4:45pm-5:00pm
WCC6

Vertical Cavity Polarization Detectors

Bora M. Onat and M. Selim Ünlü
Department of Electrical and Computer Engineering, Boston University, Boston, MA 02215

We describe a new method of polarization sensing using a resonant cavity enhanced (RCE) photodetector vertically integrated with a conventional detector. Establishing polarization selectivity in a compact semiconductor device structure is strongly desirable for many applications, ranging from imaging arrays to magneto-optic data storage. In imaging, there is a compelling motivation to study polarization vision. Beside the color and intensity of light, polarization may underlie additional information in an image. Potential applications include object recognition, material classification and applications in Marine Biology [1]. In magneto-optical (M-O) drives, the content of the stored data is coded as a change in the polarization of light [2]. The conventional M-O reading head configuration employ polarizing beam splitters and dedicated detectors for the two polarization components. A main drawback of this implementation is having heavy and bulky optical elements which limit the access time.

Monolithically fabricated detector pairs can be used for polarization sensing, in which each detector of a pair is dedicated to detect one of the two polarization states. For example, metal-semiconductor-metal (MSM) photodetector pairs with sub-wavelength electrode finger dimension have been shown to exhibit polarization and wavelength sensitivity [3]. An important drawback of polarization sensing detector pairs is the necessity for uniform top illumination for each of the detectors. Uniform illumination can be achieved by using a spot size much greater than the detector pair dimension in which case a large fraction of the incident light will be wasted.

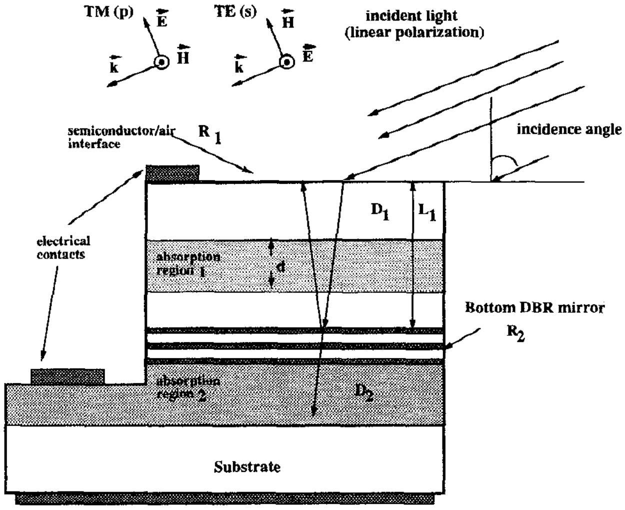

Fig. 1. Conceptual representation of the VCPD consisting of a RCE (D_1), and conventional photodetector (D_2).

We present a new vertical structure that overcomes the difficulty associated with the uniform top illumination of detector pairs for polarization sensing. In the Vertical Cavity Polarization Detector (VCPD) structure, a RCE detector (D_1) is vertically integrated with a conventional detector (D_2) as shown in Fig. 1. RCE detectors are constructed by incorporating a thin absorption region into an asymmetric Fabry-Perot cavity. The top reflector is formed by the semiconductor air interface, while the bottom mirror is a Distributed Bragg Reflector (DBR). The RCE devices benefit from the wavelength sensitivity and the large increase of the resonant optical field introduced by the cavity. This results in high quantum efficiencies at optical resonance without requiring thick absorption regions. The peak quantum efficiency for a RCE detector at resonance is a strong function of top and bottom mirror reflectivities. The resonance condition of the cavity is characterized by wavelength, cavity length and the mirror phases.

Implementation of the VCPD in the Si material system with dielectric DBR mirrors (R_2) offers a drastic contrast in the TE/TM reflectivity at off-normal incidence. Figure 2 shows the incidence angle dependence of DBR reflectivity For a 5 period SiO_2/Si_3N_4 stack. Since the top reflectivity (semiconductor/air interface) is also polarization dependent, the resulting cavity provides resonance enhancement for TE, capturing the TE polarized light in the top detector (D_1). For TM, both reflectivities are small, therefore, light is transmitted to and absorbed in the bottom detector (D_2). For a thin absorbing layer in the RCE detector (D_1 in Fig. 1), a large contrast in TE/TM response of D_1 and D_2 is achieved and

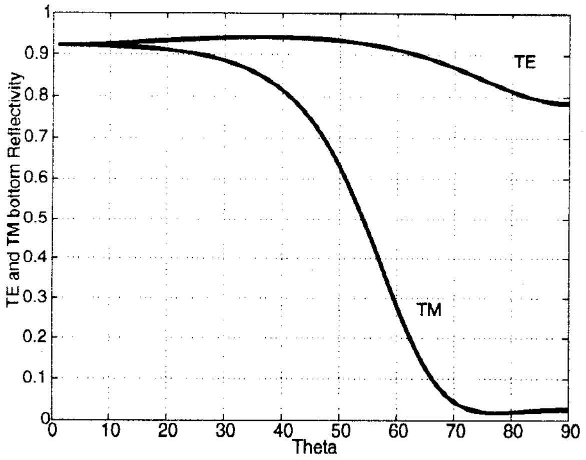

Fig. 2. Reflectivity of a 5 period DBR mirror (R_2) for the $Si/SiO_2/Si_3N_4$ material system for TE and TM polarized light versus incidence angle.

