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Discussion on position-sensitive detectors based the lateral photovoltaic effect

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Abstract: *The lateral photovoltaic effect （LPE） : the saturation values of photovoltage vary linearly with the position of laser spot. It has been widely investigated and received enormous attention for a series of applications. Under the nonuniform illumination of a laser, the linearity is expected to make MOS structure a new type of candidate for position-sensitive photodetector. In order to make the sensitivity of the lateral photovoltaic effect be further improved， this thesis is partially founded to research the sensor with higher sensitivity.*

Keyword- *lateral photovoltaic effect; MOS structure; position sensitivedetectors.*

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I. Introduction

In 1930, W. Schottky first discovered the existence of lateral photovoltaic effect (LPE) in 1957[1].Wallmark J. T. made a detailed theoretical analysis of the phenomenon of lateral photovoltaiceffect observed in floating Germanium p-n junction [2]. G. Lucovsky made a detailed theoretical analysis of the lateral photovoltaic effect of unilateral heavily doped p-n junction in 1960 [3]. H. Niu et al. improved Lucovsky's theory, focusing on the lateral photovoltaic effect in systems without heavy doping hypothesis in 1976 [4]. S. Amari extended the transverse photovoltaic effect in one-dimensional coordinates to a two-dimensional plane, and made a systematic analysis of the experimental results in 1991[5].

Bell Laboratories also studied the lateral photovoltaic effect in the mid-1980s in the United States. Willens found that the lateral photovoltaic effect also exists in the hybrid structure composed of Si-Ti superlattice and Si substrate. They studied the lateral photovoltaic effect of illumination location, laser wavelength, ambient temperature, irradiation time and applied bias in detail. The influence of PSD and its application prospect as PSD (Position Sensitive Detector) are studied in detail. In the mid and late 1990s, Martins and Fortunato's team from the Department of Material Sciences of the University of New Lisbon, Portugal, studied in detail several main parameters of PSD of hydrogenated silicon P-N junction, including position sensitivity, lateral photovoltaic correlation coefficient, linear ratio and so on. Later, more and more lateral photovoltaic effects were found in MOS structure. Scientists began to focus on how to enhance the sensitivity of lateral photovoltaic effects[6-15]. Lateral photovoltaic effects have been found in doped Al-Ga-As/Ga-As heterostructures, H-Si Schottky barrier structures, semiconductor polymer systems, perovskite structures, amorphous Ti-Si superlattices and metal-oxide-semiconductor structures.

II. The mechanism of the lateral photovoltaic effect

When a transversely inhomogeneous beam of light illuminates the surface of a heterostructure and the energy of the photon is greater than the bandgap width of the material itself, photogenerated electron-hole pairs will be generated in the material, and the concentration gradient of the carriers will be generated in the transverse direction. The drift and diffusion of the carriers in the transverse direction will produce a transverse electric field called the side. LPE: Lateral Photovoltaic Effect. The voltage between two electrodes (two electrodes are drawn out on the same surface of a p-n junction, etc.) measured by a point source moving between two electrodes is called lateral voltage. As long as the materials with p-n junctions and other structures are uniformly distributed, there will be a highly linear relationship between the lateral photovoltaic and the illumination position, as shown in Figure 1. Lateralphotovoltaic effect is also widely used in various high-precision sensor fields because of this linearrelationship[16-17].

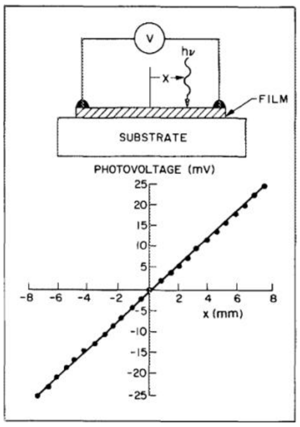

Fig1. Schematic illustration of the Lateral photovoltaic effect

We choose the most common p-n junction structure, and briefly introduce the physical mechanism of lateral photovoltaic effect. Electron-hole pairs are generated on both sides of the p-n junction when the incident light is perpendicularly uniformly incident on the surface of the p-n junction (assumed to be a p-type semiconductor). In general, because the concentration of most carriers varies slightly and the concentration of a few carriers varies greatly under illumination, the movement of a few carriers is mainly studied. Due to the strong built-in electric field in the p-n junction barrier region (the direction of the electric field is from the N region to the P region), a few photogenerated carriers at both ends of the p-n junction move in the opposite direction, that is, the redundant electrons in the p-n junction tunnel into the N region and the redundant holes in the n region reach the P region[18]. This leads to the increase of the potential in the P-region and the decrease of the potential in the n-region, and eventually forms the force at both ends of the p-n junction. This process is called the longitudinal photovoltaic effect.

