Carbon Nanotube Membranes for Energy-Efficient Carbon Sequestration

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INTRODUCTION

Membrane-based CO_2 separation

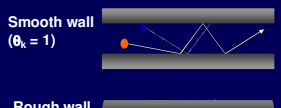
- No need of an additional chemicals or solvents
- Low energy use
- Simple process easy to operate
- However, current membrane technology for CO_2 capture need high selectivity, large permeance and high performance stability

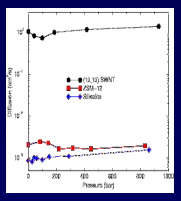
Specific issue of membrane-based CO_2 separation

- Lack of transport driving force
- Impacts of leaks and defects on selectivity
- Influence of contaminants on performance
- Maximum recovery

Carbon nanotube membranes

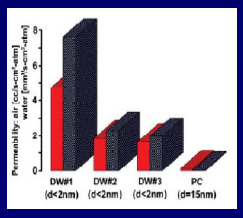
- CNTs have very high gas permeability because of the inherent smoothness of CNT surface





Transport diffusion coefficients for H_2 in a (10,10) SWNT (circles) and two siliceous zeolites: ZSM-12 (squares) and silicalite (diamonds) computed from atomistic simulations at 298 K [2]

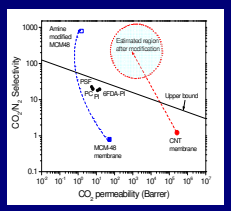
- Aligned double-walled carbon nanotube (DWNT, 1.6nm) membrane in silicone nitride matrix, 2006: Fast gas and water transport through CNTs.



Holt et al, *Science*, 312, 1034 (2006)
Noy et al, *Nano today*, 2, 22 (2007)
Fornasiero et al, *PNAS*, 105, 17250 (2008)

Advantages of CNT membrane technology

- Ultra-high permeability (10^6 barrer) almost completely negates the flux-selectivity tradeoff limitation of polymeric membranes
- Selectivity, permeability and performance stability of the CNT membranes can be tuned nearly independently



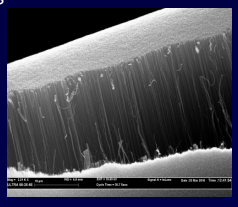
Objectives

- Investigate gas separation properties of CNT membrane using single/mixed gas permeation system
- Develop and demonstrate a comprehensive set of chemical and physical modifications of CNT membranes for CO_2 separation
- Investigate the effects of operating temperature, feed pressure, moisture, and permeate gas pairs on the CO_2 separation performance of CNT membranes

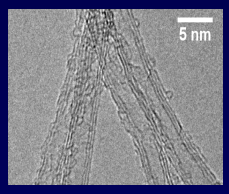
CNT MEMBRANE FABRICATION

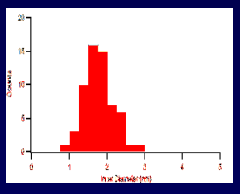
Vertically aligned CNTs

- We start by growing 4 inch size forests of vertically aligned CNTs

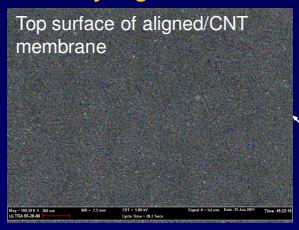


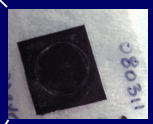
- Inner diameter ~ 2 nm

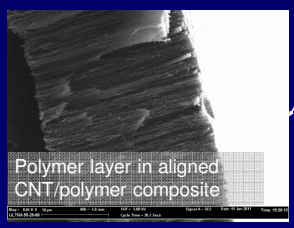




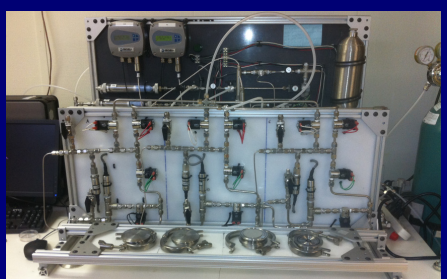
Vertically aligned CNT membranes







Multi-cell single gas permeability testing setup



- Keep both the upstream pressure constant (ca. 25 psi) and monitor the downstream pressure rise with respect to time. Rate of the downstream pressure rise gives the permeability of the membrane to each single gas (N_2,CO_2)

Porifera's CNT membrane platform: Good reproducibility, high permeability, Knudsen selectivity

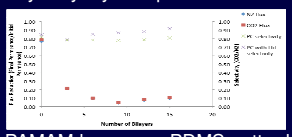
Membrane type	# of membranes tested	Gas permeability, barrer	CO_2/N_2 selectivity
CNT/polymer	Over 60	4.5e4-5.2e5	0.78-0.8

SELECTIVITY ENHANCEMENT

Amine-based functionalization (PAMAM)

(testing done on 10 nm PC membrane support)

- Layer-by-layer deposited mixed films

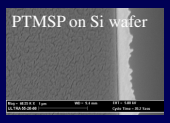


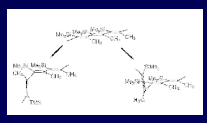
- PAMAM layer on a PDMS gutter layer

	bare membrane	PDMS (~100 nm)	PAMAM G5 (~25 nm)
CO_2 permeability (barrer)	$7.8x10^4$	77	56
CO_2/N_2	0.85	7.7	28

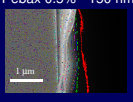
- *PAMAM is not a good material for creating high flux CO_2 selective membranes*

PEG-based functionalization on a PTMS-p gutter layer



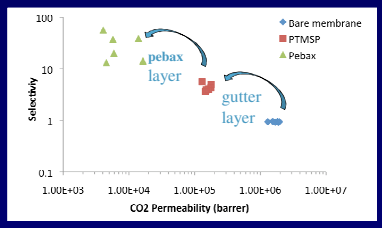


Pebax 0.5% ~150 nm

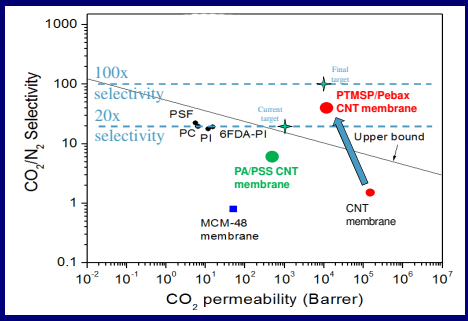


- **Pebax 1657**
  - PEG-b-Nylon-6 commercially available from Arkema Inc.
  - used in casting CO_2 selective membranes

- Functionalization produces fast and selective membranes!



Where we are now:



- Porifera's CNT membranes have high permeability and good CO_2/N_2 selectivity

CONCLUSIONS and FUTURE WORK

- CNT membranes functionalized with selective layers show promising performance for CO2 capture applications
- We have not yet reached the limits of the system performance- more improvements are possible
- *Future Work:*
- Higher flux membranes
- Better coatings
- Targeted optimization od performance for CO2 applications

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