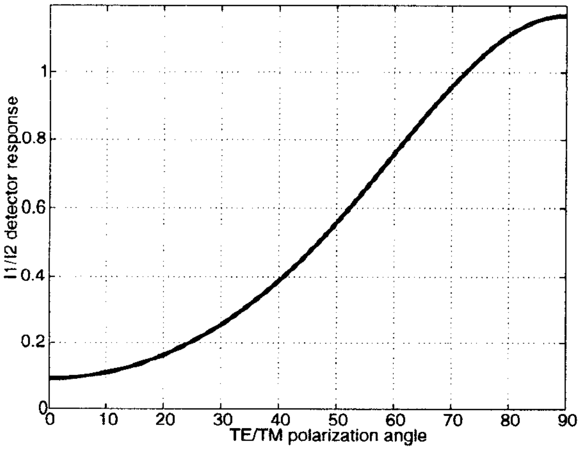

Fig. 3. The ratio of the current responses for detector # 1 and #2 for varying linear polarization angle. The incidence angle is Brewster's angle (for Si/air interface is 73.7°).

the linear polarization can be computed from their relative responses.

As an advantage, the $Si/SiO_2/Si_3N_4$ material system offers monolithic integration of the polarization detectors with VLSI circuitry implementing smart pixels and arrays for polarization sensing and imaging. We will present experimental results of a VCPD structure formed on Si. The SiO_2/Si_3N_4 DBR dielectric films will be deposited via Plasma Enhanced Chemical Vapor Deposition (PECVD). The top absorption layer in the RCE detector will be a poly-Si deposited by Liquid Phase Chemical Vapor Deposition (LPCVD). The optical and electrical properties of Si allow for fabrication of polarization detectors in visible to the near-IR wavelength range [4]. The absorption coefficient of Si changes from $2 \times 10^3\ cm^{-1}$ to $3 \times 10^4\ cm^{-1}$ for the wavelengths 700nm and 450nm respectively, satisfying the requirements for RCE photodetection [4]. For magneto-optical storage applications, the capability of fabricating polarization sensors in the visible spectrum is particularly important since the storage capacity scales inversely with the wavelength.

The ratio of the detector currents (I_1/I_2) can be used to evaluate the polarization of the incident light. Figure 3 shows the calculated detector current ratio as a function of the polarization angle for a VCPD formed by the DBR described in Fig. 2 for an operation wavelength of λ=632.8 nm. The polarization angle θ_p is defined as the angle between the total electric field and the TE coordinate. The top detector (D_1) cavity is formed by a 0.9μm thick poly-Si absorber in RCE configuration, thus the entire cavity of the RCE detector (L_1 in Fig. 1) is absorbing. The bottom detector (D_2) is assumed to detect all of the light transmitted through the DBR. The dependence of the detector current ratio to the polarization angle is a one-to-one correspondence. Therefore, the function can be inverted and polarization angle can be computed from measured detector current ratio. Thus, the resolution of the polarization sensing depends on the slope of the curve in Fig. 3.

In conclusion, we describe a new technique for detecting the linear polarization of incident radiation by utilizing resonant cavity enhanced photodetectors. The polarization sensitivity and optical detection functions are integrated into a single vertical device structure allowing for the monolithic fabrication of a polarization sensor. Therefore, the VCPD represent an attractive substitute for bulk optical components such as polarization filters or beam splitters. Theoretical and experimental results will be presented.

REFERENCES

[1] L. W. Wolff, P. Costaines, "Polarization vision for object detection," *Proceedings of the SPIE - Int'l Society for optical engineering*, Vol. 2103, pp. 106-114, Washington, DC (1994).

[2] K. Kaufmann, "Photodiodes advance optical storage devices," *Laser Focus World*, Feb. 1996, pp. 109-112.

[3] J. J. Kuta, H. M. van Driel, D. Landheer, and J. A. Adams, "Polarization and wavelength dependence of metal-semiconductor-metal photodetector response," *Appl. Phys. Lett.*, Vol. 64, pp. 140-142, (1994).

[4] M. S. Ünlü and S. Strite, "Resonant cavity enhanced (RCE) photonic devices," *J. Appl. Phys. Rev.*, Vol. 78(2), pp. 607-639, (1995).