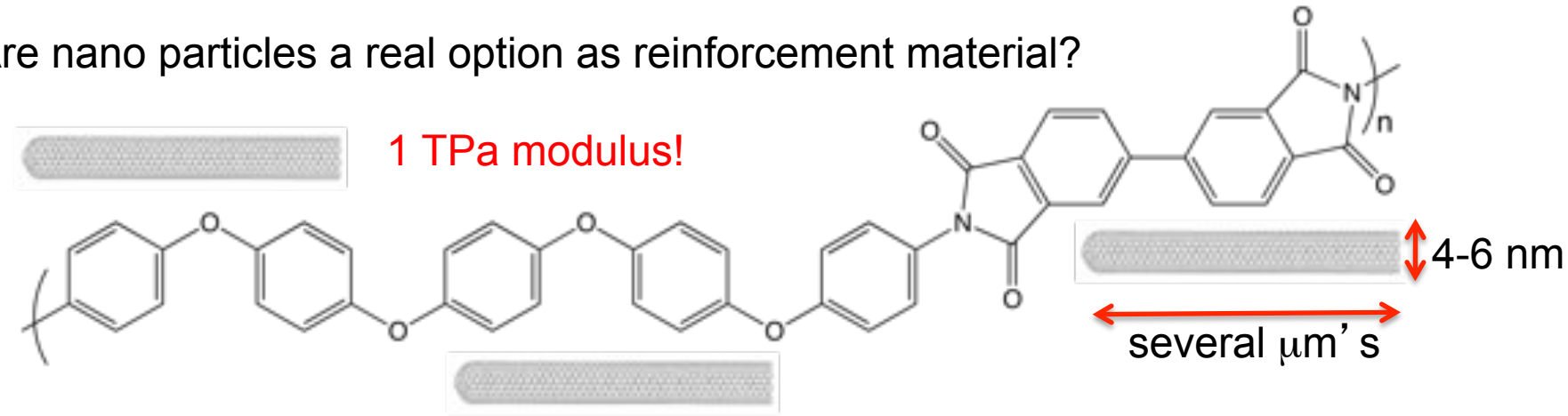


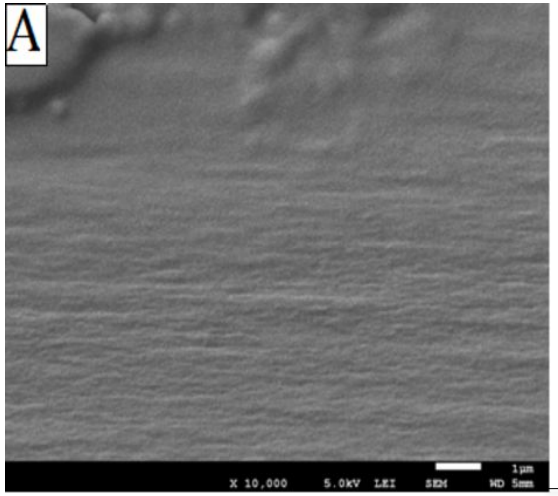


Hyper-branched reactive polymer

The role of nano reinforcement

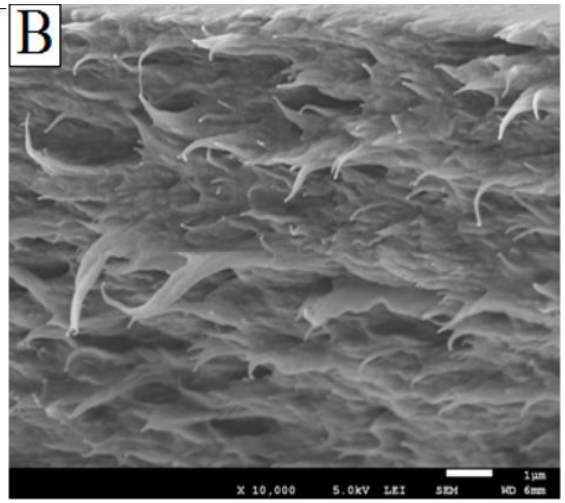
Are nano particles a real option as reinforcement material?



