Increase The Absorptive Capacity Of Light Of The Photocells By Embedded In Bow-tie Antenna

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Abstract. The application of silicon photocells has been widely used in biological and energy field, how to improve the efficiency of silicon photocells has become the research hot spots. The light absorption efficiency is not ideal, only 10% to 20% of solar energy can be transformed into electricity, the paper embeds metal bow-tie antenna in the crystals of silicon, by the field enhancement of the surface plasma, it highly increase the absorptive capacity of light of the silicon photocells.

Key Words: silicon photocell, surface plasma, bow-tie antenna

1. Introduction

With the deterioration of the Earth's natural environment and human awareness of environmental protection, solar, wind, geothermal, biomass and other new kinds of energy are payed more and more attention, they are green and easy to use, without pollution, oil, coal and other traditional fossil energy sources will soon dry up, there are wide space for the research and use of these new kind of energy.

The silicon photocells is a new kind of green energy sources by useing solar energy, it is a kind of semiconductor devices that can transform the solar energy into electrical energy, its basic structure is a PIN knot. The silicon between the two electrodes are mainly consist of monocrystalline silicon and polycrystalline silicon, when the sunlight stimulate on the silicon photocells, the photoelectric effect will generate inside of the silicon,
it will form a lot of electron-hole pairs, they will make directional movement to the two electrodes by the influence of the electrodes. Some of them reach the electrodes, this is the working principle of silicon photovoltaics.

At first crystalline silicon is applied to make silicon photovoltaic, crystalline silicon is an indirect band gap semiconductor, its absorptive capacity of light is weak, in order to increase the efficiency of the photovoltaics, the thickness of this kind of photovoltaics has to reach about 200 \( \mu m \sim 300 \mu m \); In order to reduce the cost of crystalline silicon photovoltaics, people uses a thickness of 5 \( \mu m \sim 10 \mu m \) of polycrystalline silicon photovoltaics. It can be very difficult to guarantee the efficiency as people reduces the costs at the same time. Additional, in case of the large number of defects in polysilicon, the reaching probability of the electron-hole pairs will be much lower. In order to improve light absorption efficiency, people use the polysilicon thin films with rough surface, however, it will bring more defects. Therefore, the key point to solve these problems is how to increase the efficiency as far as to compress the thickness the photovoltaic.

It was suggested that the surface plasma wave can be used to resolve this problem by its field enhancement effect, surface plasma research is a hot topic today, when metal surface exposed in specific frequency of light, free electrons in the metal surface cause collective coherent shocks, electromagnetic wave will be formed between the metal and dielectric's surface. It has spatial locality, local field enhancement and other features, it is widely used in the field of antenna technology, bio-technology and so on. Some scholars doped nanometer-scale metal particles in the polysilicon films, it formed surface plasma waves on the surface of these metal particles, around the metal particles there forms local field enhancement effect, it enhances the ability of generating electron-hole pairs, this can guarantee the absorptive capacity when people compress the thickness of the crystals.

In this paper, the method is embedding bow-tie antenna into a polycrystalline silicon thin-film, simulate the electric field distribution when the sunlight irratiate throughout the silicon film, estimate the number of electron-hole pairs generated, and by the contrast, try to prove that with the same efficiency the model embedded in bow-tie antenna can be effectively compressed the film thickness.

2. Bow-tie antenna

One important purpose of the surface plasma is making nano-antenna, bow-tie antenna is a kind of antenna, the model is shown in Figure 1, two fence-type metal sheet are placed face to face, when light of certain frequency and wave vector perpendicularly irradiates to the bow-tie antenna, there will forms surface plasma waves on the surface of metal, this kind of electromagnetic wave transmit along the metal surface to the metal tip, as the cutting-edge field enhancement effect, in the vicinity there forms an enhanced electric field. The two metal tips are positive face to face, therefore, in the center of the antenna, it will form a broader and better region of field electric enhancement, which is the electric field enhancement of the bow-tie antenna.

![Fig.1. Bow-tie antenna](image)

3. Results and discussion.

First of all, we need to identify a right kind of the bow-tie antenna element, noble metals have relatively stable physical properties and chemical properties, so select the more commonly used gold as forming the antenna.
In Figure 1, on the assumption that the thickness \( t \) is in infinite case, the size of the bow-tie antenna is decided by the three parameters, the metal film height \( h \), width \( w \), and the distance of these two pieces of metal cutting-edge \( d \). During the producing process of the silicon photocells, we want to reduce the producing costs as much as possible, so, first of all, this article selects \( h = 150\text{nm} \), so there remains \( w \) and \( d \) to be determine.

