Jacob Sagiv

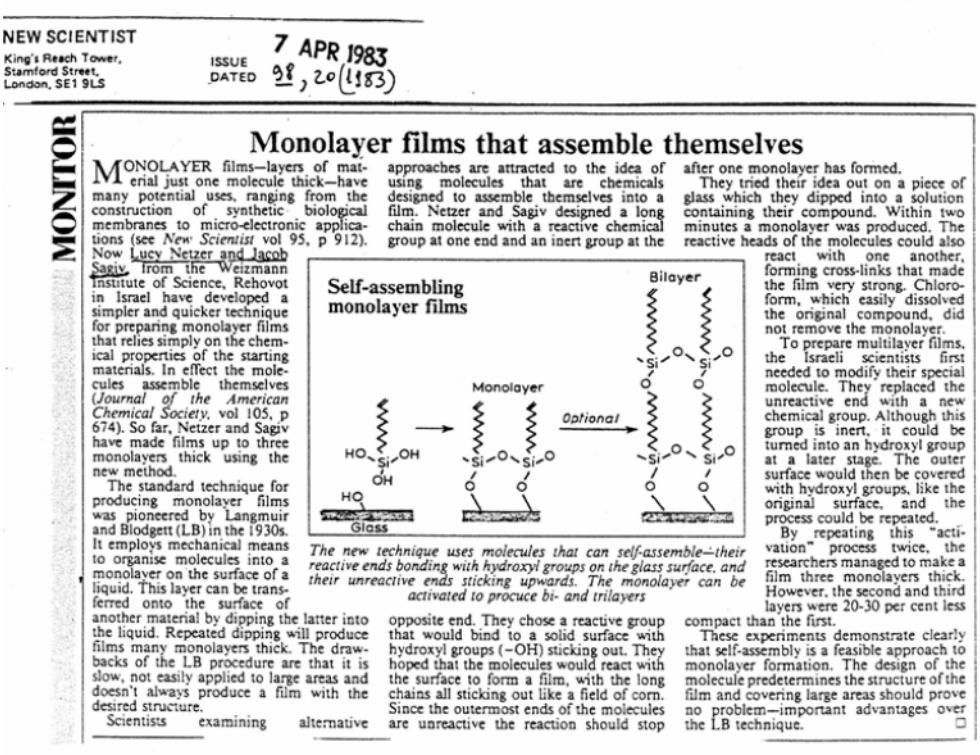
Born in Romania in 1945, in Israel since1961
B.Sc. in Chemistry (major) and Physics – Hebrew University of Jerusalem, 1969
Ph.D. – Weizmann Institute of Science, Rehovot, 1976
Postdoctoral Minerva Fellow – Max-Planck-Institut für Biophysikalische Chemie, Göttingen, Germany (with Prof. Hans Kuhn), 1975-1978

Scientist, Weizmann Institute, 1978
Senior Scientist, Weizmann Institute, 1979
Associate Professor, Weizmann Institute, 1984
Professor, Weizmann Institute, 2004

Major Research Landmarks

► Between 1978-1980, Jacob Sagiv pioneered what was to become the modern research area of self-assembling monolayers – E. E. Polymeropoulos and J. Sagiv, *J. Chem. Phys.* **1978**, *69*, 1836; J. Sagiv, *Isr.J. Chem.* **1979**, *18*, 339; 346; J. Sagiv, *J. Am. Chem. Soc.* **1980**, *102*, 92 (presently over 1, 000 citations).

► The term "*Self-Assembling Monolayer*" was later coined by a science reporter of *New Scientist* (**1983**, *98*, 20) with reference to the communication introducing the concept of chemically controlled layer-by-layer self-assembly at interfaces (L. Netzer and J. Sagiv, *J. Am. Chem. Soc.* **1983**, *105*, 674),currently the prevailing approach to planned 3D self-assembly of stratified molecular architectures on solid substrates:



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Monolayer films that assemble themselves

MONOLAYER films—layers of material just one molecule thick—have many potential uses, ranging from the construction of synthetic biological membranes to micro-electronic applications (see *New Scientist* vol 95, p 912). Now Lucy Netzer and Jacob Sagiv, from the Weizmann Institute of Science, Rehovot in Israel have developed a simpler and quicker technique for preparing monolayer films that relies simply on the chemical properties of the starting materials. In effect the molecules assemble themselves (*Journal of the American Chemical Society*, vol 105, p 674). So far, Netzer and Sagiv have made films up to three monolayers thick using the new method.

The standard technique for producing monolayer films was pioneered by Langmuir and Blodgett (LB) in the 1930s. It employs mechanical means to organise molecules into a monolayer on the surface of a liquid. This layer can be transferred onto the surface of another material by dipping the latter into the liquid. Repeated dipping will produce films many monolayers thick. The drawbacks of the LB procedure are that it is slow, not easily applied to large areas and doesn't always produce a film with the desired structure.

Scientists examining alternative approaches are attracted to the idea of using molecules that are chemicals designed to assemble themselves into a film. Netzer and Sagiv designed a long chain molecule with a reactive chemical group at one end and an inert group at the opposite end. They chose a reactive group that would bind to a solid surface with hydroxyl groups (–OH) sticking out. They hoped that the molecules would react with the surface to form a film, with the long chains all sticking out like a field of corn. Since the outermost ends of the molecules are unreactive the reaction should stop after one monolayer has formed.

