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Nanotechnology in Materials

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NANOTECHNOLOGY IN MATERIALS

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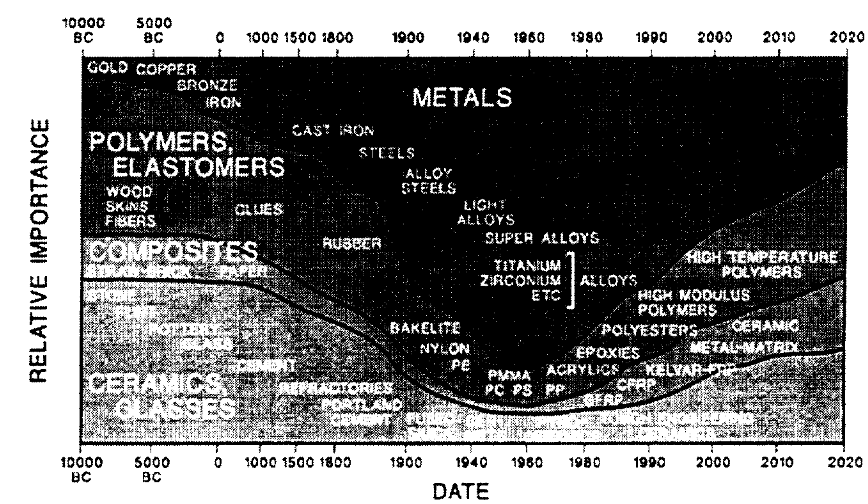
Evolution of Engineering Materials



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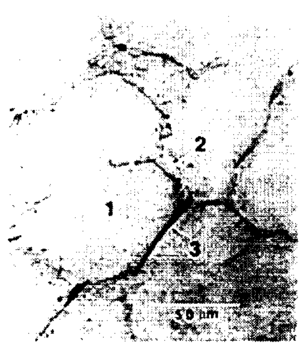
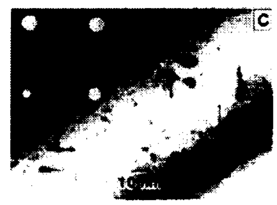
What is Nanotechnology?

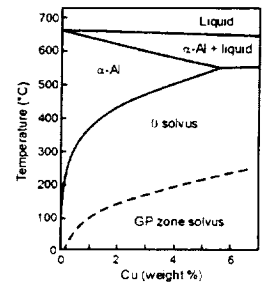
Precipitation Hardening in the First Aerospace Aluminum Alloy: The Wright *Flyer* Crankcase

Frank W. Gayle and Martha Goodway

SCIENCE • VOL. 266 • 11 NOVEMBER 1994







"An aluminum copper alloy (with a copper composition of 8 percent by weight) was used in the engine that powered the historic first flight of the Wright brothers in 1903. Examination of this alloy shows that it is precipitation-hardened by Guinier-Preston zones in a bimodal distribution, with larger zones (10-22 nanometers) originating in the casting practice and finer ones (3 nanometers) resulting from ambient aging over the last 90 years."

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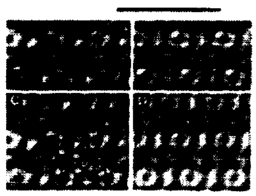
ARTICLES

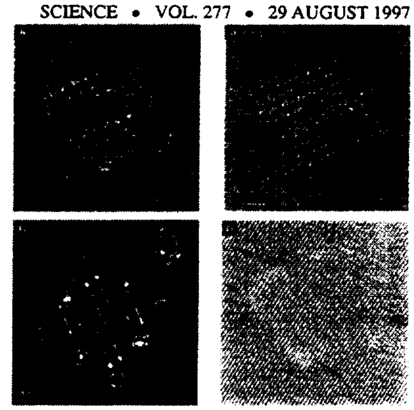
Structure Determination of Mg_5Si_6 Particles in Al by Dynamic Electron Diffraction Studies

H. W. Zandbergen,* S. J. Andersen, J. Jansen

SCIENCE • VOL. 277 • 29 AUGUST 1997

Precipitation hardening, in which small particles inhibit the movement of dislocations to strengthen a metal, has long been used to improve mechanical strength, especially of aluminum alloys. The small size of precipitates and the many possible variants of the orientation relation have made their structural determination difficult. Small precipitates in commercial aluminum-magnesium-silicon alloys play a crucial role in increasing the mechanical strength of these alloys. The composition and structure of the β″ phase in an aluminum-magnesium-silicon alloy, which occur as precipitates (typically 4 nanometers by 4 nanometers by 50 nanometers) and are associated with a particularly strong increase in mechanical strength, were determined. Element analysis indicates that the composition is Mg_5Si_6. A rough structure model was obtained from exit waves reconstructed from high-resolution electron microscopy images. The structure was refined with electron nanodiffraction data (overall R value of 3.1 percent) with the use of a recently developed least squares refinement procedure in which dynamic diffraction is fully taken into account.





"Precipitation hardening, in which small particles inhibit the movement of dislocations to strengthen a metal, has long been used to improve mechanical strength, especially of aluminum alloys."

