Design of Photodetection of Silicon Metal- Semiconductor-Metal with Photonic Crystals

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Abstract

the study performed for design of Silicon metal-semiconductor-metal photodetector with photonic crystals. One of transmission lines of optical network is photodetector. This kind of detector changes the input photons into electrons. The result electronic current is enhanced and crossed a device that is a determiner of 0 or 1 bits. In the other word, within time limit of every bit, the decision is made according to the presence or lack of light. The photoderectors are divided into three major groups regarding their mechanism for response to the incident light. The paper aims to study the semiconductor and silicon metal detector. Photonic crystal is an array of tiny antennas that is beside each other in a one, two, or three-dimensional arrangement. In this study, we used simulation to design these detectors with photonic crystals.

Key words: photodetector, semiconductor metal, silicon metal, photonic crystals

Introduction

With technological advancement and passing of time, optical system is one of the most important transmission systems in the infrastructure networks. It has some features of high capacity, low cost, high-speed transmission, and flexibility. In fact, they are an important part of optical focus. Optical metal-semiconductor-metal detectors are a class of photodectors. The semiconductor metal has an important role in data detection. This kind of metals like the other detectors receives optical signals and changes them into electrical signals. Researchers are trying for optimization of the output parameters considering the features of this kind of detectors. Among these we can refer to the structure of silicon mono crystal as a semiconductor and Nickel as a metal (Narottam and et al.2009) and also utilizing the new technique of the new technique of insulating with InGaAs (Zefram and Bart Van, 2010). These tries generally are directed toward decreasing of noise, change of optical signals containing information into the electrical signal. These kinds of detectors are divided into the three major groups including:

1- semiconductor detectors in which the incident light into the matter excites electrons from the capacity band to the conduction band.

2-photoemissive detectors like photomultiplier tubes (PMT) in which electrons exit by radiation of light to a matter sensitive to light.

3- Thermal detectors in which the temperature of the matter increases and its electrical properties changes due to the thermal effect of light.

The paper aims to investigate the semiconductor detectors. On of photo detectors is the semiconductor metal (MSM) which in addition to a large coefficient and high speed has a more simple structure compared to PIN and APD. This kind of detector is composed of a semiconductor in between and two metal connections in its sides. Bias voltage is applied from the metal electrodes' side. Since metal in connection with semiconductor play the role of a semiconductor with opposed impurities, so with connection of bias voltage we will have one Schottky contact and a direct bias contact. Optical photons are applied from Schottky contact side (Joseph 2014). Semiconductor metal photodectors are the most suitable choice for optical telecommunication because of their low cost, small size, stability, low consumption power, wide spectral range, good sensitivity and fast response. Different kinds of semiconductor photodetectors include photoconductor, photo diode PN, Avalanche photo diode (APD), metal-semiconductor-metal (MSM), and phototransistor. Because PIN, APD, MSM are used as detectors for optical network (Nalwa, 2001), this detection have two Schottky contacts and some pores for photons absorption. Figures (1, 2) show two samples of MSM structure (Riaziat 1996, Bhattacharya, 1997).