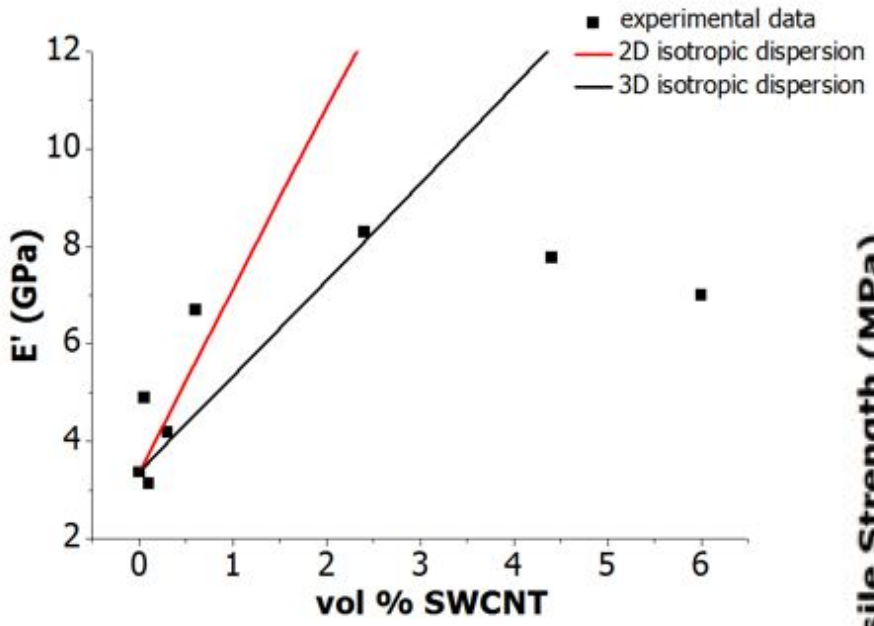


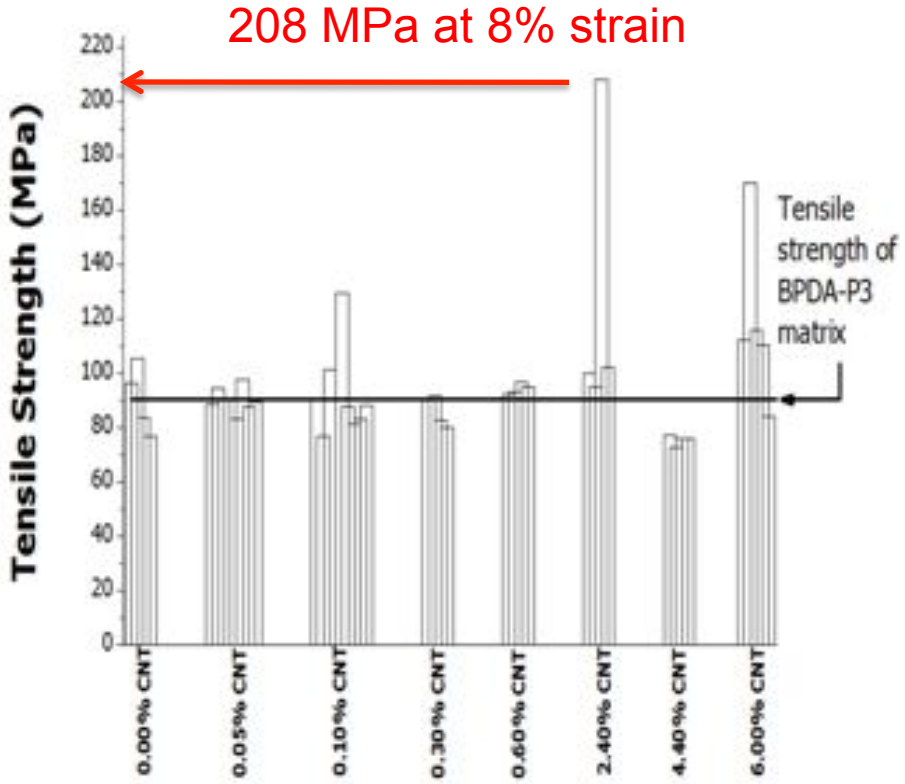
No SWCNTs:
brittle fracture

2.4 vol% SWCNTs:
tough fracture



The role of nano reinforcement



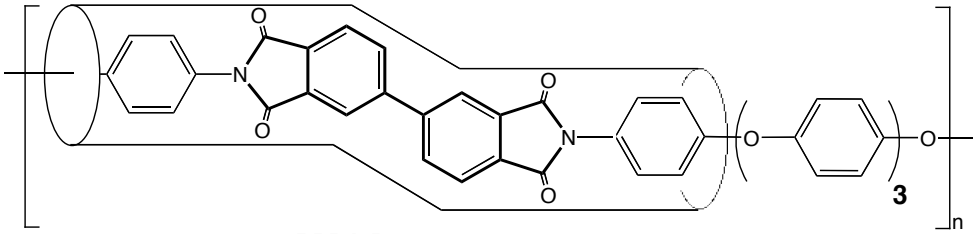


- Significant improvement in E'
- Minimal loss in elongation at break
- Doubling of the tensile strength

- Progress is slow but moves in the right direction

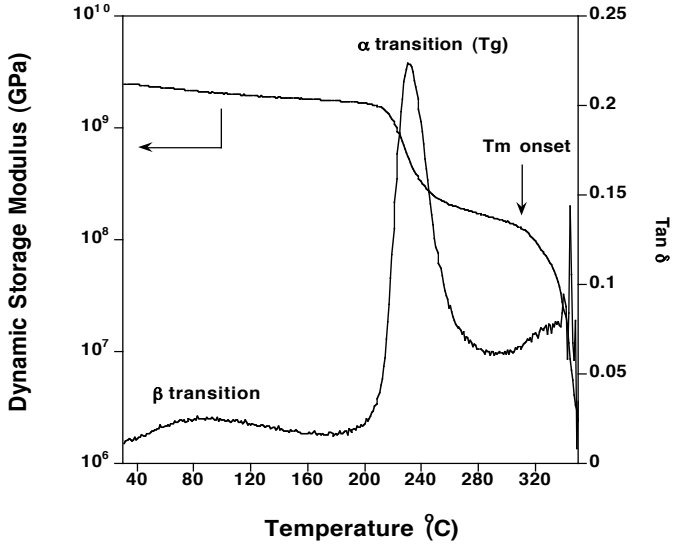
In-situ health monitoring of composites…

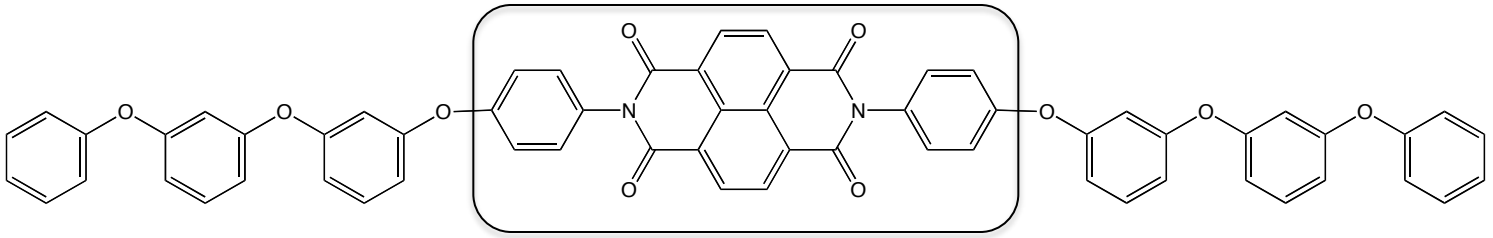
How to add function to structural?



BPDA-P3

"Classic" structural polyetherimide



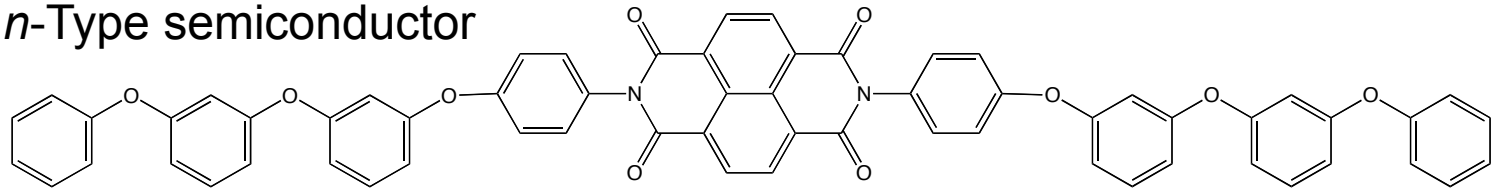


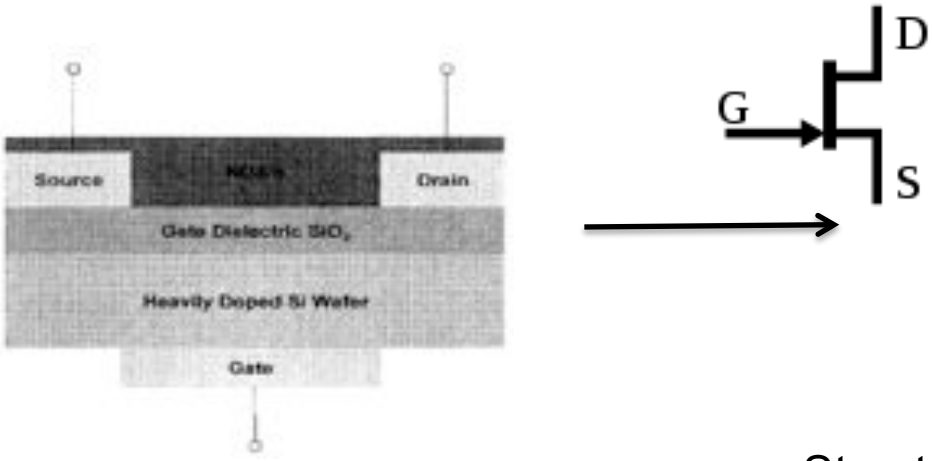
n-Type semiconductor

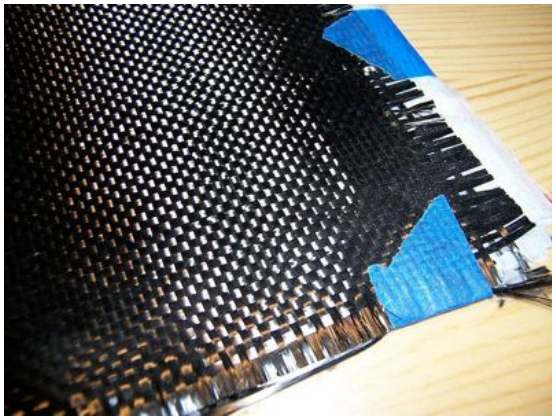
In-situ health monitoring of composites…

How to add function to structural?

