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Temperature Effects on Photovoltaic Components Characteristics

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Abstract: Temperature effects and thermally induced noise in photodetectors are significant in the detection processes. Degradation of electrical and optical characteristics of the photodetectors in the increased temperature conditions is one of the most important limitation factors for their application. Since most of the electrical processes in semiconductor devices depend, in some extent, on the temperature, investigations at temperatures higher than room temperature may reveal possible changes in output characteristics of the device. From the technological point of view, thermally induced noise increase minimum signal that can be detected, which is specially important for the low energy and non ionizing radiation detectors, since the noise level presents the major performance limitation. In this paper these effects are studied through frequency noise level measurements and measurements of the main output characteristics of photovoltaic components.

Keywords: Temperature dependence, 1/f noise, photovoltaics, output voltage, ideality factor.

1 Introduction

Due to the extensive miniaturization of the semiconductor devices based on semiconductor junctions (p-n, p-i-n, Schottky, etc.) introduces the problem of the temperature effects and thermally induced noise in such devices. Silicon solar cells belong to a wide group of semiconductor detector devises, though somewhat specific in its design (larger than most of the detectors), and that, together with the fact that they are directly exposed to the solar radiation makes them specially susceptible to the effect of the high temperature. For higher temperatures, thermal noise is dominant and significantly influences the detecting signal and output characteristics. Also, other types of noises especially frequency dependent generation-recombination noise, burst noise and 1/f noise increase with the increase of the temperature [1]. Since increased temperature influence all parts of semiconductor device, contact grid is also prone to some changes, particularly because surface effects are

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expected to be a major cause of 1/f noise. This is specially significant for solar cells because of their design (large surface to volume ratio), and materials for front contact grid should be carefully chosen. Silicides belong to a very promising group of materials which are of great interest both in physics of thin films and in microelectronics. Many of them have a low resistivity and good temperature stability that make them desirable for fabrication of reliable and reproducible contacts [2, 3]. It is known that low frequency noise (1/f and burst noise) manifests as random fluctuation of the output current or voltage, leading to lowering of the efficiency of the device. Various experiments suggest [4, 5, 6, 7, 8] that the origin of this noise is fluctuation of the number of free charge carriers connected to existence of the traps located in the vicinity or directly in the junction area, or fluctuation of the mobility of charge carriers. These effects are more pronounced when the device is exposed to high temperature conditions, since in those conditions defects, surface states and impurities that act as traps for charge carriers could be in addition thermally activated [9]. It has been found [3, 10] that ion implantation of As^{+} ions in the formation of the silicides could improve electrical characteristics of silicides regarding their noise level.

On the other hand, since all dynamic processes in semiconductor devices are temperature-dependent [1, 11], study of the variations of junction characteristic parameters (ideality factor, saturation current, etc.) due to the increased temperature is crucial. One of the most important electrical processes in junction devices is transport of the generated charge carriers across the junction. Type and temperature dependence of the transport mechanism is obtained from dark current-voltage $(I-V)$ measurements of photodetectors. Main parameter that could be extracted from $I-V$ data is the ideality factor (n), direct indicator of the output parameter dependence on the electrical transport properties of the junction. The non-ideal behavior of the device is reflected in the values of n greater than 1, and also in the temperature dependence of the ideality factor. This dependence is the result of the presence of different transport mechanisms that can contribute to the diode current at different temperatures. Determination of the dominant current mechanism is very difficult because the relative magnitude of these components depends on various parameters, such as density of the interface states, concentration of the impurities and defects, height of the potential barrier, device voltage, and device temperature. Even for a given system at a particular temperature rarely only one mechanism dominates the diode current over entire voltage regime. The main transport processes that could occur, even simultaneously, are thermionic emission, field emission, thermionic field emission, recombination-tunneling via interface states, minority carrier injection, and recombination [11] . Beside I-V measurements at different temperatures, measurements of the $n(T)$ and $n(V)$ dependence could narrow down possibilities of the dominant current component. Values of the ideality factor at different temperatures could indicate not only the transport mechanism, but indirectly, the presence and possible activation of the defects and impurities, acting as recombination and/or tunneling centers. Also, the presence of the defects in the material is considered to be the main cause of the existence of the current noise. Some types of noise in photodetectors are correlated with the presence of the excess current [11] , binding optical and electrical characteristics of such devices.