They tried their idea out on a piece of glass which they dipped into a solution containing their compound. Within two minutes a monolayer was produced. The reactive heads of the molecules could also react with one another, forming cross-links that made the film very strong. Chloroform, which easily dissolved the original compound, did not remove the monolayer.

To prepare multilayer films, the Israeli scientists first needed to modify their special molecule. They replaced the unreactive end with a new chemical group. Although this group is inert, it could be turned into an hydroxyl group at a later stage. The outer surface would then be covered with hydroxyl groups, like the original surface, and the process could be repeated.

By repeating this "activation" process twice, the researchers managed to make a film three monolayers thick. However, the second and third layers were 20-30 per cent less compact than the first.

These experiments demonstrate clearly that self-assembly is a feasible approach to monolayer formation. The design of the molecule predetermines the structure of the film and covering large areas should prove no problem—important advantages over the LB technique. □

Self-assembling monolayer films

The new technique uses molecules that can self-assemble—their reactive ends bonding with hydroxyl groups on the glass surface, and their unreactive ends sticking upwards. The monolayer can be activated to procuce bi- and trilayers

► He then continued his series of basic studies on the structure and properties of self-assembling monolayers and multilayers (e.g. R. Maoz and J. Sagiv, *J. Colloid Interface Sci.* **1984**, *100*, 465; R. Maoz, L. Netzer, J. Gun, and J. Sagiv, *J. Chim. Phys.* **1988**, *85*, 1059), while coauthoring the first reports, together with M. Lahav

and L. Leiserowitz, on the use of organized organic monolayers as templates for the control of 3D crystal growth (E. M. Landau, M. Levanon, L. Leiserowitz, M. Lahav, and J. Sagiv, *Nature* **1985**, *318,* 353; E. M. Landau, S. Grayer Wolf, M. Levanon, L. Leiserowitz, M. Lahav, and J. Sagiv, *J. Am. Chem. Soc.* **1989**, *111*, 1436), and the first report (together with I. Rubinstein and A. Shanzer) on the design and successful practical realization of a self-assembling monolayer membrane for specific electrochemical sensing (I. Rubinstein, S. Steinberg, Y. Tor, A. Shanzer, and J. Sagiv, *Nature* **1988**, *332*, 426).

► Together with R. Maoz, he later discovered and investigated expandable self-assembling multilayers with interlayer hydrogen bonding and their use as 3D templates in the hierarchical self-assembly of superlattices with evolving structural/compositional complexity (R. Maoz, R. Yam, G. Berkovic and J. Sagiv, in: "Organic Thin Films and Surfaces: Directions for the Nineties", (A. Ulman, Ed.), *Thin Films*, Vol. 20, 41-68, Academic Press, San Diego, **1995**).

► "Self-replicating multilayers" are a new class of artificial layer systems, discovered together with R. Maoz in 1995, which allow, for the first time, planned chemical deposition of more than a single ordered monolayer in a single assembly step (R. Maoz, S. Matlis, E. DiMasi, B. M. Ocko and J. Sagiv, *Nature* **1996**, *384*, 150; R. Maoz and J. Sagiv, *Adv. Mater.* **1998**, *10*, 580).

► Results of a first study (together with R. Maoz) of non-thermal microwave-induced chemical modifications of organized monolayer systems were published in 1998 (R. Maoz, H. Cohen, and J. Sagiv, *Langmuir* **1998**, *14*, 5988).

► The invention of *constructive nanolithography* (CNL) – combining self-assembly techniques with non-destructive electrochemical monolayer patterning using a conductive AFM tip – paved the way to the advancement of a bottom-up chemical approach to nanofabrication (e.g. R. Maoz, E. Frydman, S. R. Cohen, and J. Sagiv, *Adv. Mater.* **2000**, *12*, 725; S. Liu, R. Maoz, and J. Sagiv, *Nano Lett.* **2004**, *4*, 845; D. Chowdhury, R. Maoz, and J. Sagiv, *Nano Lett.* **2007**, *7*, 1770).

► Rapid parallel patterning of monolayer films – *constructive microlithography* (CML) was then advanced by replacing the scanning AFM tip employed in *constructive nanolithography* with a conductive stamp (S. Hoeppener, R. Maoz, and J. Sagiv, *Nano Lett.* **2003**, *3*, 761).

► Using the monolayer pattern itself as stamp was recently shown to offer the unprecedented option of one-step *contact electrochemical replication* of entire monolayer patterns (S. Hoeppener, R. Maoz, and J. Sagiv, *Adv. Mater.* **2006**, *18*, 1286; A. Zeira, D. Chowdhury, R. Maoz, and J. Sagiv, *ACS Nano* **2008**, *2*, 2554). These novel strategies for the generation and effective processing of chemical information imprinted on a molecular surface layer establish a basis for the advancement of a unified bottom-up nanofabrication methodology applicable over the entire range of relevant dimensions from nanometer to centimeter.

The 2005 Prize for Excellence of the Israel Chemical Society: *…"to Professor Jacob Sagiv for his pioneering contributions to modern surface science by developing the self-assembly method of ordered arrays of molecules on surfaces."*
In 2010, J. Sagiv was awarded the Kolthoff Prize in Chemistry for his contributions to the Self-Assembling Monolayers research (awarded by the Technion - Israel Institute of Technology).