The investigation of the transient photovoltage in HgCdTe infrated photovoltaic detectors

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Abstract—**The changed polarity of transient photovoltage (TPA) from negative to positive induced by ultra fast lasers illumination is studied in the HgCdTe p-n junction photovoltage detector. The negative photovoltaic-response decrease obviously and even disappear by blocking the laser beam with an aperture to limit the illumination area of the linear array detectors. A combined theoretical model of p-n junction and Schottky contact can explain this new phenomenon well. Using the TPA technique and the combined model, the characters of p-n junction and Schottky contact will be distinguished. Therefore, it could be used in characterizing the Ohmic contact of the detectors electrodes, and its sensitivity is expected to be much higher than the steady states methods.**

Keywords- HgCdTe, transient photovoltage, polarity change, Schottky contact

I. INTRODUCTION

Since the first synthesis in 1958, HgCdTe infrared detectors have been intensively developed over the past fifty years [1, 2]. In a pixel of the linear array of HgCdTe photovoltaic detectors, the photo-generated carriers separated by the p-n junction will be injected in the readout circuit from HgCdTe-metal interface. Therefore, for the n^+-on-p backside illuminated hybrid linear array detectors, the electrodes preparation is one of the most important issues influencing the detectors performance. Generally, a coupled of methods have been devoted to characterizing the Ohmic contact of the detectors electrodes [3, 4]. Most of the methods are using steady-state electric testing techniques, such as *I-V*, *C-V* test. However, the signals of HgCdTe-metal interface and p-n junction are in superposition with each other in the electric steady-state testing. As a powerful tool to investigate the electric property of the detectors, the *I-V* testing hardly distinguishes the photoelectric signals of the HgCdTe-metal interface from p-n junction, and the information from the interface will be captured difficulty. Moreover, the electrical *I-V* testing can only indirectly reflect the influence of HgCdTe-metal interface on the devices photoelectric properties. It is an indirect measurement method.

In this paper, an advantageous technique, transient photovoltage (TPV) [5-7], could largely complement this subject. For example, when irradiated with a picosecond pulsed laser, the transient photo response show the changed polarity of TPV, that is, there is an apparent negative valley first then it evolves a positive peak. By considering the electrode and the pixels configurations in the linear array of the detectors, the negative and the positive photovoltages can be attributed to the HgCdTe-metal interface barriers behavior and p-n junction respectively. Thus, the photovoltaic responses could be distinguished from the time domain and polarity. Such a changed polarity of TPV phenomenon gives us an insight into observing the photo-generated carriers immigrate and could be used in charactering the Onmic contact of the electrode.

II. EXPERIMENTAL RESULTS

A. Experimental setup

The HgCdTe n^+-on-p photodetector was grown by MBE on (100) GaAs substrate with a buffer layer of CdTe. The p-n junction was formed by B^+ implantation into the p-type HgCdTe layer, resulting in an abrupt n^+-on-p structure. The acceptor and donor concentration are 8×10^{15} and 1×10^{17} cm^{-3}, respectively. The sample was mounted in a liquid nitrogen-cooled Dewar for measurement.

The incident laser pulse was provided by a commercial optical parametric oscillator and difference frequency generator pumped with a picosecong Nd:YAG laser (EXSPLA PG401/DFG). The pulse duration was 30 ps and the repetition rate was 10 Hz. Comparing to the shortest rising time of tens of nonoseconds in the pulsed response profile of the HgCeTe photodiode, the laser pulse can be approximated as a δ function in our experiment. A small portion of the laser beam was reflected by a beam splitter and measured using an energy detector in order to monitor the exciting energy. The pulsed photo-response of the HgCdTe detector was measured from the voltage drop across a 50 Ω load-resistor. Both signals from the energy detector and the HgCdTe detector were fed into an oscilloscope to monitor and record the puls profiles. An average of 500 pulsed profiles was recorded to eliminate the pulse-to pulse fluctuation and improve the signal-to noise ratio. An aperture was used to limit the illumination area of the linear array detectors by blocking the laser beam.

B. Experimental results

In the ideal case, the photo-response of a photodiode irradiated by laser should show a simple rapid increase and slow decay process due to the relative large value of capacitance and resistance of p-n junction. However, the photo-response profiles of the HgCdTe photodiode excited by pulsed laser are very different. When irradiate with the laser, the time profile of the responding voltage shows an apparent negative valley during the first 15 ns, and then it evolves a positive peak. By changing the excitation laser intensity the transient photo-response of the detector show the similar time evolution profiles, no matter for the case of single photon absorption transition that the photon energy is larger than the bandgap or for the case of two-photon absorption transition that the photon energy is smaller than the bandgap. The contradictions of the ideal situation and the experimental results means that a photovoltaic mechanism different with p-n junction may exist.

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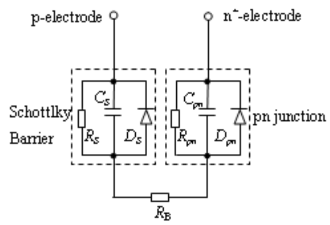

Fig 1 The equivalent circuit of the HgCdTe photodiode

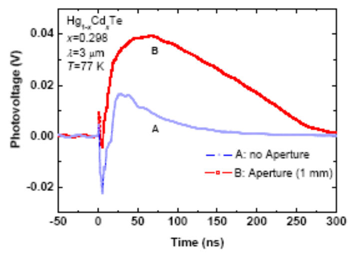

Fig 2 Transient photovoltage of the HgCdTe photodiode with no aperture and 1 mm aperture.