Supposing \( w = 60\text{nm} \), assuming the inputting wavelength is 750nm, the sine amplitude is 1V/m of sunlight, calculating by the method of FDTD(Finite Difference Time Domain), to the central point O, the relation between the electric field strength \( E \) and the distance \( d \) is shown in Figure 2 (1) .

![Fig.2. Analyse diagram.](image)

Analysis of Figure 2 (1), we could get the results as follows, as \( d \) increases, the center field strength \( E \) is getting smaller and smaller, it is because the coherence coefficient between the two metal cutting-edge electric field in the O point is gradually decreasing, causing the electric field strength generated getting weaker and weaker, but considering the scope of the electric enhance field is getting smaller with the decreasing of \( d \), this is not good for the improvement of the efficiency of photocells, so selecting the distance of \( d = 10\text{nm} \) comprehensivng these two factors.

After determining \( d = 10\text{nm} \), \( h = 150\text{nm} \), with the same assumption that the input is 1V/m amplitude sine wave, through the FDTD method, we can get the relationship between the electric field strength \( E \) of point O and the metal width \( w \) as it shown in Figure 2 (2). The upper line is about the sunlight with the wavelength of 800nm, the lower line is about the sunlight with the wavelength of 600nm. We can drew a conclusion that as \( w \) increase \( E \) appeared a few extreme values, whose reason is the effect of SPR (Surface Plasmon Resonance) between the electronics and the metal particles, according to the curve in the diagram, we choose one of the extreme value \( w = 60\text{nm} \) for the antenna.

In this way, we get a gold bow-tie antenna with the size of \( d = 10\text{nm} \), \( h = 150\text{nm} \), \( w = 50\text{nm} \), in this structure, the antenna produces the best electric field enhancement when exposed in the sunlight.

4. Simulation of light absorption capacity calculation and comparison

![Fig.3. Film of bow-tie antenna.](image)

The model of the film with bow-tie antenna is shown in Figure 3, simultaneously select a cylinder of 310 nm×60nm both in the polycrystalline film and the model consisted of bow-tie antenna, about the transverse section, consider the absorption capacity of the 5 \( \mu \) m polysilicon, that is, to calculate the number of the electron-hole pairs, select 600nm, amplitude 1V/m sunlight as the source, irradiate on the surface of the transverse section, as the result of FDTD calculation, the electric in different locations of the film shows no great difference, the mean value is 0.984V, set light intensity as \( I \), the number of the electron-hole pairs as \( Q \), we can get this:
\[ Q = kSI = kS \, E^2 \]
\[ = k \times 1.86 \times 10^{-14} \times 0.984^2 \]
\[ = 1.8 \times 10^{-14} \]

![Diagram](image)

**Fig. 4.** Electric field strength. Now we calculate the absorption capacity of the film with this \( d = 10 \text{nm}, h = 150 \text{nm}, w = 60 \text{nm} \) bow-tie antenna, the wavelength is also 600 nm, 1V/m sine wave, the result is shown in figure 4. It can be seen that around the bow-tie antenna (two pieces of metal around the edge, and two around the corner) has been significantly enhanced of the electric field effect, in other field, the electric field strength did not change significantly, in the entire transverse section, it's the semiconductor silicon where generate electron-hole pairs in, but gold parts not, so we divided the whole transverse section into six regions, as the figure shown, the electric field strength is shown in figure 4.

We can calculate the number of electron-hole pairs generated as this:

\[ Q = k \sum S I = k \sum S \, E^2 \]
\[ = k \left( 3127 \times 10^{-18} \times 4.62^2 + 896 \times 10^{-18} \times 3.16^2 + 6577 \times 10^{-18} \times 0.99^2 \right) \]
\[ = 8.218 \times 10^{-14} \]

By comparison, we can see that with the same thickness, the light absorption capacity of the film with bow-tie antenna is 4.56 times to the polycrystalline silicon. It means if we want to have two photocells of the same efficiency, one is a 5 \( \mu \text{m} \) polycrystalline silicon, the other only has to be a film of 1.09 \( \mu \text{m} \) with bow-tie antenna embedded in, this significantly reduced costs.

**5. Conclusion**

This article used bow-tie antenna embedded in the polycrystalline photocell, through the method of finite-difference time-domain simulation, for the internal electric field distribution, under the sunlight, we calculated the number of the electron-hole pairs generated as a way to assess this structure, especially the absorption capacity of light. Though the comparing form the two kinds of photocells, we found that, the kind with bow-tie antenna has a higher efficiency, as it has a lower cost of production, this method has a broad space for developing. But as the calculating process in this paper, the author ignore the problems caused by optical
nonlinear and some other complex factors, it is necessary to conduct further simulation, computing and improved.

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7. References
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