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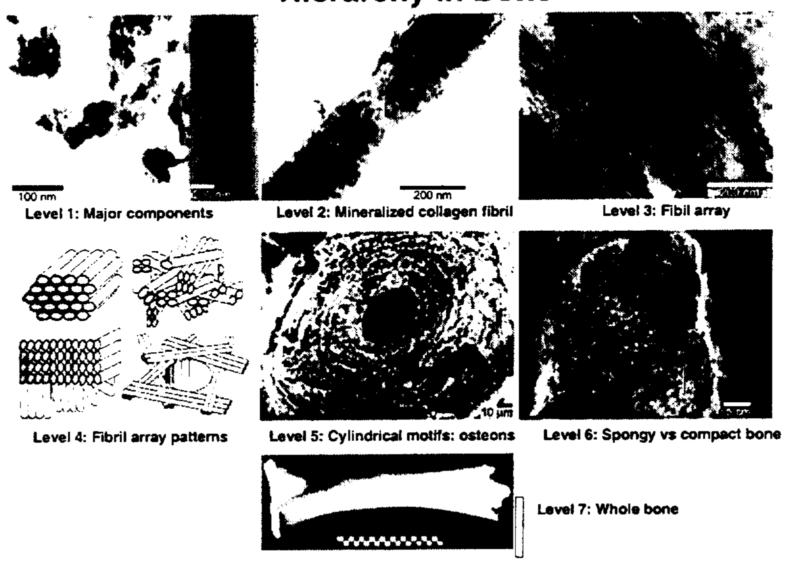
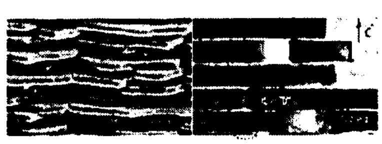
Hierarchy in Bone



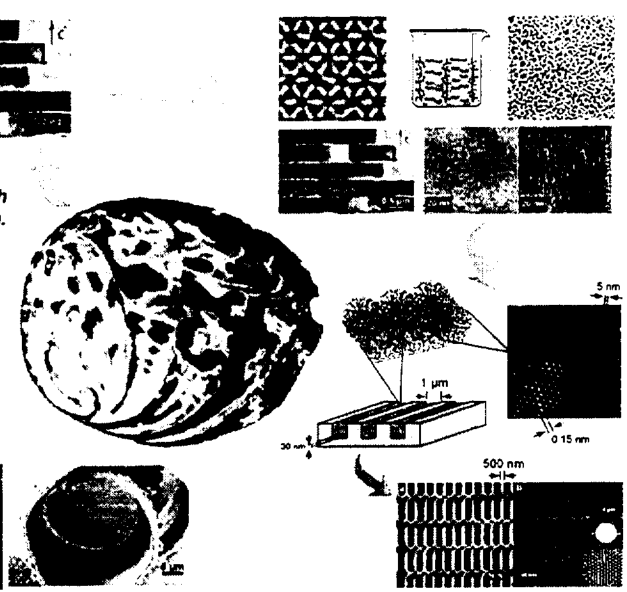
S. Weiner and H. D. Wagner, *Ann. Rev. Mater. Sci.* **28**, 271-98 (1998).

Princeton University



Three Key Lessons:

- ***Discrete levels and/or scales with organization starting at 1-100 nm.***
- ***Levels of structural organization are held together by specific interactions.***
- ***Hierarchical composite systems designed to meet a wide range of functional requirements.***



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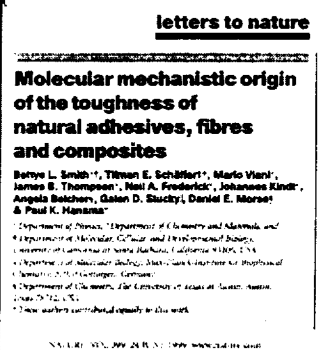
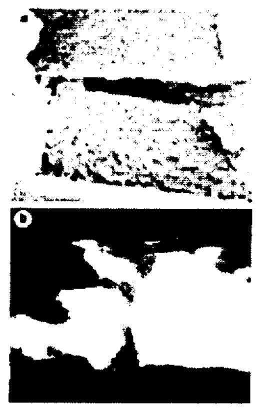
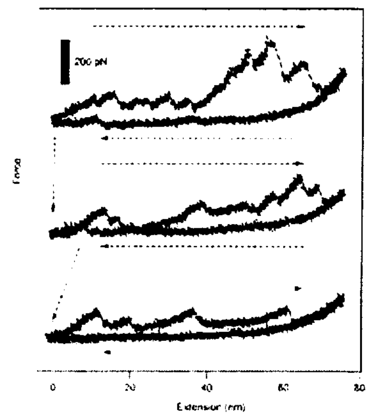
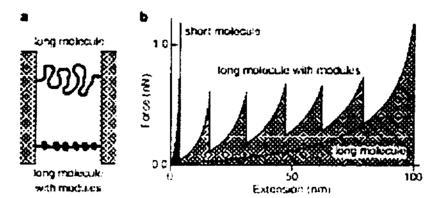






"Thus the break strength of each adhesive molecule would be the force required to break a strong bond: of the order of one nano-newton (estimate by dividing one electron volt by an extension of one ångström). For a material with many strongly bound molecules in parallel, the macroscopic tensile strength is expected to be of the order of several giga-pascals."