n-Type semiconductor



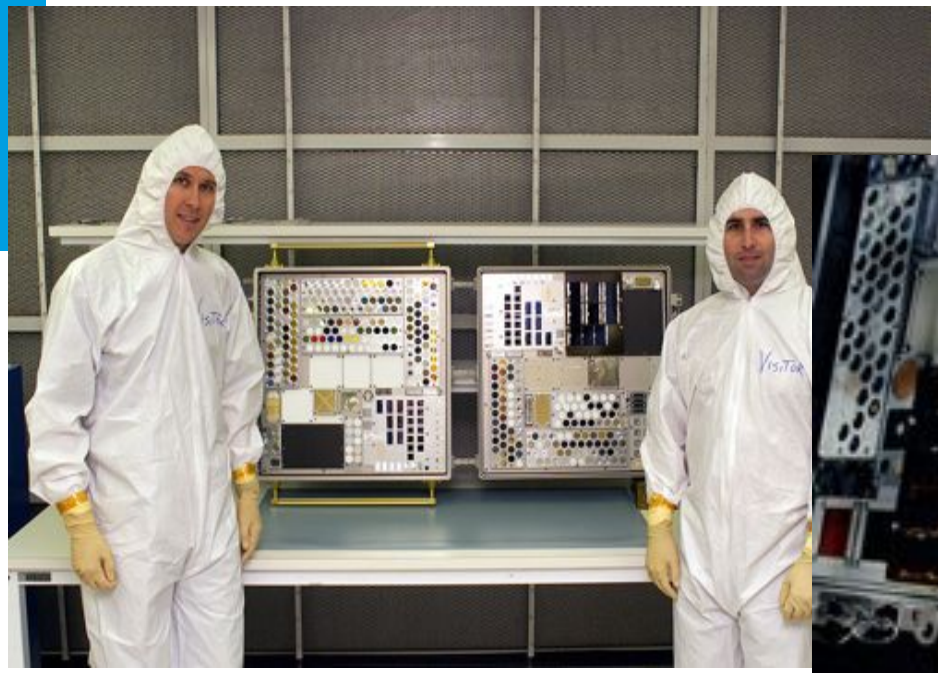


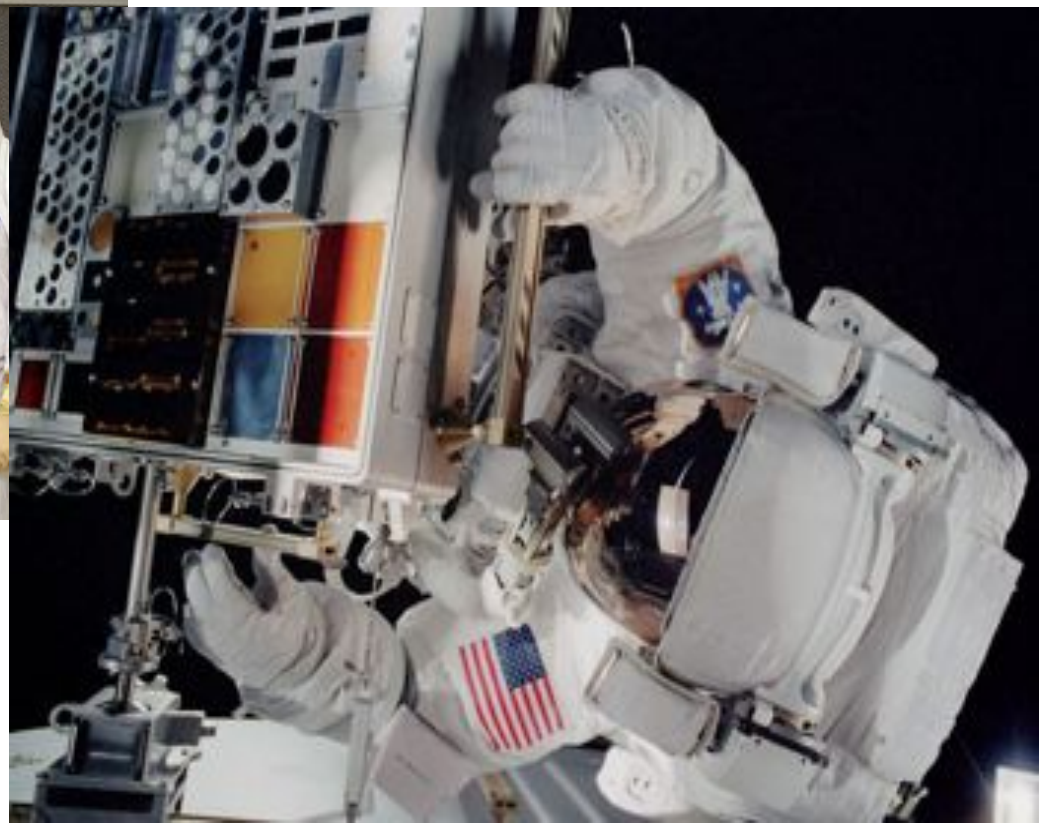


Structural composite + sensing function

Chem Mater. **2004**, *16*, 966-974; *Thin Solid Films* **2006**, *500*, 9-14; *J. Vac. Sci. Technol. B.* **2006**, *24(6)*, 2653-2658

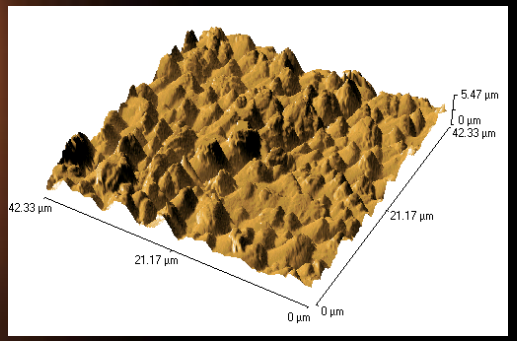
Functional polymers and the space environment



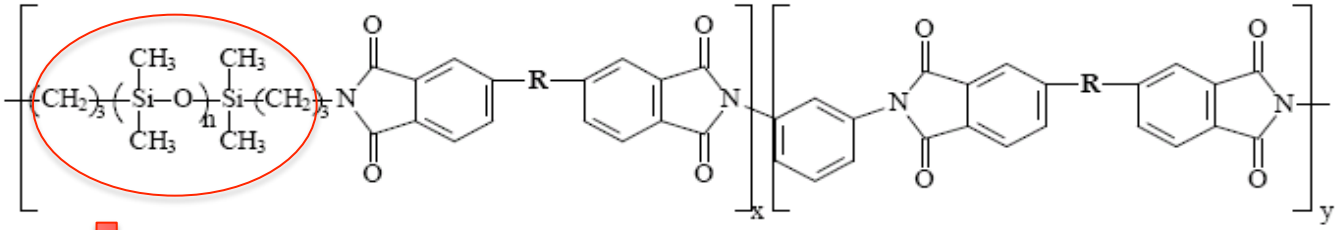


MISSE 3
Long duration space exposure test facility

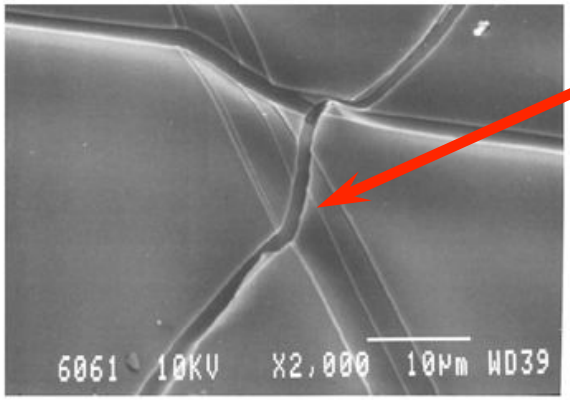
Polymer films as used on satelites are vulnerable to AO and UV



