Metal organic alloys: a new class of materials of immense potential

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The last barrier amid conventional chemistry disciplines broke in 2002 when Avnir and co-workers in Israel reported the discovery of a new hybrid material: a noble metal (silver) molecularly doped with organic molecules (1). Not only water-soluble Congo red, Safranin-O, and thionine were successfully entrapped in metallic silver, but also Sudan III insoluble in water could be entrapped by dissolving it with sodium dodecyl sulfate.

It is enough to reduce Ag^+ dissolved in water with a reducing agent like sodium hypophosphite in the presence of the organic molecules dissolved or emulsified, to obtain a completely unexpected class of materials for which we in 2009 coined the term MORALS (metal-organic alloys) (2).

A new type of alloy, accessed at room temperature via a wet and mild chemistry process, upon which organic molecules are *not* adsorbed at the surface of the metal but rather 3-dimensionally caged within the narrow pores of agglomerated metal nanocrystals.

Reviewing the new field in 2014, Avnir emphasized how the newly achieved ability to functionalize metals with any "the many millions of organic, inorganic, and bioorganic molecules" and their "rich library of chemical, biological, and physical properties that do not show up among the approximately 100 metals" (3).

Figure 1. A MORAL comprised of Ag entrapping a bactericidal organic species.
[Photo courtesy of Prof. Yael Albo, Ariel University].

From both the fundamental and the applied research viewpoints, MORALs are truly exceptional materials offering along with novel properties, entirely new possibilities including that to modify the most fundamental attributes of metals such as copper, gold and silver and their numerous applications.

Regardless of many findings concerning the application of new MORALs to fields as important as chemical catalysis and antibacterial materials (Figure 1), for more than fifteen years these new materials remained the object of academic studies published in leading chemistry and materials science journals.

Then in mid-2019 a joint team in Israel reported a major discovery that is poised to enable low cost hydrogen fuel cells: an ionomer@Ag MORAL used to produce the cathode of an anion-exchange membrane fuel cell dramatically enhances its performance when fueled with hydrogen and air (4).
The organic molecule entrapped in silver is FAA-3, namely a polyaromatic polymer widely used in making the membrane of alkaline fuel cells. Compared to more efficient and durable proton exchange membrane (PEM) fuel cells used in today's hydrogen fuel cell electric vehicles in which the ion exchanged is proton (H^+) and the electrocatalyst at both anode and cathode is platinum, in alkaline fuel cells the ion exchanged is the hydroxide anion (OH^-) and the electrocatalyst promoting O_2 reduction can be silver.

Using the ionomer@Ag MORAL to produce the cathode of an anion-exchange membrane fuel cell, the team reported a peak power density value of ~200 mW cm-2, which is more than one order of magnitude higher than the peak power density obtained with the standard Ag electrocatalyst (~12 mW cm^{-2}).

Replacing the previously separated organic species (the polymer) and metal (the electrocatalyst) with a MORAL enabled the team to impart the electron conducting Ag electrocatalyst with new ionic conductivity properties completely absent in pure Ag.

Now that stable polymeric membranes for alkaline fuel cells are available (5), anion-exchange membrane (AEM) fuel cells will suddenly attract the interest of the hydrogen fuel cell industry due the well-known, but so far unfulfilled, potential of the technology to greatly reduce the cost of fuel cells.

Similar dramatic progress, we anticipate, will concern many domains of the chemical, energy and metal industries.
The chemical industry will both make and use metal-organic alloys for milder and greener chemical productions.
The industry of new energy technologies will use MORALS both for new generation hydrogen fuel cells and Li-ion batteries.
The metal industry will find in these materials a new opportunity to diversify its offer, by integrating the MORAL production in its production processes.

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