Purpose of this paper is to present temperature dependence of main characteristics of solar cells in connection to the temperature dependence of 1/f noise level in silicides and ideality factor in photodiodes.

2 Experimental procedure

Due to the complexity of the subject, three types of measurements were performed in this experiment. Investigations of temperature dependence of 1/f noise in silicides were performed for TiN/Ti/Si samples. Ion implantation with As^{+} ions, annealing and electrical characterization were performed on the samples. Implantation of arsenic was performed at 350 keV with the dose range between 1x1015 ions/cm2 to 1x1016 ions/cm2. Thermal treatment for all samples was performed at different temperatures for 20 min. The distinction of these measurements compared to other of this type is that they were based on the temperature dependence of the noise level in silicides for two temperatures: -18^{o}C and 50^{o}C. Noise level measurements were performed with the measurement equipment consisting of the multichannel analyzer ND-100, low noise pre-amplifier, and amplifier (standard ORTEC equipment). MAESTRO II code was used for automatic energy calibration.

Experimental measurements concerning solar cells were carried out on the commercially available silicon solar cells manufactured by Leybold. Current-voltage data were used for the characterization of the properties of solar cells. Temperature dependence was measured in the range from room temperature (21^{o}C) to slightly above 40^{o}C (41^{o}C).

For determining temperature dependence of ideality factor for commercially available p-i-n and p-n silicon photodiodes were used (all samples were produced by SIEMENS, trademarks BP 104, BPW34, BPW 43, and SFH 205). Direct bias dark I-V characteristics of the diodes were measured at four different temperatures, using standard configuration for I-V measurements (Hewlett-Packard current-voltage source, and two digital multimeters - SIMPSON and LEADER). Temperature range was in agreement with the operating/storage range supplied by manufacturer (21^{o}C - 83^{o}C). Measured I-V data were analyzed using ORIGIN program package. Diode parameters were obtained using standard and numerical fit methods with the correction due to the presence of series resistance.

Experiment was performed in well controlled laboratory conditions with combined measurement uncertainty less than 5% within all measurement procedures [12, 13].

3 Results and discussion

3.1 Frequency noise level measurements

Temperature dependence of 1/f noise level was observed for this type of silicides, as could be expected. Spectra of frequency dependent noise on lower (-18^{o}C) and higher (50^{o}C) temperature are shown in Figures 1 and 2, respectively. Not only that the assumption that higher temperature induces higher noise level was confirmed, but the essential part of this measurements is that it was observed that implantation dose used for fabrication of silicides could influence the increase of noise level. The possibility of improvement of silicide characteristics by ion implantation and thermal annealing was reported earlier [10], but primarily in connection to the radiation damage. Structural RBS analysis have shown that ion implantation did not induce redistribution of components for lower implantation doses, but for higher doses of implantation (1x1016 ions/cm^2) a disordered structure was registered. Also, it was found [2, 3] that thermal treatment induce relaxation of crystal lattice and improvement of the crystal structure of the silicides.

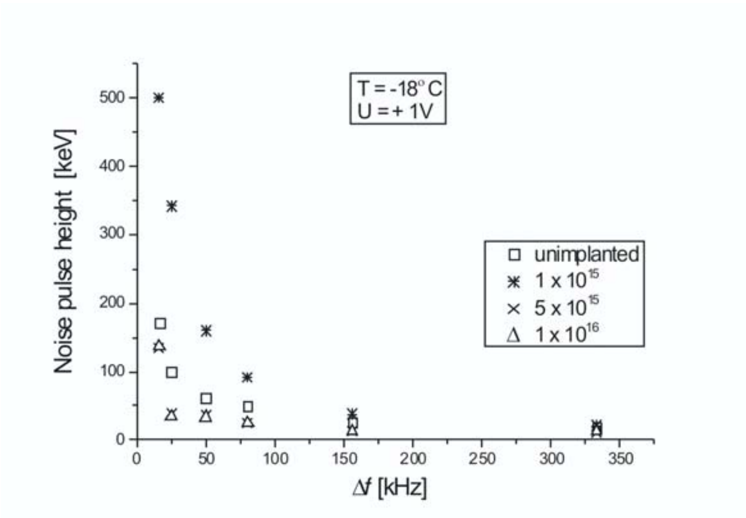

Fig. 1. Frequency noise level of three implanted and one unimplanted sample at -18^{o}C