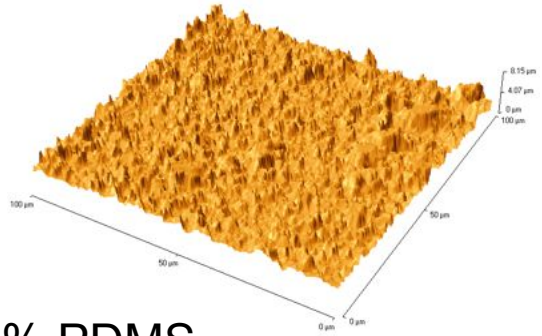
Self-repair capability in space…



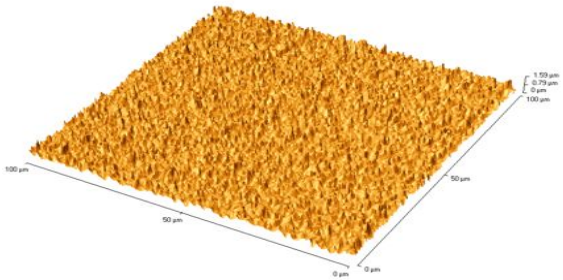
ATOX



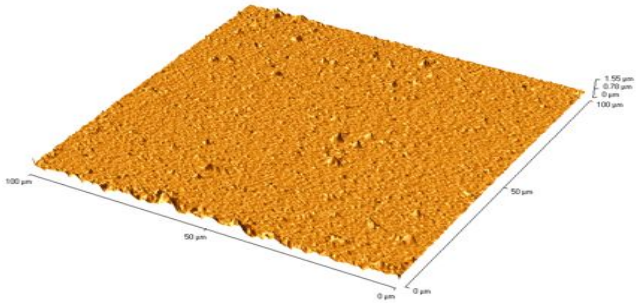
Self-healing capability of PDMS demonstrated by formation of glassy layer on each generation of cracks.



0 % PDMS



6 % PDMS



10 % PDMS

Dutch Space
An EADS Astrium company

TNO | Kennis voor zaken

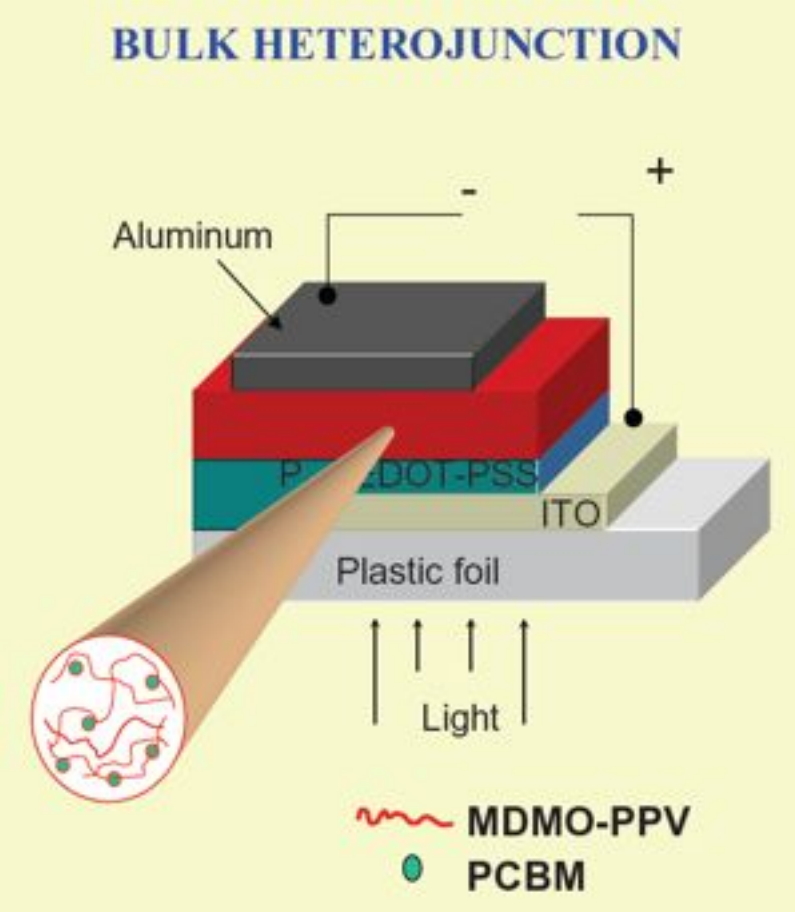
esa

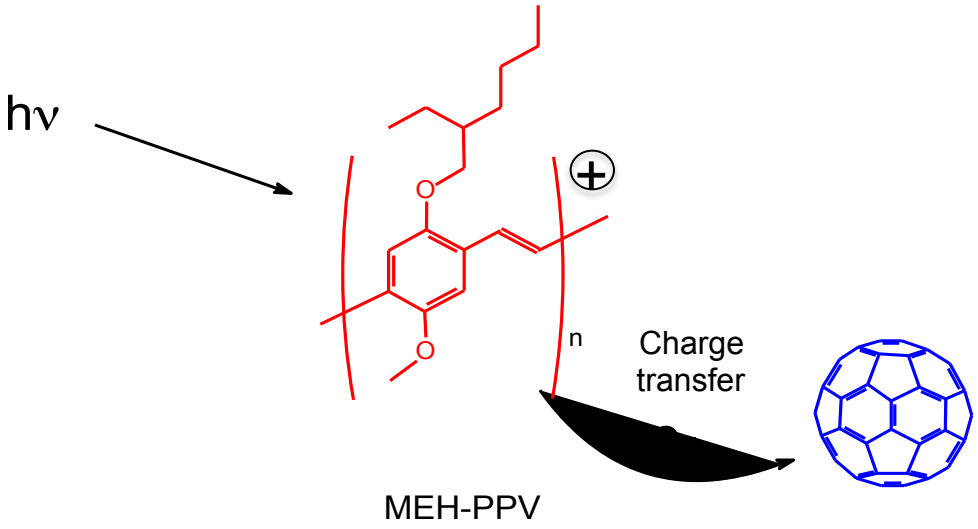
Silicon solar cells…

- Crystalline silicon wafers
- 0.3 mm thick, **brittle** and **heavy**
- **99.9999 % pure** material
- 25 % conversion efficiency

…polymer-based solar cells?

