SUGGESTED REFERENCES

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- *Topics in Applied Physics, vol 94*: **Silicon Photonics** Edited by Lorenzo Pavesi and David J. Lockwood. (Springer-Verlag Heidelberg, 2004).
- *Rocky Mountain Research Center* www.rmrc.org Click on the "cool photonic science" link.
- *Silicon Photonics, Research and Development at Intel*, http://www.intel.com/labs/sp/
- *Professor Sajeev John Research* Home, http://www.physics.utoronto.ca/~john/
- *Description of Photonic Crystals*, http://encyclopedia.thefreedictionary.com/photonic%20crystals

NATIONAL SCIENCE EDUCATION STANDARDS

5 - 8

Physical Science
Properties and Changes of Properties in Matter
Transfer of Energy

Science and Technology
Understandings About Science and Technology

Science in Personal and Social Perspectives
Science and Technology in Society

9 - 12

Physical Science
Interactions of Energy and Matter

Science and Technology
Understandings About Science and Technology

**Source: National Science Education Standards, 1996, National Academy Press*

CREDITS

The producers thank Electric Sky for materials used in this program.

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VOLUME 35 ISSUE 5

LIGHT MACHINES - PHOTONIC DEVICES OF THE FUTURE

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SYNOPSIS

This program explores the development of photonic devices. They are being developed to replace electronics in devices such as microprocessors. Light is much faster than electrons, and hardware that can control photons will lead to products that are thousands of times faster than current electronics.

Students will see how science and technology interact to help develop the key components of photonic devices. They will begin to understand the relationship between new ideas developed by scientists and the products that can result when scientists collaborate with computer engineers.

CURRICULUM UNITS

- CHEMISTRY
- COMPUTER ENGINEERING
- ENGINEERING
- INTEGRATED SCIENCE
- PHYSICS
- SOFTWARE ENGINEERING

RUNNING TIME

15:40

BACKGROUND

Electronic computers have been at the center of the technology revolution for over forty years. Electronic devices resulted from work on electricity. We have been exploiting electrons to drive electrical devices for over a hundred years. The problem with electrons is that they carry a charge. Because of this, they can be repelled by like forces and you can't get two electrons to run in opposite directions on the same wire because they would interfere with each other.

The properties of light photons have been used for many years, but we have never been able to control light photons in the same way that we control electrons. The photoelectric effect, using light energy to drive a flow of electrons, is used in solar powered calculators, but we have not been able to capture light photons to actually control a device.

In 1986 Sajeev John and Eli Yablonovich each independently conceived of a material that would block light from traveling in any direction except for one. The two men met and named their materials "photonic band gap materials." These materials would be analogous to opals, a naturally occurring gemstone primarily composed of silicon.

Capturing light led scientists to try to conceive of ways to move the light around so that there would be no loss. If you look at a typical light source, such as a light bulb, the light is diffuse; it spreads out equally in all directions. Capturing any wavelength of that light is possible, but it would represent only a small portion of the total energy produced. Most of the light energy would be lost.

The source of light could not be natural light. Laser light was determined to be the best source of light, but lasers are expensive and large. Engineers were able to manufacture a class of laser that could be switched on and off rapidly. This laser, known as a ViCSEL, is a microscopic device that is can fit easily onto a typical silicon wafer.

Once the light source was developed, scientists and engineers had to develop a process to create the photonic band gap structure on the same silicon wafer as the lasers. The process uses techniques similar to those used to produce transistors on microprocessors. Engineers needed to carve out tubes that resemble a diamond crystal lattice. John and Yablonovich have been working on this for many years, but the process has finally been worked out and a silicon semiconductor that acts as photonic band gap material is now functioning.

Finally, the optical device needed a switch, a way to control the photons of light so that they go wherever the engineer wants them to go in the circuit. Most scientists thought that mirrors would work best because none of the light energy would be lost from the reflection off the mirror. But mirrors on a micro, or nanoscale were too hard to control. So scientists looked for other ways. One group devised a technique that used gas bubbles to direct the light. The bubbles could be captured within the silicon wafer and placed at junctions to reflect light in any direction. Because of their extremely low cost and ease of manufacture, gas bubbles turned out to be an excellent solution.

The development of photonic microprocessors allows us to take advantage of the properties of light to build faster computers and devices that are simply not possible with electronic microprocessors. This will result in new devices that will allow us to communicate large amounts of data instantaneously.

ADVANCED ORGANIZERS

Prior to showing this video, students should have some understanding of the following benchmarks for Science Literacy, Oxford University Press which are excerpted and, in some cases, abbreviated below. Refer to the Benchmarks for more information.

Benchmark 3: The Nature of Technology

Section A - Technology and Science
Know by Grade 8
- Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems. But they usually have to take human values and limitations into account as well.

ADVANCED ORGANIZERS (continued)

Know by Grade 12
- Technology usually affects society more directly than science because it solves practical problems and serves human needs (and may create new problems and needs). In contrast, science affects society mainly by stimulating and satisfying people's curiosity and occasionally by enlarging or challenging their views of what the world is like.

Benchmark 4: The Physical Setting

Section F - Motion
Know by Grade 12
- Waves can superpose on one another, bend around corners, reflect off surfaces, be absorbed by materials they enter, and change direction when entering a new material. All these effects vary with wave length. The energy of waves (like any form of energy) can be changed into other forms of energy.

Section G - Forces of Nature
Know by Grade 12
- Different kinds of materials respond differently to electric forces. In conducting materials such as metals, electric charges flow easily, whereas in insulating materials such as glass, they can move hardly at all. At very low temperatures, some materials become superconductors and offer no resistance to the flow of current. In between these extremes, semi conducting materials differ greatly in how well they conduct, depending on their exact composition.

**Benchmarks can be found at www.project2061.org/tools/benchol/bolintro.htm*

CRITICAL THINKING EXERCISES

1. Compare an electronic microprocessor and a photonic microprocessor.
2. Describe how a computer might look if its components could be widely separated from each other.
3. Describe ways in which scientists and engineers might work together to build a new device.
4. Explain why scientists are dependent on engineers to develop new tools to answer scientific questions.
5. Design an experiment to test the photoelectric effect using a solar powered calculator.
6. Compare the properties of photons of light and electrons.

VOCABULARY

Electromagnetic Spectrum
Iridescent
Laser
Laser Diode
Optical switch
Optoelectronic devices
Photoelectric effect
Photonic band gap materials
Photonic device
Photons
Semiconductor

CAREER POSSIBILITIES

- CHEMIST
- COMPUTER ENGINEER
- PHYSICIST
- SOFTWARE ENGINEER