However, these temperature dependent measurements indicate another very important fact that ion implantation could provide temperature stability of silicides regarding 1/f noise. Namely, from Figures 1 and 2 could be seen that samples implanted with doses of 5x1015ions/cm^2 had lowest noise level and very good temperature stability. This could lead to an improvement of electrical characteristics of silicides and devices based on silicides as contacts (for example, solar cells).

3.2 Temperature dependence of electrical characteristics of photodetectors

When the temperature dependence of solar cell characteristics is concerned, although an increase of the current with the temperature increase was observed, main output characteristics such as efficiency were negatively influenced by high temperature. This is due to the fact that open circuit voltage rapidly decreases with an increase of the temperature, as could be seen in Figure 3.

The rate of the decrease ($\partial V_{oc}/\partial T$) for this particular cell was -2,48mV/^{0} C (using linear approximation method), and that made it particularly temperature sensitive. Also, because of the working conditions of solar cells (direct exposure to the solar radiation), their

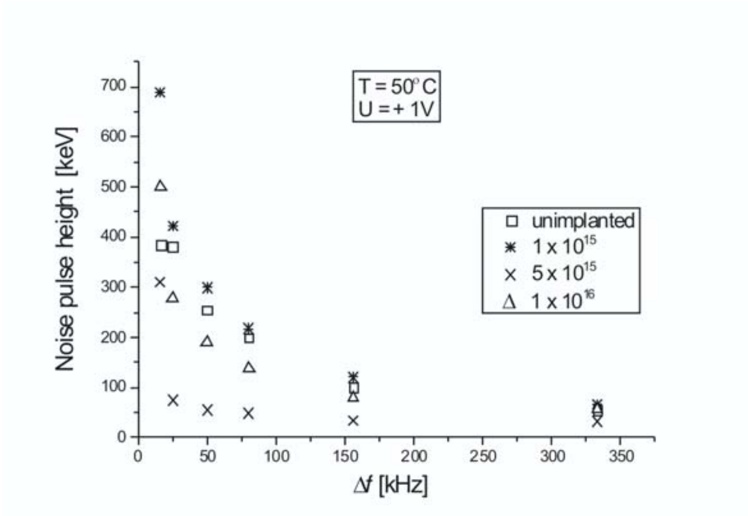

Fig. 2. Frequency noise level of three implanted and one unimplanted sample at 50°C

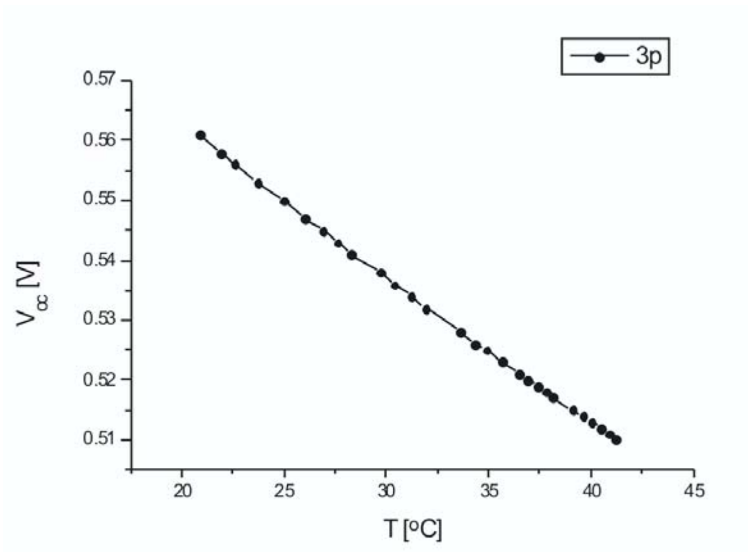

Fig. 3. Temperature dependence of open circuit voltage V_{oc}.

