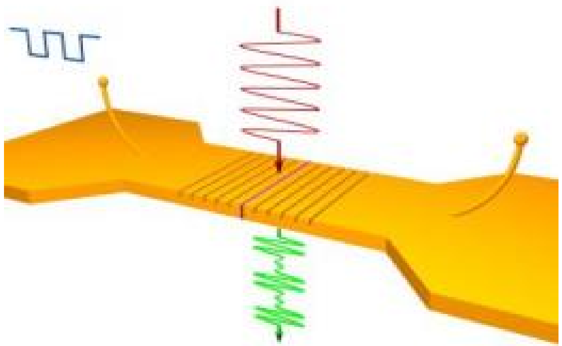
Nanoscale nonlinear light source created

September 22 2011



This schematic shows two gold electrodes separated by a nanoslit filled with a nonlinear material. Nanoscale grating on either side of the slit directs plasmonic waves toward the slit intensifying the light field by 80 times. A small voltage is applied to the electrodes producing a massive electrical field across the narrow slit producing an EFISH light source. Credit: Mark Brongersma

Not long after the development of the first laser in 1960 scientists discovered that shining a beam through certain crystals produced light of a different color; more specifically, it produced light of exactly twice the frequency of the original. The phenomenon was dubbed second harmonic generation.

The green laser pointers in use today to illustrate presentations are based on this science, but producing such a beautiful emerald beam is no easy feat. The green light begins as an infrared ray that must be first processed through a crystal, various lenses and other optical elements before it can illuminate that PowerPoint on the screen before you.

It was later discovered that applying an electrical field to some crystals produced a similar, though weaker, beam of light. This second discovery, known as EFISH – for electric-field-induced second harmonic light generation – has amounted mostly to an interesting bit of scientific knowledge and little more. EFISH devices are big, demanding high-powered lasers, large crystals and thousands of volts of electricity to produce the effect. As a result, they are impractical for all but a few applications.

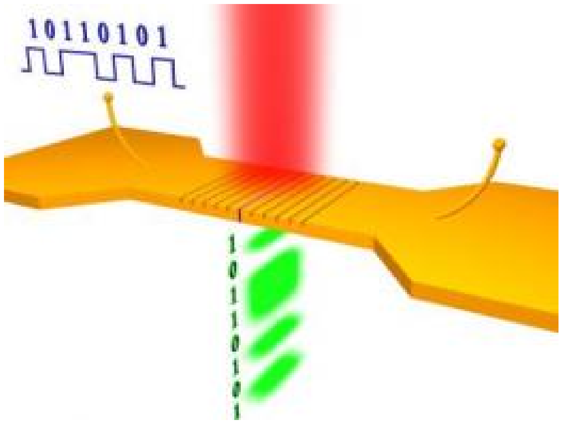
In a paper published today in *Science*, engineers from Stanford have demonstrated a new device that shrinks EFISH devices by orders of magnitude to the nanoscale. The result is an ultra-compact light source with both optical and electrical functions. Research implications for the device range from a better understanding of fundamental science to improved data communications.

Spring-loaded electrons

The device is based on the physical forces that bind electrons in orbit around a nucleus.

"It's like a spring," said Mark Brongersma, an associate professor of materials science and engineering at Stanford.

In most cases, when you shine a light on an atom, the added energy will pull the electron away from the positively charged nucleus very predictably, in a linear fashion, so that when the light is turned off and the electron springs back to its original orbit, the energy released is the same as the light that displaced it.



This schematic demonstrates how the EFISH device's dual electric and optical functions could be used to communicate data in a chip-based environment. Credit: Mark Brongersma

The key phrase here being: "in most cases." When the light source is a high-intensity laser shining on a solid, researchers discovered that the farther the electrons are pulled away from the nuclei the less linearly the light interacts with the atoms.

"In other words, the light-matter interaction becomes nonlinear," said Alok Vasudev, a graduate student and co-author of the paper. "The light you get out is different from the light you put in. Shine a strong near-infrared laser on the crystal and green light exactly twice the frequency emerges."

Engineering possibilities

"Now, Alok and I have taken this knowledge and reduced it to the nanoscale," said the paper's first author, Wenshan Cai, a post-doctoral researcher in Brongersma's lab. "For the first time we have a nonlinear optical device at the nanoscale that has both optical and electrical functionality. And this offers some interesting engineering possibilities."

For many photonic applications, including signal and information processing, it is desirable to electrically manipulate nonlinear light generation. The new device resembles a nanoscale bowtie with two halves of symmetrical gold leaf approaching, but not quite touching, in the center. This thin slit between the two halves is filled with a nonlinear material. The narrowness is critical. It is just 100 nanometers across.

"EFISH requires a huge electrical field. From basic physics we know that the strength of an electric field scales linearly with the applied voltage and inversely with the distance between the electrodes – smaller distance, stronger field and vice versa," said Brongersma. "So, if you have two electrodes placed extremely close together, as we do in our experiment, it doesn't take many volts to produce a giant electrical field. In fact, it takes just a single volt."

"It is this fundamental science that allows us to shrink the device by orders of magnitude from the human scale to the nanoscale," said Cai.

Enter plasmonics

Brongersma's area of expertise, plasmonics, then enters the scene. Plasmonics is the study of a curious physical phenomenon that occurs when light and metal interact. As photons strike metal they produce waves of energy coursing outward over the surface of the metal, like the ripples when a pebble is dropped in a pond.

Engineers have learned to control the direction of the ripples by patterning the surface of the metal in such a way that almost all of the energy waves are funneled inward toward the slit between the two metallic electrodes.

The light pours into the crevice as if over the edge of a waterfall and there it intensifies, producing light some 80 times stronger than the already intense laser levels from which it came. The researchers next apply a modest voltage to the metal resulting in the tremendous electrical field necessary to produce an EFISH beam.

Practical applications

"This type of device may one day find application in the communications industry," says Brongersma. "Most of the masses of information and social media interaction we send through our data centers, and the future data we will someday create, are saved and transmitted as electrical energy – ones and zeros."

"Those ones and zeroes are just a switch; one is on, zero is off," said Cai. "As more energy-efficient optical information transport is rapidly gaining in importance, it is not a great leap to see why devices that can convert electrical to optical signals and back are of great value."

For the time being, however, the researchers caution that practical applications remain down the road, but they have created something new.

"It's a great piece of basic science," said Brongersma. "It is work that combines several disciplines – nonlinear optics, electronics, plasmonics, and nanoscale engineering – into a really interesting device that could keep us busy for awhile."

Provided by Stanford University