

## Elements on Demand – the Infinite Alchemy?

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Programming is powerful because code determines the complex paths that electrons follow within a logic chip and that determines system events. A program can simulate reality and let us experience the future. The Boeing 777 aircraft flew on a computer before it was ever built. But what else can we program besides semiconductor chips? The DNA molecule is considered to be the *program of life* and a single strand may hold the equivalent of 1 million pages of code. Your DNA “program” determines what you look like and a lot more. Molecules are made up of atoms consisting of subatomic particles. So if molecules can be “programmed”, then what about atoms? Could we re-program an atom to control how it would behave and what elemental properties it displayed? Perhaps!

Material science operates on the theory that matter is made of molecules containing atoms composed of protons, neutrons and electrons. The chemical elements fall neatly into property groups, or families, based on the number of electrons surrounding each atomic nucleus. This is the basis for the periodic table and the 92 natural elements. We believe that properties of the elements are primarily determined by the electron configuration around the nucleus. The electrons are thought to have quantized wave motion that can be depicted as an electron cloud. Could we somehow modify the electronic waveform of one element to mimic a different one? What would happen if we did perturb the electronic wave function of a semiconductor, like silicon, to make it behave like something else? If the Si electron cloud were programmed to behave like the one surrounding a gold nucleus, would we see a piece of bright metal instead of a slice of silicon? Some, like Wil McCarthy (author and Wired Magazine columnist) say yes, and he defines programmed matter (PM) as a material whose properties can be adjusted by the application of energy, such as light, electrical, magnetic, etc. And this is the dream of the new alchemists who seek to deliver “infinite alchemy”, any properties by design and on demand. Programmed matter would change properties when we applied external energy and switched on the change, or perhaps we could have a selection of changes.

Programmed matter would be made up of *artificial atoms* - manmade systems based on nanotechnology that confine electrons in a special way. Artificial atoms can be made using nanoscale semiconductor structures, like the quantum dot (QD), that confines electrons in a very tiny 3-dimensional space that force them into quantum wave function behavior. Trapped electrons in a QD behave like an electron cloud around atomic nucleus. Negatively-charged electrons repel one another to form a diffuse cloud, the opposite of real atoms where electrons are attracted to the positive nucleus. A QD is usually made within a very thin 10 to 30 nm PN junction. Researchers are fascinated by quantum dots, especially those that emit light because such dots are expected to become the basis for a new generation of lasers.

Quantum mechanics dictates that electrons confined in a small enough region can only assume discrete energies. A QD device traps particle electrons in a space so small that an electron waveform results to generate an artificial atom. Advanced photolithography makes it possible to produce nano spaces that quantize the electron’s charge and energy. The QD can be fashioned as a tiny bump on a substrate by etching away surrounding material. Isolating a small volume of the material with electric fields using overlying metal electrodes can make a dot-like region within a semiconductor sandwich. Semiconductor QDs can be fabricated from indium arsenide embedded in gallium arsenide and grown using techniques developed within the past decade that allow much smaller nanostructures to be created. A planar array of millions of dots could form an artificial atomic lattice. Scientists have created such arrays but have not yet been able to control crystalline uniformity and electrode placement precisely yet. The QD array of artificial atoms becomes our piece of programmed matter. QD artificial atoms are currently one of the hottest research fields in semiconductor physics.

Can we really hope to transmute silicon into gold or other valuable elements – even “impossible” ones? And in the future, will we simply program matter to produce designed properties on demand? And is there a reasonable chance that we could produce artificial compounds by reacting artificial atoms? All 3 may be possible.

But let's keep in mind that natural atoms are here for the taking. Artificial atoms must be made, a few at a time, using painstaking processes – at least for now. And during power failure, the “gold” would revert back to silicon rock.

How far along is programmable matter? The simplest examples, like electro- and thermo-chromic materials are already here. Self-tinting eyeglasses are an old, low-tech example. Moving beyond the relatively easy optical phenomenon could be up to a decade away. But sooner or later, physics, chemistry and *atomic programming* will come together for the Ultimate Alchemy – Virtual Unreality!