To explain the polarity change in TPV, a combined theoretical model including p-n junction and Schottky barrier are proposed, the equivalent circuit of the HgCdTe photodiode is shown in Fig1. For n^+-on-p type HgCdTe optoelectronic device, it is generally believed that n^+ electron interface is a good Ohmic contact. While there is a big work-function between the p-HgCdTe and metal, therefore, p electrod interface is not easy to form Ohmic contacts, and it is even possible to form a Schottky contact. The opposite built-in electric filed of the Schottky barrier contact comparing to p-n junction provides the possibility for the generation of negative valley and positive peak in the TPV, while the high-frequency character of the Schottky barrier provide the possibility for the generation of negative photovoltage prior to positive photovoltage.

Two aspects of evidence are discussed in order to verify the correctness of the above theoretical model. (a) Considering the common p-electrode configurations surround around all pixels in the linear array of the detectors and the laser spot size is much larger than the pixel size, the common p-electrode coverage area will be illuminated inevitable, even constitute the main part of the photoexcited area. Thus, if the p-electrode interface formed a Schottky barrier, the electrode interface will generate an apparent negative photovoltage. The experimental results (Fig 2) show that the negative photovoltaic-response decrease obviously and even disappear by blocking the laser beam with an aperture to limit the illumination area of the linear array detectors. (b) In the following, we estimated the concentration of the photo-generated carrier, and the results show that the concentration is high enough to form an obvious photovoltage in the p-electrode interface no matter for the case of single-photon and two-photon absorption transition. The photoexcited carriers density within the absorption region induced by one-photon absorption processed are expressed as: $\Delta n = \dfrac{W \cdot \lambda \cdot \alpha}{1.24 \cdot S} \cong 10^{14}\text{-}10^{16}\,\text{cm}^{-3}$, the concentration decline by

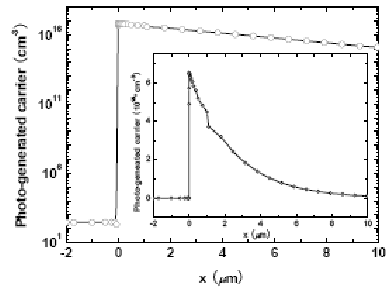

Fig 3 The photo-excited carriers density distribution after the laser illumination. The inset is the semi logarithmic coordinates.

about one order of magnitude near the electrode away from the incidence plane (Fig 3). For the case of two-photon absorption transition, the photo-excited carriers density in the irradiated region of the device are uniformly distributed, which is expressed as: $\Delta n = \dfrac{\beta I^2}{2\hbar\omega}\Delta t \cong (0.5\text{-}30)\times 10^{12}\,\text{cm}^{-3}$. The above calculations show that there are relatively high concentrations of photo-excited carriers at the electrode interface which is far from the plane of incidence. Therefore, if the p-electrode interface formed a Schottky barrier instead of Ohmic contact, the photo-excited carriers at the electrode interface will be separated and formed a negative photovoltage.

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REFERENCES

[1] W. Lu, L. He, X.S. Chen, L. Ding, S.L. Sun, J. Tang, J.H. Su, The development of HgCdTe infrared detector technology in China,Proc. of SPIE Vol. 7298,2009, 72982Z

[2] J. Shao, X. Lü, S.L. Gou, W.Lu, Impurity levels and bandedge electronic structure in as-grown arsenic-doped HgCdTe by infrared photoreflectance spectroscopy, Physical Review B, 2009, 80(15):155125-1-155125-11

[3] J. V. Mikhelashvili, G. Eisenstein, V. Garber, S. Fainleib, G. Bahir, D. Ritter, M. Orenstein, ON theextraction of linear and nonlinear physical parameters in nonideal diodes. J. Appl. Phys. 1999, 85(9):6873-83

[4] M. Y. Lee, Y. S. Lee, H. C. Lee, Behavior of elemental tellurium as surface generation recombination centers in CdTe/HgCdTe interface, Appl. Phys. Lett., 2006,88(20):204101-3

[5] Y. Yao, S. X. Yu, B. F. Ding, D. L. Li, X. Y. Hou, C. Q. Wu, A combined theoretical and experimental investigation on the transient photovoltage in organic photovoltaic cells, Appl. Phys. Lett., 2010,96(20):203306-8

[6] H. Y. Cui, Z. F. Li, Z. L. Liu, C. Wang, X. S. Chen, X. N. Hu, Z. H. Ye, W. Lu, Modulation of the two-photon absorption by electric fields in HgCdTe photodiode, Applied Physics Letters,2008,92(2):021128-30

[7] H.Y. Cui, Z.F. Li, F.J.Ma, X.N.Hu, Z.H.Ye, W.Lu, Negative photovoltaic-responses in HgCdTe infrared photovoltaic detectors irradiated with picosecond pulsed laser, J. Infrared Millim. Waves, 2009, 28(3):161-164