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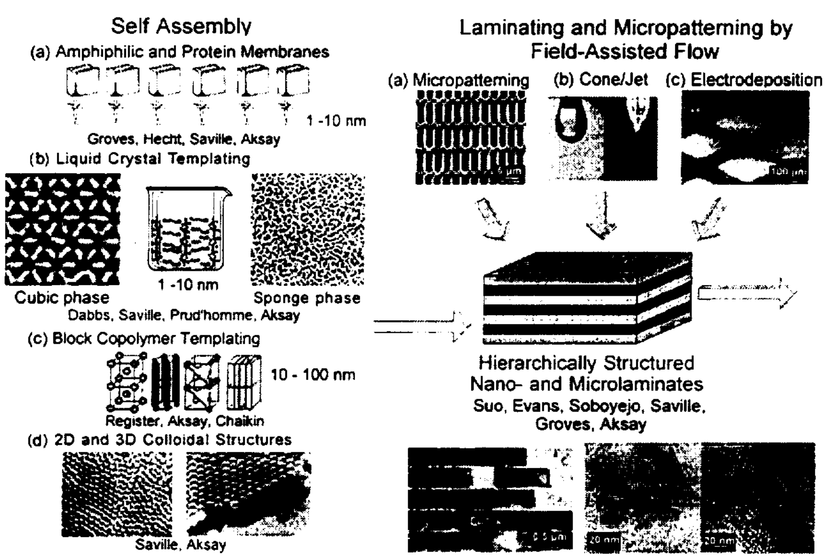
Goals and Organization

PROCESSING TECHNIQUES



OPTIMAL PROPERTIES

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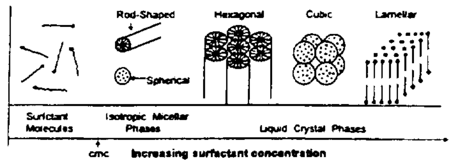
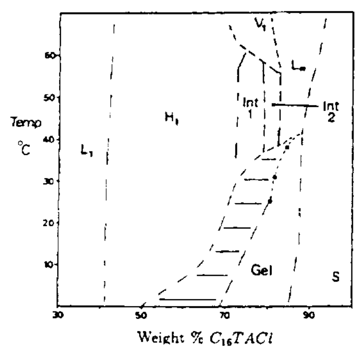
CTAC (Cetyltrimethyl Ammonium Chloride)



Phase sequence of surfactant-water binary system

D. Myers, *Surfactant Science and Technology*, VCH: New York (1992)



Partial phase diagram for the CTAC-water system

- **L_1: micellar solution;**
- **H_1: hexagonal phase;**
- **L_α: Lamellar phase;**
- **Gel: Monolayer interdigited gel phase;**
- **V_1: bicontinuous cubic phase;**
- **S: Solid phase; Int-1 and Int-2, intermediate phases.**

Gel phase is separated from the H_1 phase by a two-phase region

U. Henriksson *et al., J. Phys. Chem.* **96** 3894-902 (1992)

Princeton University

TEOS (Tetraethoxysilane)

Hydrolysis and Condensation

1) Hydrolysis

$$\equiv Si - OR + H_2O \leftrightarrow \equiv Si - OH + ROH$$

The R represents an alkyl group. In this reaction, the alkoxide groups (OR) are replaced by hydroxyl (OH) groups.

2) Alcohol Condensation

$$\equiv Si - OR + HO - Si \leftrightarrow \equiv Si - O - Si \equiv + ROH$$

Siloxane bonds (Si – O – Si) and Alcohol (ROH) are produced.

3) Water Condensation

$$\equiv Si - OH + HO - Si \leftrightarrow \equiv Si - O - Si \equiv + H_2O$$

Siloxane bonds and water (H_2O) are produced.

At low pH and high water concentration: The hydrolysis finishes in a very short period of time; therefore, the hydrolysis and condensation reactions are well separated.

C. Jeffrey Brinker *et al., Sol-gel Science* (Academic Press, San Diego, 1986)

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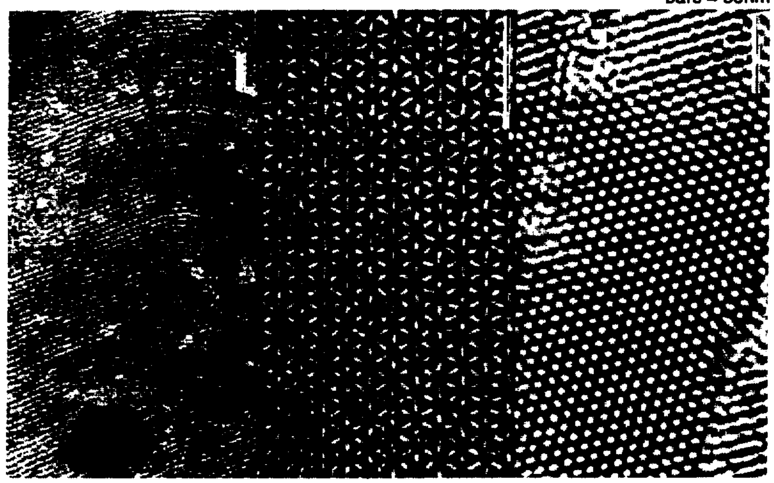
Lamellar, Cubic and Hexagonal Mesoporous Structures