Polymer-based photovoltaics

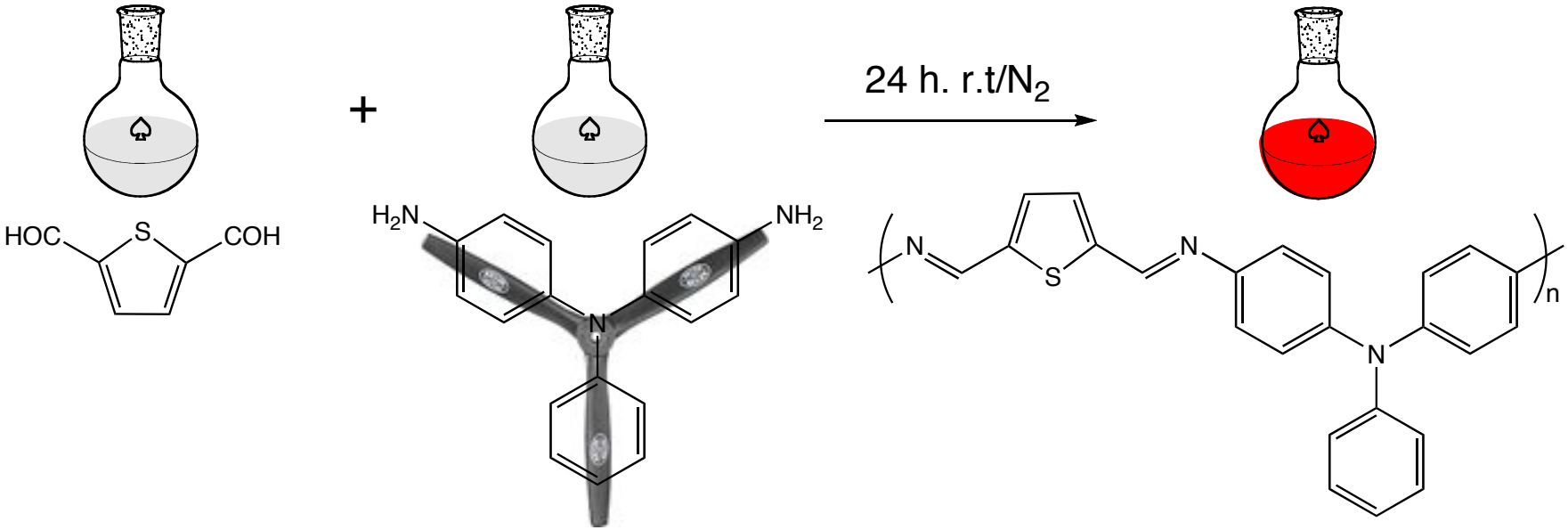




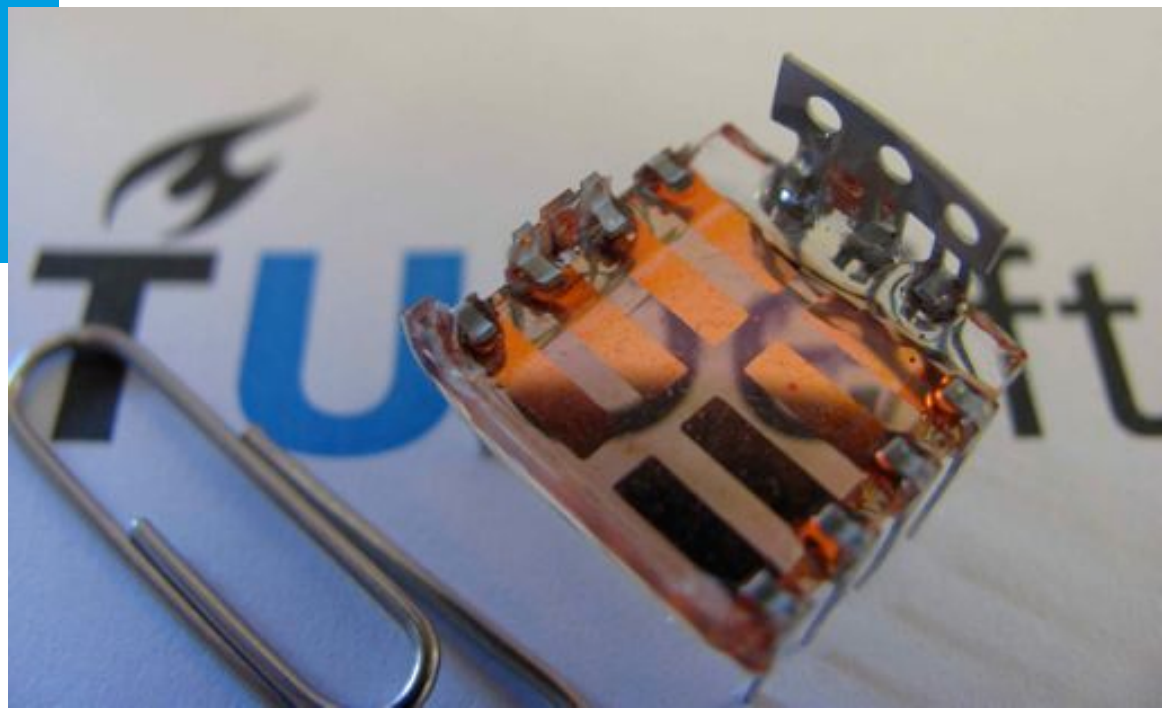
- Expensive materials (monomers, catalysts, PCBM)
- Lack of e^- accepting polymers
- Challenging synthetic, polymer clean-up and processing step
- ***Low efficiencies ~ 8%***
- ***Limited life time top electrode due to O_2***

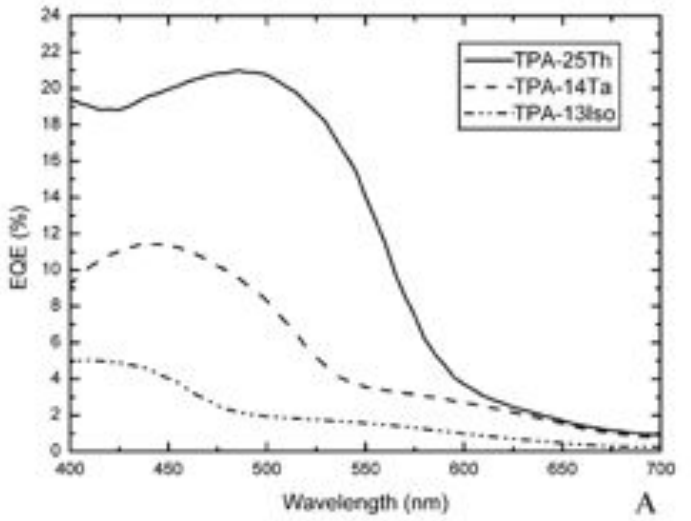
Polymer-based photovoltaics

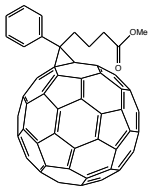
- ***Cheap, simple and affordable chemistry***
- Use of cheap e^- acceptor TiO_2
- One step device preparation



