An Elemental View of Optoelectronics and Electronics

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We've tracked optoelectronics and related topics like optical MEMS for a few years. Much coverage was at the module and systems level, but what about the actual devices? How different are optoelectronic (OE) devices from ordinary electronic diodes and transistors? Electronics is obviously based on electrons while optoelectronics adds and emphasizes photons. Atoms contain subatomic particles, called electrons with a negative charge and specific mass. Electrons readily travel along copper conductors because metals easily release and share electrons forming a conductive *"sea of electrons"*.

Photons, while not a component of atoms, are very useful and this is what photonics is about. Photonics is a very broad technology that harnesses the photon to do all kinds of tasks. Areas include communications, displays, imaging, detection, materials processing, analysis, testing and much more to make photonics an all-encompassing field. Photonics is older than electronics if we include astronomy, the oldest science. And if you want a date for an early photonic invention, 1880 was the year when Alexander Graham Bell demonstrated his wireless Photophone that sent voice over light. Photonics is still the "darling" advanced technology that is indispensable for high-speed Internet communications that relies on photons as *speed-of-light* marathon *instant messengers*. The photon has no charge and no mass (under most circumstances). It's pure energy that doesn't care to stop and wait except in exotic research laboratories. Photons are the long-distance champions boasting a 1-million times higher proficiency than promiscuous electrons that want to park and play. Photons produced at the moment of creation (theory), have traveled for billions of years to just now reach the Hubble telescope.

Optoelectronics (OE) is a subdivision of photonics – a hybrid technology that blends photons and electrons. Electrons easily generate photons using solid-state devices like LEDs and lasers. Photons can then be employed for well-suited tasks like traveling around the world within thin glass fibers. These data-rich photons can then be converted back to electrons at the end of the optical fiber with receivers (photodetector diodes). Once back into electronic format, *tried and true* electronics is applied. Since it is extremely difficult to store photons (no practical photonic capacitor) or use them in computing, the traditional strategy is to inter-convert as necessary. This provides the best of both worlds where photons and electrons are each harnessed for optimum tasks.

Most solid-state electronic devices are based on silicon, a natural element with four electrons in the outer shell (orbit). But molecular structures favor eight electrons in the outer shell. Adjacent silicon atoms, with 4 outer electrons each, can equally share to yield the *magic eight*. But if we add a dopant, an element with either 5 or 3 outer electrons, this creates an unbalanced semiconductor lattice with either one extra (negative) or one deficient electron (hole). Holes (P) and extra electrons (N) provide charge-transfer characteristics – the material has no net electrical charge. This is the basis for making N- and P-doped silicon that combine to form the all-important P-N junctions of diodes and transistors.

OE uses many of the same principles as solid-state electronics. Optoelectronic P-N junctions are formed but photonic characteristics are enhanced. Although silicon electronic devices can emit light and have photosensitivity, these photoelectric effects are purposely suppressed to prevent problems. Conversely, OE devices are highly optimized for photonic responses. Although silicon is a starting point for optoelectronic devices, other elements are much better for delivering the right band gaps (determines wavelength response) to produce desired light characteristics and sensitivity. A photon is produced when an excited atomic electron drops back to its normal ground state. Gallium arsenide (GaAs) comes closer and is used extensively in OE. But it takes many other elements to build all the devices and achieve optimum performance. Indium (In), phosphorus (P), and aluminum (Al) can be used to make good photodiodes. So in addition to GaAs-based devices, we use InP, GaInP, AlGaAs, and InGaAsP. But there's more. Other elements found in OE devices include oxygen (O), yttrium (Y), erbium (Er), magnesium (Mg), fluorine (F), lead (Pb), gold (Au), platinum (Pt), palladium (Pd), germanium (Ge), iron (Fe), chromium (Cr), rubidium (Rb), lithium (Li), niobium (Nb), praseodymium (Pr), titanium (Ti), nickel (Ni), nitrogen (N), silicon (Si) and all kinds of combinations of elements. These elements are incorporated into the structures and are not process chemicals. Wow, we're talking about a big chunk of the periodic table!

Viewed from the chemist's angle, optoelectronics is like solid-state electronics, but with too many elements. Why too many? OE devices are made with elements and combinations that can be incompatible with other OE device compositions. This will create real problems for wafer-level integration. Although the optical IC has other hurtles, materials processing and chemical incompatibility will be a challenge.

Simply put, the fundamental difference between optoelectronics and electronics is ***elementary***.