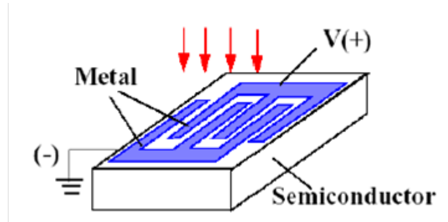

Figure 1: detector structure of MSM

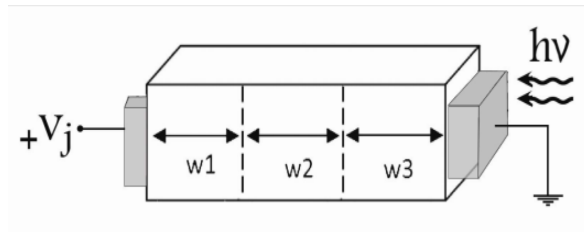

Figure 2: simple structure of a MSM detector

According to the conducted studies, per of each absorbed photon in the semiconductor, one electron leaves its capacity level. The produced hole have role in the process of current production. In this way, the produced electron-hole pair in the semiconductor speeds because of drift of field and moves toward the contacts. This field is generated by the applied bias voltage and in addition to speed the movement of carriers, prevent them from recombination across the path and increase the total current of the device (Ruibin, 2014). Advancements in the area of Plasmonic science have enhanced different parts and properties of this kind of detectors. Among these properties we can refer to the higher sensitivity, more efficiency, and improvement of the coefficient of optical absorption. In these structures, it has been tried to use metal diffraction grating and nanoparticles to optimize the detectors' properties. Plasmonic science has paved the way for construction of detectors in tiny size which has sped the trend toward the optical integrated circuits. Today, plasmonic has wide spread application in the different field of optical and electronic equipment. In 2004 it was shown that putting a semiconductor nanoscale layer between two electrodes close to each other, we can get a MSM detector with more than 50% efficiency and cut-off frequency more than 300 GHz (Collin, 2004). In this structure, nano-scale semiconductor threads were used between metal threads having section smaller than$\lambda/8$. The results showed that we can get theoretically the efficiency of 75% and cut-off voltage of 500 GHz. This structure has designed for wavelength of 800nm. In 2006, properties of surface Plasmons were used for increase of ratio of signal to noise of a photodetector in the middle infra-red frequencies, via improvement of absorption (Collin, 2004). Experiments of these scientists to achieve more speed and bandwidth were based on trial and error, expensive and time consuming. Since 1991, some scientists have been tried to estimate the behavior of a device before it is manufactured (Eiichi, 1991). Later the circuit model of the device was spread and the effect of field and lifelong of carriers was taken into account in it (Jau and et al 1996). Since then semiconductor materials with heterogonous structures replaces the simple structure of the device and results were significant. In 2010, a circuit model including capacitor equal of junction and equal flowing current registered for increasing of bandwidth (Narotam and et al, 2009; Chio, 2003).

In line with this, there is a collection of wave dissipaters well known as photonic crystals which has been laid beside each other in the desired directions regularly. In this way, there is substantial similarity between a photonic crystal and an array of same shaped antennas which is very instructive (William, 2015). So that we can say that photonic crystal is an array of tiny antennas in a regular one, two, three dimensional arrangement. If we used isotropic antennas, we have a network of antennas which like an array of antennas was able to dissipate the input power into special directions by constructive and destructive interference of the network members in different direction of space. But if we use the antennas with non-isotropic pattern, the dispersion pattern will be the result of superposition of patterns of each of antennas and the interference model of network. However, there are some differences. While one array of antennas is fed for transmission of power in a special direction, in the source photonic crystals the input wave dissipates around by the dissipaters. In addition, considering that the most important range of using the photonic crystals is in the limit of light waves, infrared and millimeter waves, in spite of antennas arrays using of metals because of their high loss is not common within the above said frequency range. So we can imagine the photonic crystal as an array of dielectrics having definite geometric shapes (like Cylinder) and regular arrangement (a wavelength away from each other) (Ozbay and et al, 2004). Photonic crystals have invented inspired by the natural crystals. Almost all of metal and so many insulated elements and composite materials are found in crystalline form in nature. In these materials, atoms and molecules have the role of dissipaters for the electron waves. Electron waves are dissipated around because of Coulomb repulsion and moves toward special directions in which the dispersion effect of ions collection is constructive. Considering that free electrons of materials have duty of electrical conduction, the shape of crystal and the kind of used atoms have direct role in the electrical properties of structure (Tudela, 2014).