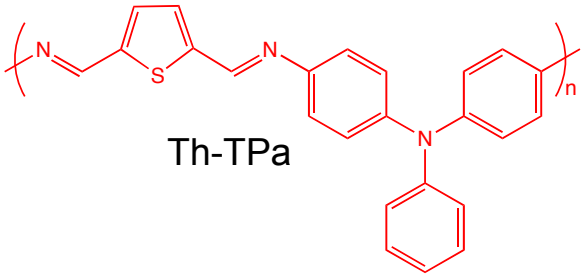
Polymer-based photovoltaics



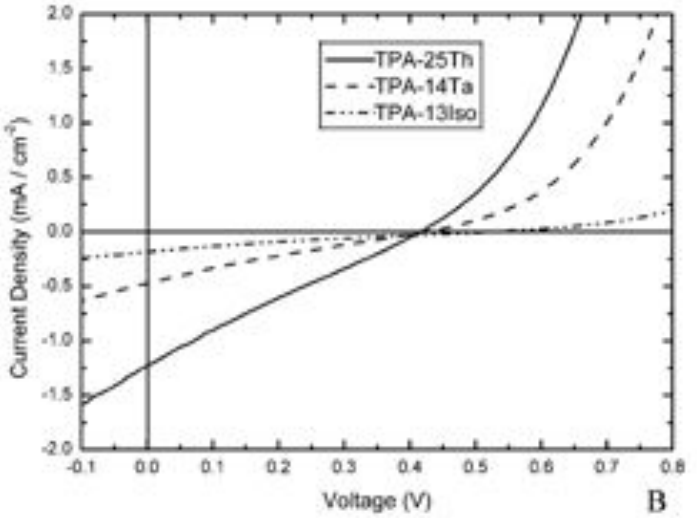




PCBM



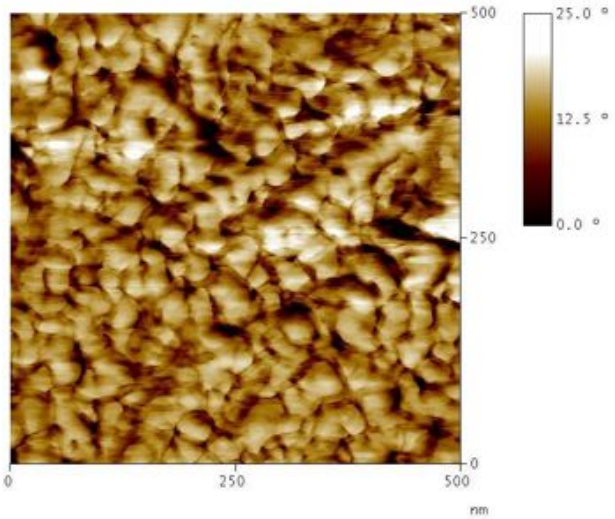
Th-TPa



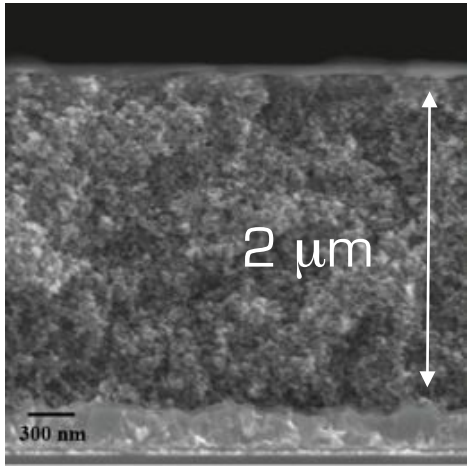
J. Mater. Chem. **2010**, *20*, 937-944

Polymer-based photovoltaics

- Cheap, simple and affordable chemistry
- ***Use of cheap e⁻ acceptor TiO_2***
- ***One step device preparation?***



AFM (ODPA-M1)+ Ti(IV)isopropoxide (50/50 wt%)

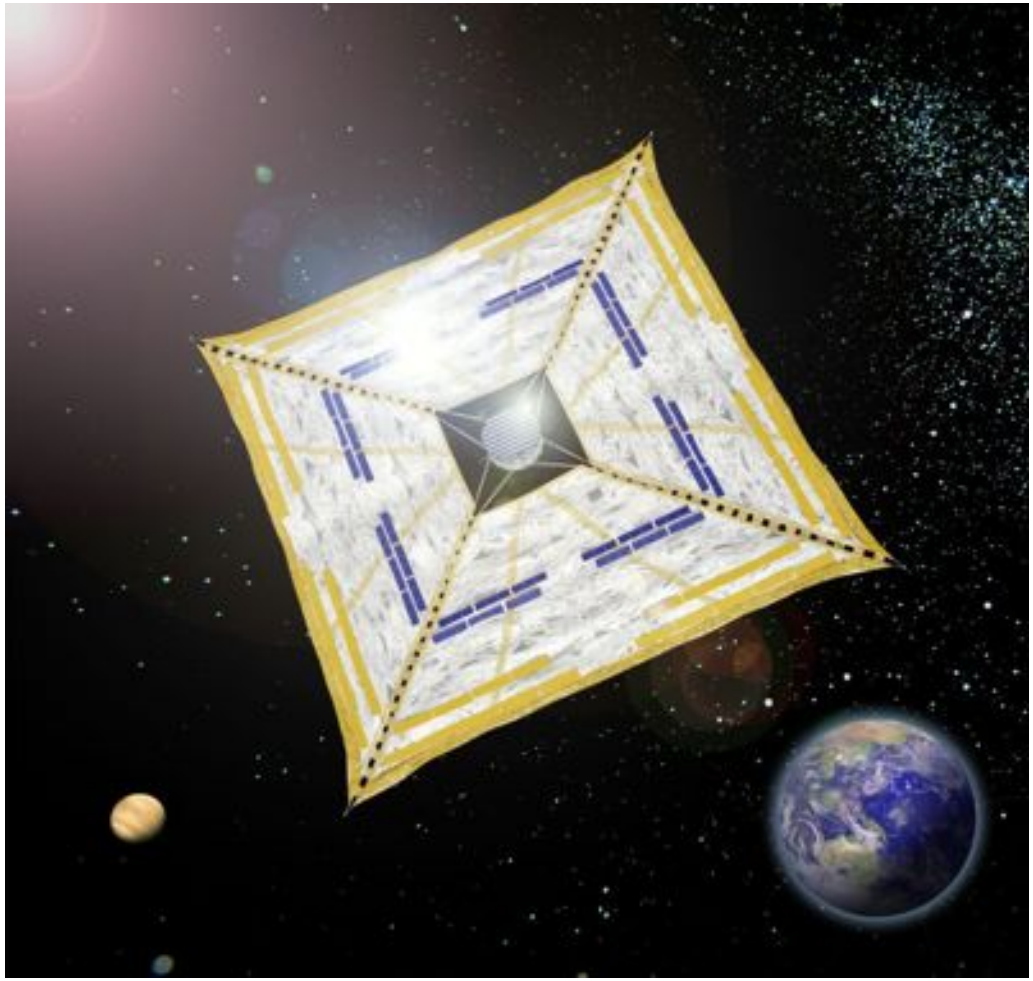


SEM meso-porous structure TiO_2 (60% pore volume)+ ODPA-M1

+ high Tg and thermal stability
+ LC order in order to promote chain-to-chain charge transfer and nano-scale separation
+ good tunability with respect to opto-electronic properties
+ useful for large-scale film production