III. Research on enhanced lateral photovoltaic effect

In order to meet the requirements of high-precision sensors, scientists have studied the sensitivity enhancement of lateral photovoltaic effect from theoretical derivation to experimental research. Generally speaking, it focuses on increasing the moving speed of carriers, increasing the concentration of carriers and reducing the recombination rate of carriers. By solving the two-dimensional drift-diffusion equation with time as the main parameter, the mechanism of perovskite oxide heterojunction enhanced lateral photovoltaic effect is obtained. The calculation results show that the P-type material can form a larger drift electric field in the interior than the n-type material, thereby enhancing the carrier movement and obtaining a stronger lateral photovoltaic effect. In addition, the built-in electric field formed between the substrate and the film of p-type material can also enhance the lateral photovoltaic effect [17]. In order to absorb more energy from the laser and obtain greater potential difference and voltage sensitivity between the two electrodes on the surface of the conductive layer, carbon films were deposited on the surface of the metal layer of the traditional MOS structure to form C-Au-SiO2-Si structure. The maximum voltage of Au-SiO_2-Si and C-Au-SiO_2-Si structures is 14.3 mV and 18.6 mV, respectively, when the electrode spacing is 3 mm, the wavelength is 514 nm and the power is 9 mW. The maximum voltage of C films is increased by 30.1%, and the voltage sensitivity is also improved obviously[18].

In order to further expand the application value of the lateral photovoltaic effect, scientists found that in the Bi2Sr2Co2Oy-LaAlO3 structure, the lateral photovoltaic effect can also be obtained, which promotes the research of the lateral photovoltaic effect in more materials. Bi2Sr2Co2Oy thin films were grown on LaAlO3 substrates by chemical deposition. When the electrode spacing was 8 mm, the surface of Bi2Sr2Co2Oy-LaAlO3 structure was irradiated by a laser with wavelength 532 nm and power of 1 mW. The voltage sensitivity at unit power was 20V / (mm mW) [19].

The substitution of single-walled carbon nanotubes (SWNTs) for SiO2 oxide layers in MOS structures can shorten the width of depletion layer due to electron escape, thus greatly reducing the potential barrier for electron penetration into the conductive layer and achieving higher diffusive electron concentration in the metal layer. The Ti/SWNTs/Si structure obtained by the method can also enhance the lateral photovoltaic effect to a certain extent. The SiO2 oxide layer on the surface of n-Si was corroded by HF and then immersed in SWNTs solution. After drying, Ti film with a thickness of 3.3 nm was deposited on the surface of SWNTs-Si by magnetron sputtering. The voltage sensitivity of Ti/SWNTs/Si structure irradiated by laser with 532 nm wavelength and 5 mWpower is 67.02 mV/mm [20].A-Si:H was coated on the surface of c-Si(100) substrate by plasma enhanced chemical vapor deposition (PECVD). The surface of a-Si:H/c-Si heterostructure was irradiated by laser with wavelengths of 405 nm, 532 nm and 980 nm, respectively. The maximum voltage sensitivity was 17.1 mV/mm, and the electrode spacing was 11 mm when the electrode spacing varied from 2 mm to 24 mm.

The laser wavelength is 980nm and the power is 70mW. At the same time, it is found that the voltage sensitivity changes little with the increase of laser power when the laser power is increased to 10 mW[20-21].

IV. Conclusion

Compared to BRE: (Bipolar Resistance Effect), the study of lateral photovoltaic effect is more mature and has a wide range of applications. The new PSD developed in the 1980s based on the lateral photovoltaic effect is the main application of the lateral photovoltaic effect [22-24]. PSD is mainly applied in the field of aligned sensors with accurate needs in the field of optics, including biological aspects, application technology in the field of robotics, process control and position information system, etc. [25]. At the same time, it can also be used in rotary control, surface profile, telephone information system, Angle measurement, triangular base distance sensor, guidance system, and some positions requiring precise and automatic control. In the process of position detection, PSD has its own advantages. Its high resolution and the feature that position detection is independent of spot intensity, distribution, symmetry and size have a broad application prospect in the field of position monitoring. Meanwhile, it can directly measure the Angle, displacement, height, distance and other information. For example, small Angle measurement, small distance measurement, vehicle laser radar and rotary encoder.

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