temperature increases very rapidly (up to 40 C in the first 2-3 minutes of work), so better temperature stabilization of characteristics, and/or adequate cooling are main requirements for successful and long-term operation of solar systems. This is specially important because for non-ideal devices ideality factor n is greater than 1, indicating more complex temperature dependence of basic properties such as diffusion length or charge carrier lifetime

Direct dependence of the ideality factor on the temperature for photodetector is shown in Figure 4, where more or less linear increase of n could be seen. From the physical point of view, this behavior could be explained with the fact that, at the increased temperatures, imperfections of basic material are more pronounced. Namely, defects in the crystal lattice such as vacancies or intersticies tend to accumulate when thermally stimulated, disturbing the periodicity of the potential field in the crystal. Such deviations could induce scattering of the charge carriers, and, consequently, a non-ideal behavior of the device, reflected in the values of $n > 1$. Besides, dislocations and impurities in the material with energy levels deep in the energy gap also tend to precipitate. Such localized energy states could act as traps or recombination centers for charge carriers, modulating output current and inducing current noise in photodetector devices (at low and medium voltages). Burst and 1/f noises are an example of the low frequency noises characterized by discrete current fluctuations, usually referred to as excess current. This excess current was observed in all samples at medium voltages, indicating the existence of the low frequency noises in the devices.

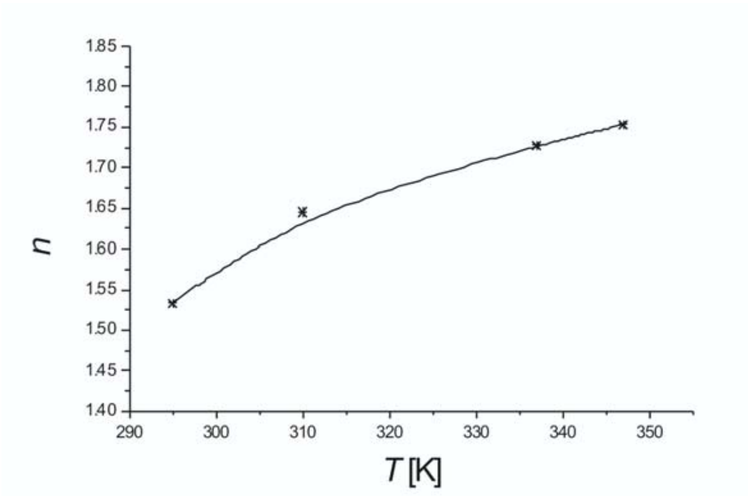

Fig. 4. Temperature dependence of the ideality factor n.

4 Conclusion

One of the major performance limitations of photodiodes is the degradation of electrical and optical characteristics of the photodetectors in the increased temperature conditions. First part of the paper was oriented to the frequency dependent 1/f noise in contacts, since temperature increase induces higher level of noise. It was established that both physical and electrical properties of used silicides are influenced by the implantation doses. But the results of frequency noise measurements indicate that ion implantation could successfully be applied in order to achieve a more homogeneous silicidation and very good temperature stability, if carefully optimized dose (in our case 5×10^{15} ions/cm^2) was used.

On the other hand, from the I-V measurements obtained data have shown that though there is significant increase of solar cells current with an increase of temperature, other electrical characteristics rapidly degrade leading to the decrease of the efficiency. Owing to the strong correlation between burst noise and excess current, degradation of both electrical and optical output characteristics of the device could be monitored through the ideality factor. Observed increase of the ideality factor with the temperature, indicates an increase of the current noise and detection threshold, and decrease of the resolution of the photodetector device. For this reason monitoring of the device characteristics should be performed continuously, especially because solar cells are exposed to the severe working conditions such as increased temperature.

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