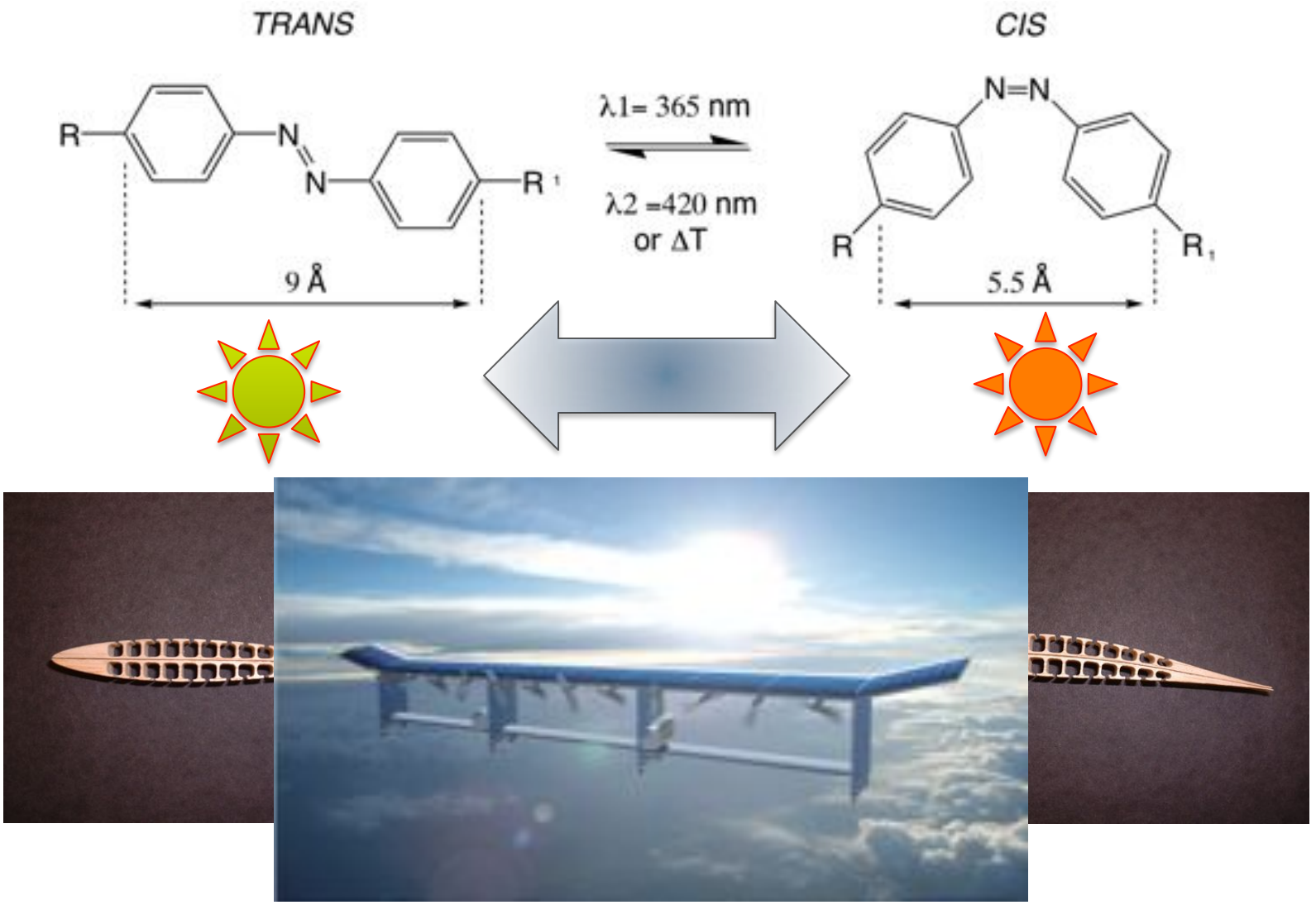
IKAROS

Interplanetary
Kite-craft
Accelerated by
Radiation
Of the
Sun (JAXA)



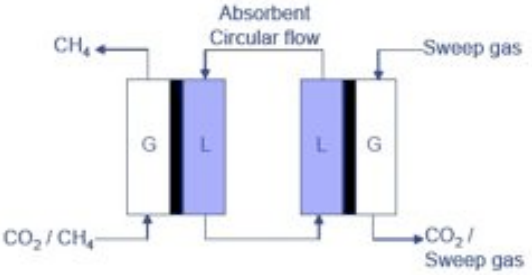
Tafelkleed dat zeilt op de zon…
Volkskrant, zaterdag 29 mei 2010

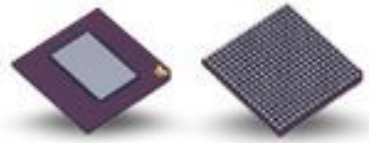
Morphing wings: light actuated?



Are aerospace polymers for aerospace only?

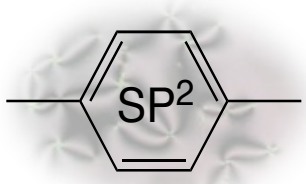
Poly(ether)imides
CO_2 management





Poly(ether)imides
dielectrics for (opto)electronics and structural foils

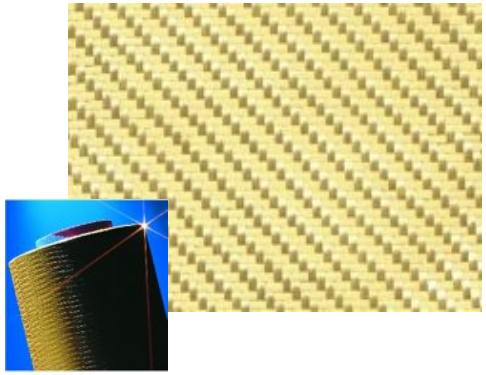
Poly(azomethine)s
plastic solar cells



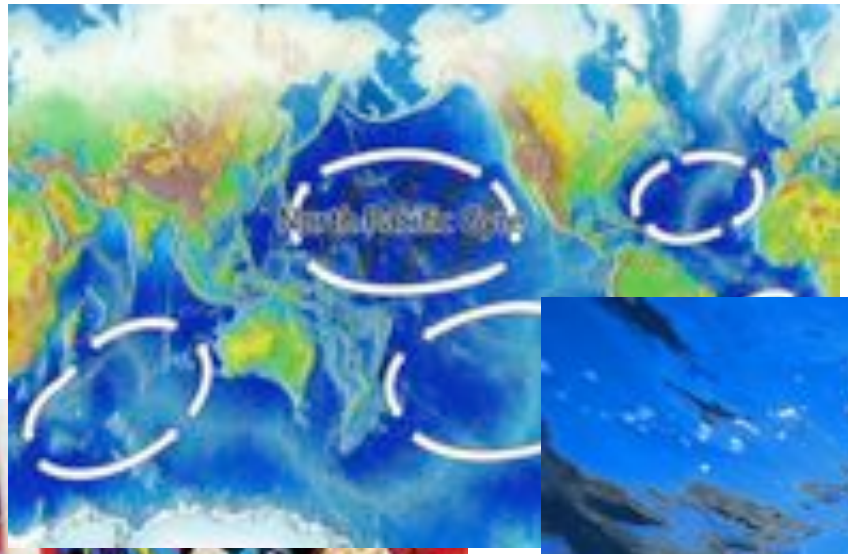
C/LCT
Fibers, ropes, composites

LCTs
Coatings and electronic packaging

Para-aramids
Fibers, composites, ballistics



Polymers and society?



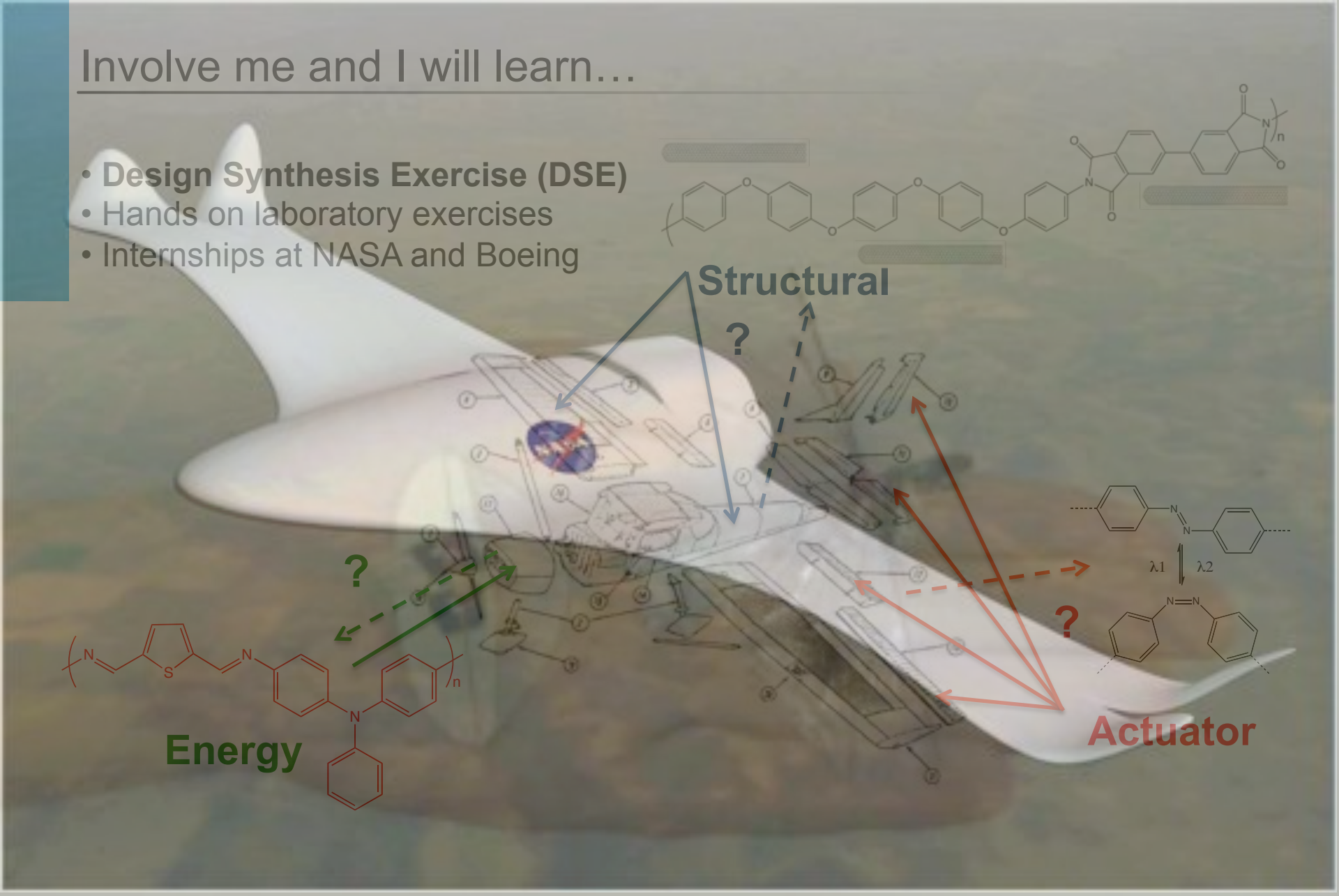
Education

Education

A typical TU Delft materials professor

Involve me and I will learn…

- **Design Synthesis Exercise (DSE)**
- Hands on laboratory exercises
- Internships at NASA and Boeing