bars = 30nm



M. D. McGehee, S. M. Gruner, N. Yao, C. M. Chun, A. Navrotsky, and I. A. Aksay, *Proc. 52nd Ann. Mtg. MSA* 448-9 (1994)

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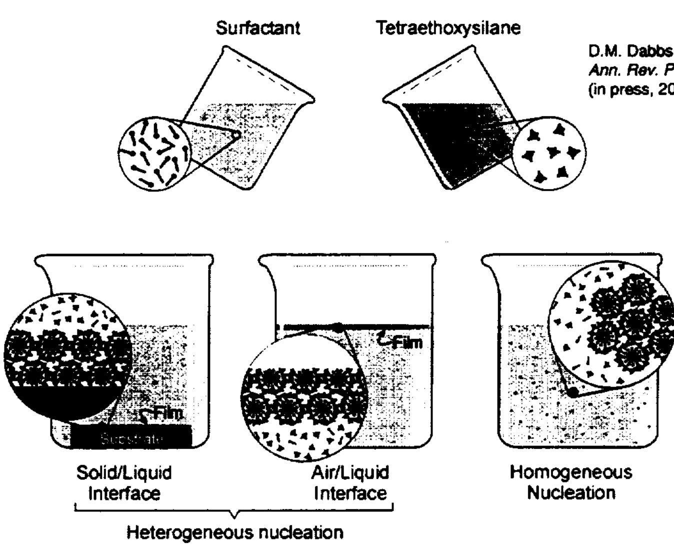
Templating Self-Assembled Surfactants

D.M. Dabbs and I.A. Aksay, *Ann. Rev. Phys. Chem.* (in press, 2000)



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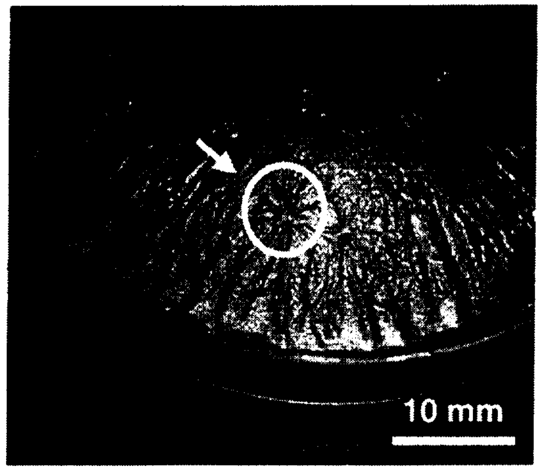
Self Healing Inorganic/Organic Films



N. Yao, A. Y. Ku, N. Nakagawa, T. Lee, D. A. Saville, and I. A. Aksay, *Chem. Mater.* **12** [6] 1536-548 (2000)

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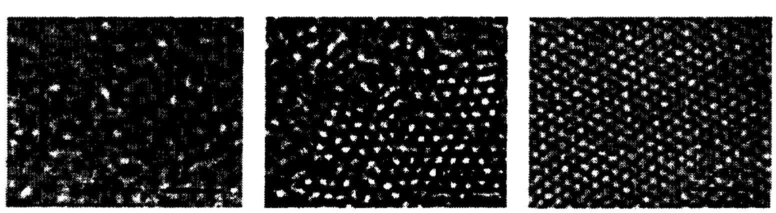
Film Growth: Mesoscopic Crystallization



30 minutes | 5 hours | 2 days

N. Yao, A. Y. Ku, N. Nakagawa, T. Lee, D. A. Saville, and I. A. Aksay, *Chem. Mater.* **12** [6] 1536-548 (2000)

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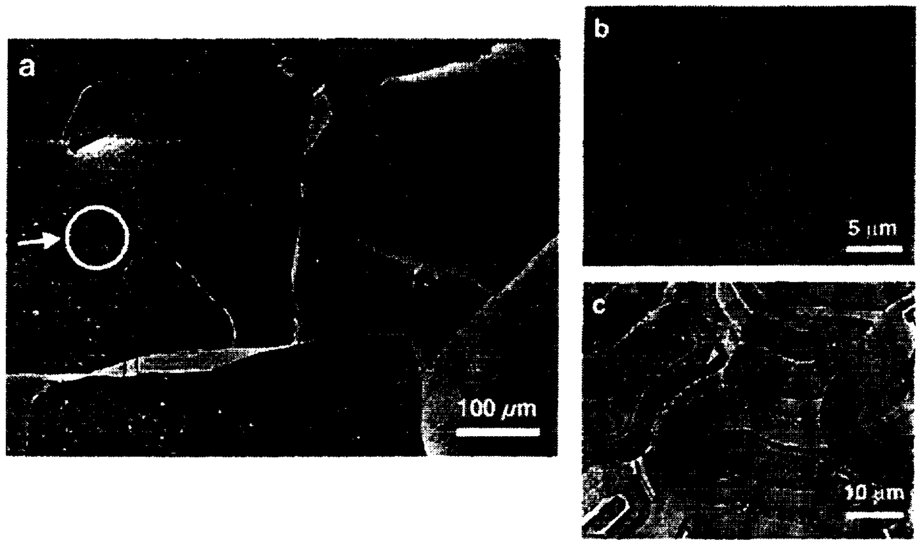

