Wireless nanowire lasers absorb infrared, emit blue light

Enlarge / This article is about lasers (not necessarily the one pictured).

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Some of us are anxiously awaiting the photonics revolution, where photons will band together to overthrow the tyranny of electrons. One of the perpetual problems that’s slowing up the revolution is light sources: you need to have a laser that is coupled to a circuit that is going to do something. All of this has to be on a tiny scale that can compete with electronics. It shouldn’t consume much power either.

That’s a hard collection of hurdles to clear. But there is a loophole: a photonic circuit could have the sort of application that electronic devices don’t do very well.

Now, researchers have used that loophole as an excellent excuse to do a very cool experiment in powering lasers. The researchers showed how to power a laser with a laser—something that anyone with a modicum of laser physics knowledge can do. However, this is quite different: the powering laser changes the electronic structure of the medium to trick it into lasing.

Return of the band gap

Before we jump into the details, let’s take a quick trip down population inversion lane to visit the semiconductor laser. From our perspective, a semiconductor consists of electrons that are trapped in the valence band (where they cannot move) and electrons in the conduction band (where they can move). There’s an energy gap between the highest energy electron in the valence band and the lowest energy electron that can conduct.

For an electron to go from the valence band to the conduction band, it has to gain at least enough energy to cross the gap. For an electron to return from the conduction band to the valence band, it has to lose enough energy to cross the gap. It can make these transitions by absorbing or emitting a photon of light.

To get a semiconductor laser, electrons have to be excited from valence band to the conduction band so that they emit light as they lose energy and return to the valence band. On its own, this will get you a light emitting diode. To turn that into a laser, you have to achieve population inversion, which means that you have to have more electrons in the conduction band than in the valence band.

Once that is achieved, stimulated emission can take over. The presence of a light field drives the electrons in the conduction band to emit light of the same color and traveling in the same direction as the field.

Getting a semiconductor laser to go is really easy with a battery: you just supply current at the right voltage and you’re done. But you don’t have to use a battery. You can also supply light with photons at an energy greater than the gap. Let’s say that your semiconductor material will naturally emit red light as electrons cross the gap. If you pump in green light, the green photons will excite electrons. The overly-

excited electrons will bounce around like toddlers mainlining sugar, losing energy as they go, until they hit the bottom of the conduction band. At this point, the electron will emit a photon and return to the valence band.

Put in sufficient green light, and you will get a red-light emitting laser.

Bending the band gap

Now, imagine that you have an entire stack of lasers that you can’t hook up to wires, so you want to power it with light. Your green laser is not going to work. The problem is the top laser on the stack will absorb almost all the light. If you turn the power of the green laser up to force more light through, it is going to burn the top laser before it powers the next laser in the stack.

This is where the researchers’ new work comes in. Let’s return to our picture of a semiconductor. All the electrons are sitting at low energy, trapped in the valence band. Instead of directly absorbing energy, electrons can also tunnel through barriers to get to the conduction band. For this to work, the energy difference between the conduction band and the valence band needs to be reversed. This can be done by applying a very large electric field to the semiconductor. The field raises the energy of the valence band and drops the energy of the conduction band, allowing electrons to jump to the conduction band.

The researchers apply that field using a very bright laser, which works because light has an electric field. When the light is turned on, the electrons can tunnel from what is now a high energy valence band to the low energy conduction band. After the laser is switched off, the conduction band energy increases, dragging the electrons with it.

Suddenly, the semiconductor finds itself with lots of

electrons at high energy wanting to emit light. Hence, a laser is born.

Wireless lasers

The cool thing about this is that the color of the light used to drive the laser doesn’t matter much. The only conditions is that the photon energy should be much lower than the energy required to excite an electron to the conduction band. That means you can choose a color that suits the application (e.g., choosing light that is transparent to the material in which the photonic circuit is embedded). Mostly, you don’t have to worry about which color of light suits the semiconductor material.

It also works best on tiny lasers, like nanowires of Zinc Oxide (this is the material the researchers used). These are the types of lasers that are best suited to photonics applications that need to use inert materials—oxides are very unreactive—and need to be small. Finally, because the lasers only turn on when the light focuses on them, you can switch between different lasers by shifting the point of focus (admittedly, the lasers need to be spaced by quite a large distance in this case).

So, where will these be used? I’ve no idea at this point, and I don’t really care—I just love the physics. More seriously, it takes a very bright light to turn a laser on like this (think ~1TW/cm^2), so the applications will certainly be niche.

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