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Involve me and I will learn…

- Design Synthesis Exercise (DSE)
- Hands on laboratory exercises
- **Internships at NASA and Boeing**

Facilities

Infrastructure before…

2003

Infrastructure after…

2010

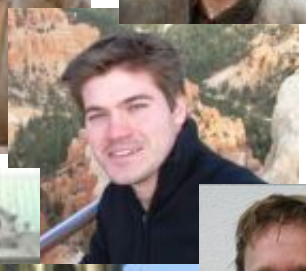
Chemistry lab

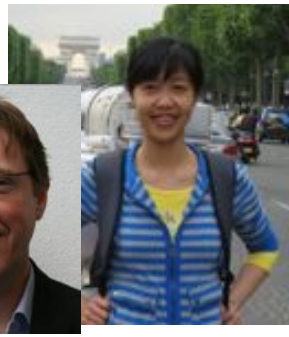
Physical characterization lab

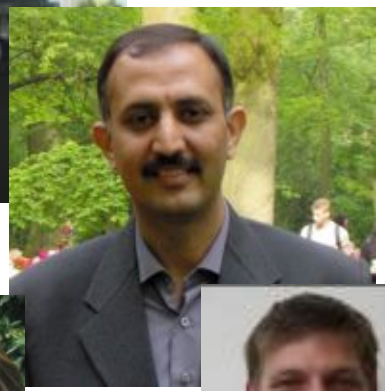
Partners

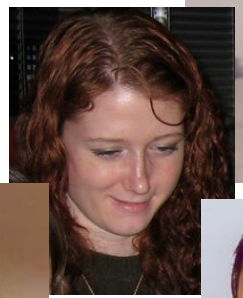
Funding and industrial partners

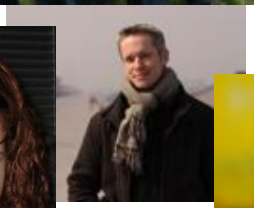
The people involved…

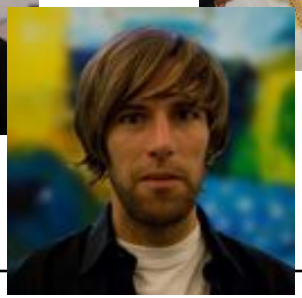


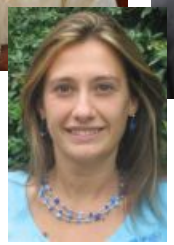


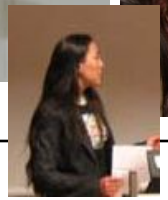


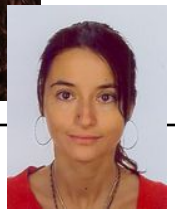






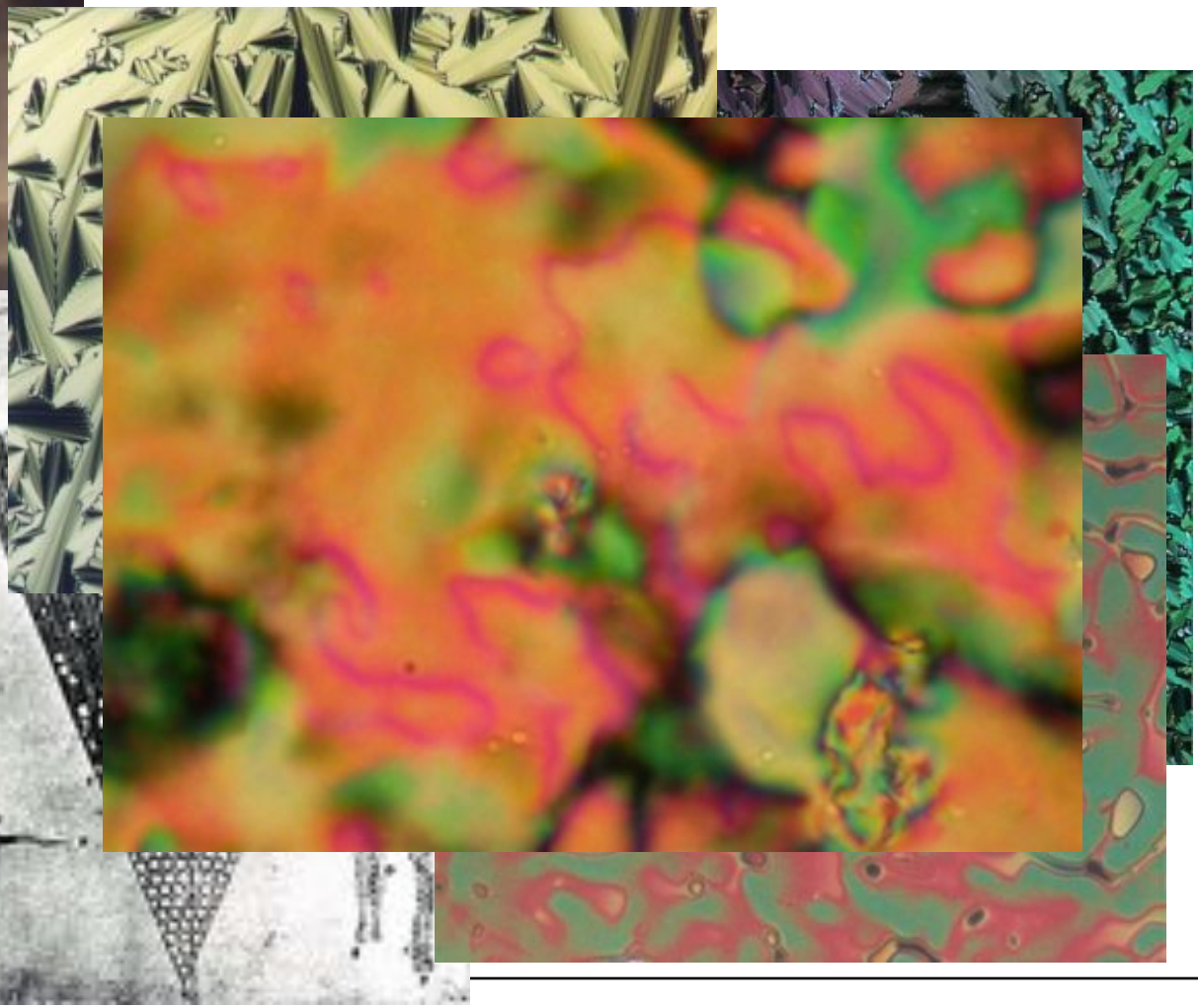






“I’ ve spend more time than many will believe [making microscopic observations], but I’ ve done them with joy….”

Anthonie van Leeuwenhoek, Delft, June 12, 1716

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