N. Yao, A. Y. Ku, N. Nakagawa, T. Lee, D. A. Saville, and I. A. Aksay, *Chem. Mater.* **12** [6] 1536-548 (2000)

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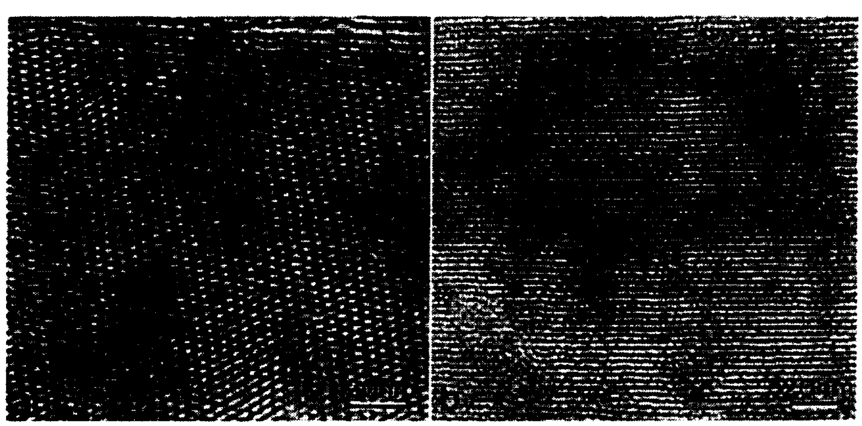
Mesostructured Silica Film on Mica



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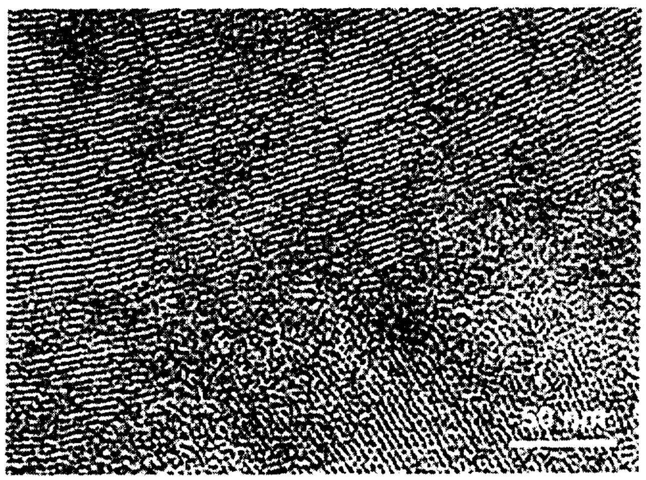
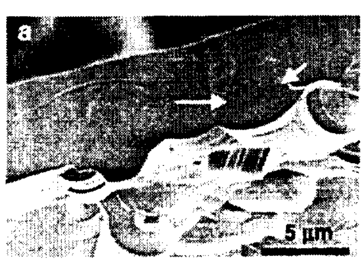
Cross-Sectional TEM:
Film at the Air-Water Interface

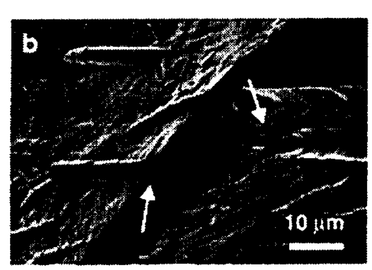


N. Yao, A. Y. Ku, N. Nakagawa, T. Lee, D. A. Saville, and I. A. Aksay, *Chem. Mater.* **12** [6] 1536-548 (2000)

Princeton University

Film Grown at the Air/Water Interface





N. Yao, A. Y. Ku, N. Nakagawa, T. Lee, D. A. Saville, and I. A. Aksay, *Chem. Mater.* **12** [6] 1536-548 (2000)

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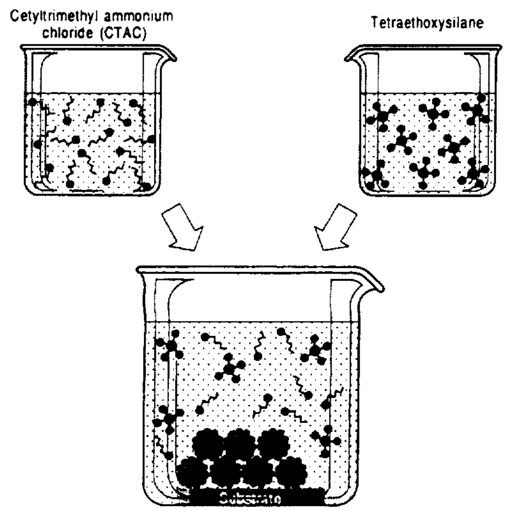
Synthesis of Mesostructured Silica Films



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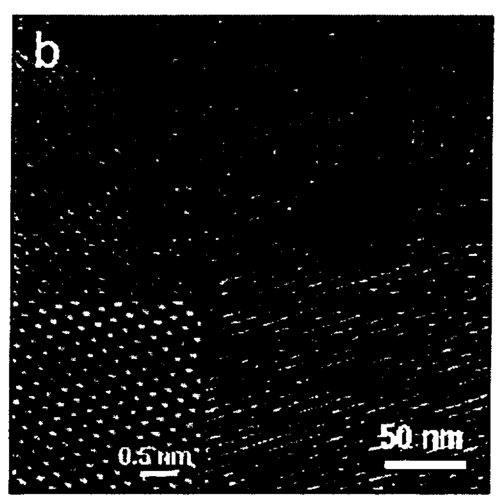
Mesostructured Silica on Graphite–AFM



