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Detector registers polarized light -- Single device could replace complex and bulky optical components in MO drives

By Gail Robinson

Boston - A novel device architecture that detects not only light but also its polarization could substantially reduce the number of optical components in a range of systems. Using traditional semiconductor fabrication methods, researchers at Boston University have designed a single mesa device consisting of two vertically integrated photodetectors that differentially respond to incident polarization. The monolithic device eliminates the need for several discrete components, such as polarization filters and beam splitters, thus cutting out critical alignment problems that make many optical systems difficult to manufacture.

New optical component

Image sensors built with the devices would represent an essentially new type of optical component. "Sensitivity to polarization of light is similar to full-color imaging, where the eye can pick out details against a background based on color differences," explained M. Selim Unlu of the Center for Photonics Research at Boston University, who originated the design with colleague Bora Onat. Because the human vision system is not able to detect polarization, there is no natural way to describe the operation of a polarization-sensitive imaging system. However, biologists have determined that some animals have that ability.

"On leaves, the reflection is different for different polarization depending on the coating thickness," said Unlu. "While we cannot see it, other living creatures do." A range of new applications may exist for a compact polarization imager. The military would benefit from an imaging system that could detect ships on the horizon or low-flying missiles, Unlu said. With the sky and water both blue, an object may blend in and not be visible to the eye. Using polarization, light is reflected off the water and is strongly polarized, thus revealing the horizon line in sharp contrast. The study of nature could also offer new possibilities, where the polarization of light reveals more information than humans can directly perceive.

Nearest beneficiary

Unlu also foresees immediate applications in technology, particularly in simplifying magneto-optical read heads. Magneto-optical (MO) drives use polarization to distinguish between a logical 0 or 1. Current MO read heads split a beam of light reflected from the disk and then use two different detectors to sense the relative polarization intensity. A separate prism is required to take the reflected light and separate it into two components. Two separate detectors read the electric and magnetic components of polarization. In addition, the light must be split up again when a quadrature detector is used for alignment tracking. Thus, three or four components must be critically aligned.

Hard drives, with access times of about 7 ms, are inherently faster than MO drives due to the mass of the read head. MO access rates-on the order of 20 ms-result from the bulkiness and weight of the head. In addition, high inertia makes stopping precisely at a specific location difficult. Not only that, but the optical components must be carefully aligned, making the systems difficult to manufacture. A monolithic imager that could directly detect the polarization would eliminate the bulky and error-prone optical components, making MO read heads much more like magnetic disk components.

The Boston University team, which also tapped experts in silicon process design and magnetic optical storage, has also designed masks that could accommodate quadrature detectors or linear arrays of detectors. "The first application may not only replace the separate polarization and detection paths, but also the tracking system-combining all of them into one device," said Unlu. "We would like to demonstrate that we can track the beam and also read its polarization simultaneously with one device." Demonstrations for quadrature deduction-position sensing as well as polarization sensing in a monolithic device-are expected within the next three to four months. The long-term application goal will be making sensor arrays. "We can envision making CCD-like arrays of these devices to build a polarization camera," he said.

The current device structure, which can sense polarization at a single pixel location, is the latest refinement of a detection scheme called resonant-cavity-enhanced (RCE) photodetection. The technique uses a pair of resonant cavities that can be defined in either silicon or gallium arsenide materials systems. The cavities are defined by Bragg reflectors formed by alternating dielectric layers. In the silicon system, the layers are formed from repeating sequences of silicon-silicon dioxide-silicon nitride layers, and in the GaAs system from GaAs-aluminum gallium arsenide-indium gallium arsenide layers. Two such periodic regions form a cavity that traps photons that bounce between the two Bragg reflectors. The quantum efficiency, a measure of the sensitivity of a detector, is controlled by tuning the cavity length to achieve a maximum response.

Slightly recessing the top of one detector causes light arriving at an angle to the pair to be reflected and absorbed at different intensities depending on the orientation of the electromagnetic components of the photons. "If you have transverse electric or transverse magnetic components of polarization, they will behave differently when they strike the top of the detector," said Unlu. "Light will reflect more strongly for transverse electric compared to transverse magnetic components." By registering and comparing the response of the pair of detectors, the ratio of intensity of response can be translated into a measure of the polarization angle of the incoming light.

In order for the RCE scheme to be reliable, both detectors must get exactly the same amount of illumination. That requirement introduced alignment and tuning problems that Unlu was trying to eliminate with the polarization detectors. The latest wrinkle in the design places the two devices on top of one another, creating a single device that is differentially sensitive to magnetic and electric components. Called vertical cavity polarization detectors (VCPDs), they are constructed so that the top resonant cavity traps photons with a large electric vector normal to the surface while transmitting photons with a large normal magnetic vector to the bottom detector. Thus, the combined detectors register a differential response depending on the polarization of the light striking the top surface.

Process described

During the fabrication process, a resonant cavity photodiode is formed by a silicon nitride-silicon dioxide bottom mirror and reflection from the top silicon air interface. The bottom part of the structure is another silicon detector fabricated with standard photolithography ion implantation and metalization processes. A liquid-phase chemical-vapor-deposition process was used to put down a polycrystalline silicon layer on top of the mirrors.

"The big advantage to this kind of structure is that light is illuminating one mesa, so you don't have to worry about alignment. If you misalign and scale the light illuminating the device, you are going to be scaling both polarizations equally and you always get the value of linear polarization," Unlu explained.

The current challenge will be getting accurate thickness control in the dielectric deposition. "The mirrors have to be precisely controlled and you have to deposit alternating layers of silicon dioxide on silicon nitride," he said. Other challenges will include positioning the second photodiode on top of the first as well as finding a good-quality semiconductor material. Otherwise, the process is fairly straightforward, said Unlu, who expects to have discrete devices working within the month. "In an optimized setting of silicon fabrication, this should pose almost no problems," he said.

Originally, Unlu and colleague Onat turned to silicon because it is inexpensive, but it also turns out that for the specific application of magneto-optical drives the wavelength of light is about 650 nm. For that wavelength of light, the absorption coefficient of silicon is almost ideal for the application.

While the work specifies linear polarization, the researchers also are looking at the possibility of further development in designing devices for circular and elliptical polarization components. A patent application for the structure was filed last summer. The work was partly sponsored by the National Science Foundation and the Office of Naval Research.