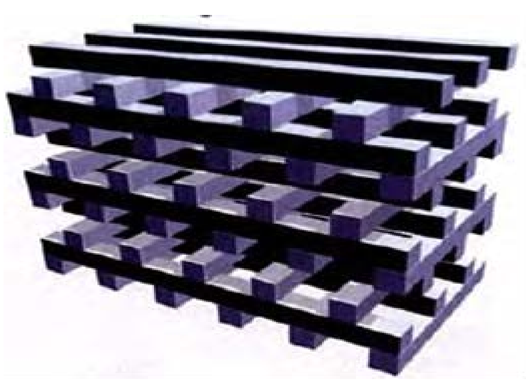

Figure 3: a schematic of FCC structure of photonic crystal

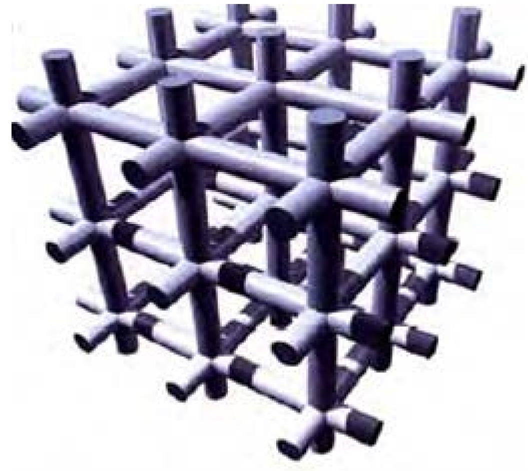

Figure 4: a schematic of cube photonic crystals

There are different methods of analysis of photonic crystals which most of them are inspired by analysis methods of natural crystals in the solid state physic. One example is plane wave expansion method (Leung, 2004) which are similar to the nearly free electron model, or Wannier function method which is similar to the tight binding method. There are other methods like transmission lines methods that are exclusive of photonic crystals, considering the special form of Maxwell equations (Busch and et al. 2003).

1- Material used in the photonic semi-conductor detectors (Nalova, 2001). According to the researches, it is necessary to determine the composed material of a detector to response to it. For a light emitting diodes, the material with the longest desired wavelength and energy split less than the photons' energy, has the proper sensitivity and large quantum efficiency. This condition makes it possible to achieve a large quantum efficiency and fast response in addition to decrease of dark flow. For detection of spectral range of 800nm-900nm, different material can be used like si, Ge, GaAs, In Ga As, and In Ga AsP. Si has a wide spread usage because of its least increase of avalanche noise in addition to its developed technology. In wavelength above 1 µm, Si sensitivity is very low because photons don't have enough energy for excitement of electrons from valance band to conduction band. So, other materials with high sensitivity have been offered for the wavelengths of 1 µm-1/65 µm including Ge, InP, InGaAsP, GaAlSb, GaAlAsSb, HgCdTe, InGaAs. Germanium has a high absorption coefficient (nearly $104cm^{-1}$) for wavelength of 1-1/55 micrometer and is ideal for detection of long wavelength. Although Germanium photo diodes are sensitive and speedy, having charged ionization rate of 2, their noise additional coefficient is large for avalanche increasing. Smaller band split of Ge compared to Si and its dark flow much higher than Si limits its avalanche utility. In spite of this, Ge avalanche photo diodes have been successful in long wavelengths. In addition to Ge, other kinds of v-III semi-conductor alloys like InGaAsP, GaAsSb, InGaAs, GaSb, GaAsSb have studied for long wavelengths. There are different reasons for study of these alloys: because energy split of these alloys are dependent upon their molecular composition, so through changing of molecular concentration of their composed materials we can choose the light absorption coefficient in the longest needed wavelength. In this way we can obtain detection with large quantum efficiency, proper response time and low dark flow. Another reason of searching for such alloys is finding a material with big difference between its electron ionization rates and cavity. Unfortunately, balanced ratios of ionization rate in all V-III materials are less than Si, thus we obtained a limit avalanche utility (Keiser, 1991). Light reflection from the interface of air and semi-conductor is an undesired phenomenon which leads to decrease of light absorption and output flow. For example in normal radiation to the surface of GaAs, 30 percent of incident light is reflected. To decrease the light reflection, the surface of semi-conductor is insulated with an anti-reflector layer. The most common anti-reflector cover is SiO_2 which decreases the reflected light to 6 percent of the incident light (Sterlin, 2001).

Conclusion

semi-conductor metal (MSM) has an important role in detection of information. This kind of metals like other detectors receives photo signals and changes them into electrical signals. In fact the duty of photodetectors is changing of photo signals containing information into electrical signals. Developments of plasmonic science have improved some properties of these detectors. Today, plasmonic has a wide spread use in the electrical and electronic areas. In 2004 a study showed that putting a nano-scale semi-conductor light absorbent layer between two close electrodes, we can obtain a MSM detector with sufficiency above 50% and cut-off frequency larger than 300GHz.

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