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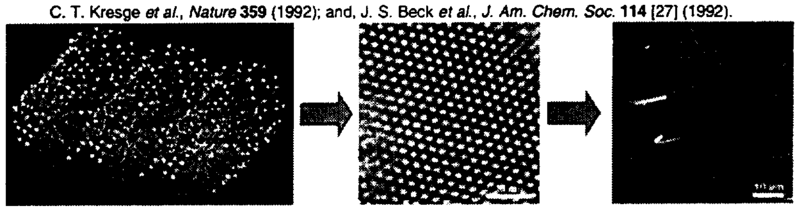
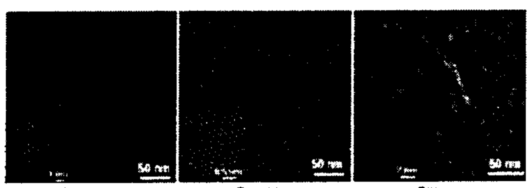
Mesostructured Inorganics Through Liquid Crystal Templating

- ***Surfactant-based procedure yields mesostructured inorganic materials***

C. T. Kresge *et al.*, *Nature* 359 (1992); and, J. S. Beck *et al.*, *J. Am. Chem. Soc.* 114 [27] (1992).



I. A. Aksay, M. Trau, S. Manne, I. Honma, N. Yao, L. Zhou, P. Fenter, P. M. Eisenberger, S. M. Gruner *Science* 273 892–98 (1996).



Mica | Graphite | Silica

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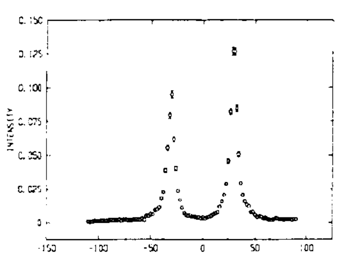
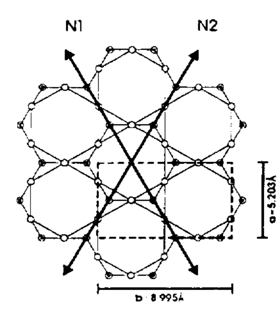
In-plane Orientational Alignment: On Mica



A 2-D azimuthal scan of the (101) Bragg peak for the film grown on mica for 24 hours. Note that peaks are observed at φ=±30°, corresponding to the tubules along N1 and N2 (φ=± 60°), but no peak is observed at φ=±90°, which would correspond to tubules laying along the b-axis direction.



Schematic of the lattice structure of the mica surface. The tubules of the film are aligned along the two next-nearest-neighbor directions N1 and N2 of the pseudo-hexagonal structure.

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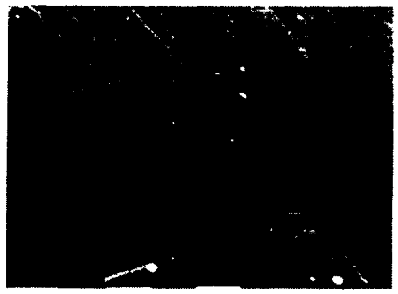
Mesostructured Thin Film on Mica



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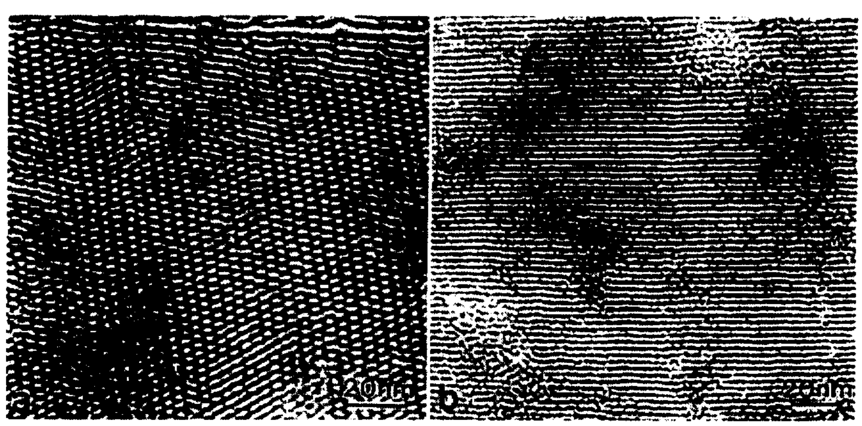
Mesostructured Silica Film on Mica



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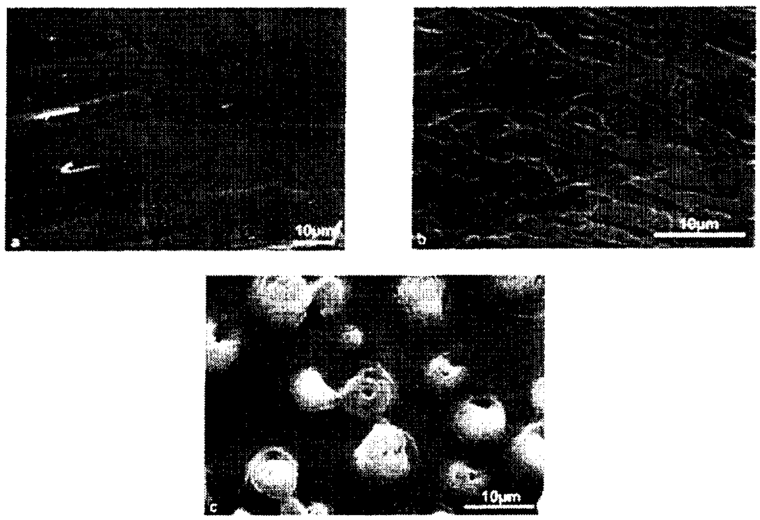
Mesostructured Thin Films



