Variations on Microtoroids and Their Uses

Kim Venta
Supervisor: Professor Lan Yang

Department of Electrical and Systems Engineering
Washington University in St. Louis
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Abstract

Microresonators have many applications from biomedical detecting to computing [1-8]. This semester I studied two such applications and began work researching them. The first microresonator application is to improve the ability of titanium dioxide to use light to create a current or turn water into hydrogen and oxygen for fuel[9-10]. The second use is to make a microlaser using quantum dots as a gain medium[11]. For both projects, the more useful microresonator shape is the microtoroid instead of a microsphere, since a microtoroid can be integrated with other devices on a chip much more readily than a microsphere can.

Overview

Microresonators are optical devices that can trap light and have a width on the order of microns [12]. They are often in the shape of spheres (Figure 1) or toroids (Figure 2). Light can be evanescently coupled (light travels briefly through a forbidden region of space into an allowed region) into the microresonator using a tapered waveguide. From basic wave properties we know if the circumference of the microresonator is an integer number of the wavelength of the light coupled into it, a photon coupled into the system will interact constructively with itself and light can be trapped in the microresonator by continuous total internal reflection. This is a whispering gallery mode, or WGM.

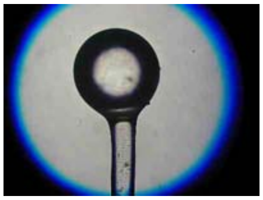

Figure 1

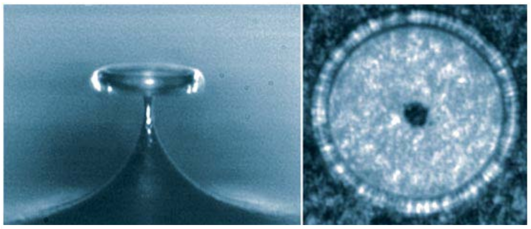

Figure 2

Researchers use microtoroids a great deal and publish many new papers each year. Silicon dioxide microresonators are now widespread, and papers exist concerning the use of erbium doped microresonators as lasers (some written by Washington University's own Dr. Lan Yang)(Kippenberg 051802-1)[5,13-16].

The first project I worked on was making microtoroids out of titanium dioxide instead of silicon dioxide. Titanium dioxide has the property that, with the aid of ultraviolet light, it can generate electricity or separate water into hydrogen gas and oxygen gas[17-18]. This makes titanium dioxide extremely promising for use with alternative energy sources. Electricity production makes titanium dioxide a solar power source, and hydrogen gas is useful for hydrogen powered cars. The limiting factors on titanium dioxide's usefulness are the wavelengths of light these processes work with (solar light is mostly in the visible spectrum, not the ultraviolet, which is why our eyes are adjusted to see visible light), and its low efficiency (a measure of how much energy is obtained from the system given the amount of energy put into the system).

Various groups are working on different methods of lowering the band gap of titanium dioxide and increasing the efficiency. The method we looked into involves using titanium dioxide microresonators instead of a thin film to absorb solar radiation. The hypothesis is that while most light will pass through the microresonators and interact once with the titanium dioxide in the same way it would with a thin film, some of the light will couple with the resonators and become trapped. These photons can interact multiple times with the titanium dioxide and increase its efficiency.

This experiment is still in its theoretical stages. The materials needed to create titanium dioxide microtoroids have just recently arrived, and experiments to fabricate and test these microtoroids should begin soon.

The second project I worked on involves using quantum dots instead of erbium doping for a lasing medium in microlasers[19]. Quantum dots are nanometer sized structures that can still act as atoms or molecules when dealing with excitation levels. Because quantum dots act in a similar way to atoms, they emit light at discrete wavelengths. These wavelengths occur at integer divisions of the length of the quantum dot for much the same reason that WGMs occur at integer divisions of the circumference of a microtoroid. One flaw that inhibits the use of quantum dots as a gain medium is that quantum dots intermittently stop emitting photons [20]. This is due to a process known as Auger ionization. Auger ionization causes a photon released in a gain medium to interact with an electron so that the electron is ejected from the material, not a photon. This electron will not add to the laser gain and thus compromises the laser. This ionization can be overcome, and my project was to make a quantum dot laser.

The method I looked into involves combining the ideas of microtoroid lasing and quantum dots as a lasing medium. We will add quantum dots to microtoroids instead of doping the microtoroid material with erbium and see if we can get lasing. This experiment is also still in the theoretical stages. Quantum dots are on their way and the fabrication of microtoroids with these quantum dots should begin soon.

Conclusions

Though both of these projects have not been run experimentally, the photonics lab is brand new and still in the process of gathering all of the necessary equipment. Meanwhile, much progress has been made on developing the ideas that will be required to make these projects work.

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