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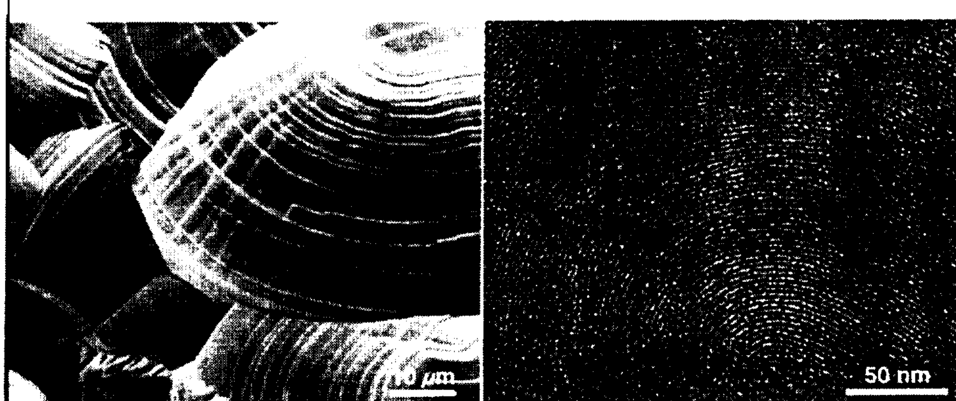
Hierarchically Structured Mesoscopic Silica Film



On silica substrate

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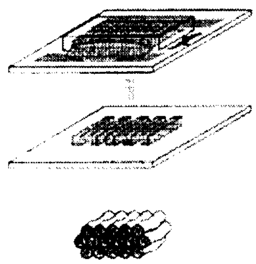
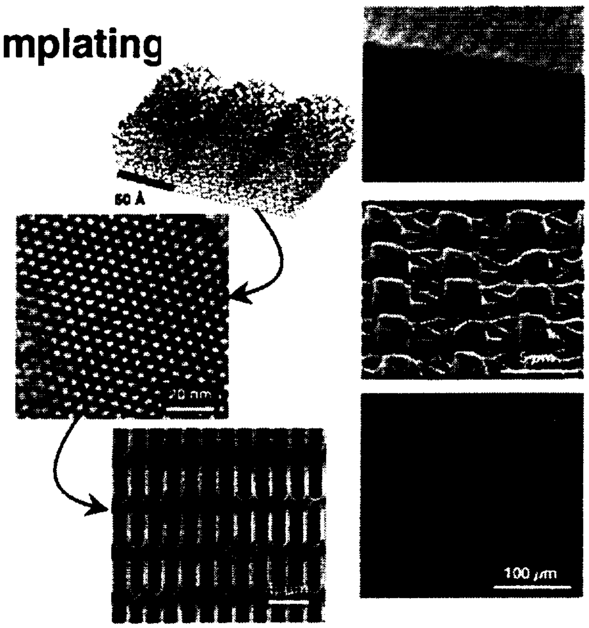
Liquid Crystal Templating





I. A. Aksay, M. Trau, S. Manne, I. Honma, N. Yao, L. Zhou, P. Fenter, P. M. Eisenberger, S. M. Gruner, *Science* 273 892–98 (1996);

M. Trau, N. Yao, E. Kim, Y. Xia, G. M. Whitesides, I. A. Aksay, *Nature* 390 [6661] 674-76 (1997)

A. Y. Ku, D. A. Saville, I. A. Aksay, unpublished research (2000)

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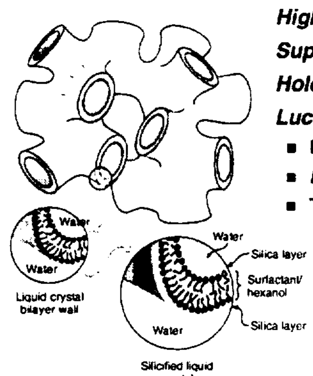
L_3-Templated Silicates

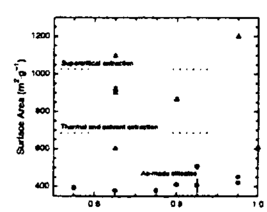
High surface area with contiguous, uniform pore structure

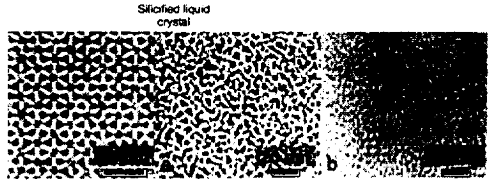
Supercritically extracted to remove template (N. Mulders)

Holographic storage medium (H. Katz, Lucent Technologies):

- **High permeability for precursors**
- ***In-situ* reaction and curing**
- **Two-photon write-and-read**







Cubic phase L$_3$ silicate, dried Silica xerogel

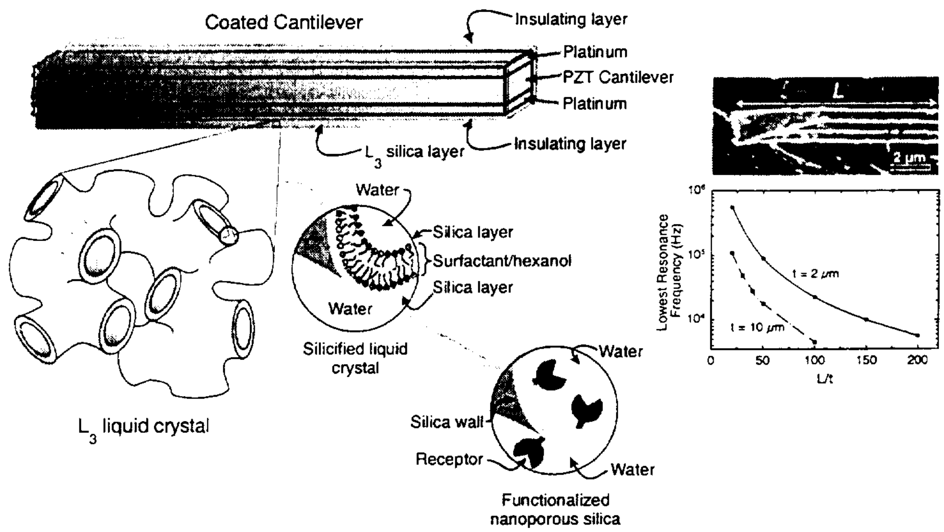
Cubic Phase:
M. D. McGehee, S. M. Gruner, N. Yao, C. M. Chun, A. Navrotsky, and I. A. Aksay, *Proc. 52nd Ann. Mtg. MSA* (1994) 448-9.

L_3 Silicates:
K. M. McGrath, D. M. Dabbs, N. Yao, I. A. Aksay, and S. M. Gruner, *Science* 277 552-6 (1997).

K. M. McGrath, D. M. Dabbs, K. J. Edler, N. Yao, I. A. Aksay, and S. M. Gruner, *Langmuir* 16 398-406 (2000).

D. M. Dabbs, S. M. Gruner, N. Mulders, and I. A. Aksay, unpublished research (2000).

Mesostructured Coating on PZT Cantilever



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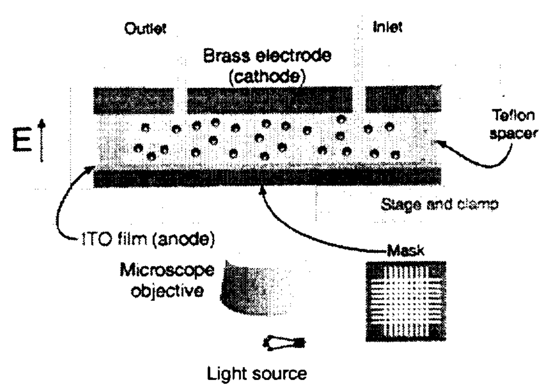
Light-Modulated Electrophoretic Deposition



Schematic of apparatus

R. C. Hayward, D. A. Saville, and I. A. Aksay, *Nature* **404** 56-9 (2000).

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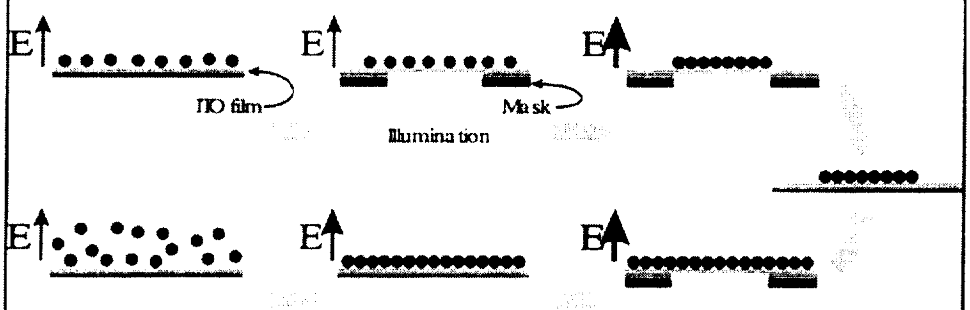
Pattern Formation

Patterned assembly followed by fixing to substrate



General assembly followed by patterned fixing to substrate

R. C. Hayward, D. A. Saville, and I. A. Aksay, *Nature* **404** 56-9 (2000).

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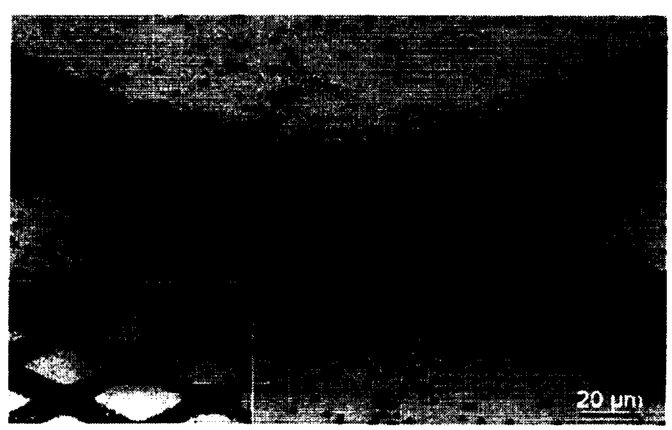
Patterned Colloidal Particles



R. C. Hayward, D. A. Saville, and I. A. Aksay, *Nature* **404** 56-9 (2000).

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