# Determination of minority carrier lifetime in mercury-cadmium telluride photovoltaic detectors using parallel resistance method

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***Abstract*—This paper presents a minority carrier lifetime extraction method using transient photovoltage method. The excitation light source is a picosecond pulsed infrared laser. A parallel resistance has been introduced to minimize the effect of the equivalent junction series resistance effect. A storage oscilloscope has been used to record the photovoltage of the photodiode. By fitting the exponentially decay curve, the time constant has been obtained which is regarded as the photo-generated minority carrier lifetime of the photodiode. The experimental results show that the carrier lifetime is in the range of 0.7~110 ns at 77 K for the measured detectors of four compositions. The results indicate that the lifetime become longer with the increase of Cd composition.**

***Keywords- mercury-cadmium telluride, minority carrier lifetime, parallel resistence, Cd composition***

## I. INTRODUCTION

Because of the attractive characteristics of tunable absorption wavelengths, high quantum efficiency, and wide operating temperature range, mercury-cadmium telluride photovoltaic detector has been used for many infrared imaging systems [1]. However, because of the instability of HgCdTe, which the material property may be changed during the process of the formation of *pn* junction, the minority carrier lifetime determination is still an ambiguity issue [2]. In addition, there are great differences between the device parameters and the design parameters such as trap concentration, carrier concentration, the junction depth, therefore, the parameters of the raw material cannot be applied to the properties of *pn* junction devices. In order to determine the minority carrier lifetime, the measurements must be carried out on the finished devices then the extracted parameters are applied in devices design and simulate. Many measurements have been developed to determine the minority carrier lifetime such as: short-circuit current, open-circuit voltage decay (OCVD), pulse recovery technique etc [3]. However, the minority-carrier lifetimes extracted will often be influenced by the effective circuit (RC time constant) result the lifetime values of these methods being inaccurate.

The purpose of this paper is to measure the minority carrier lifetime using a small parallel resistance method, which reduces the effects of the junction equivalent capacitor and the trap center on the measurements. The experiments results show that the carrier lifetime is in the range of 0.7~110 ns at liquid nitrogen temperature for the measured detectors of four compositions.

## II. EXPERIMENTAL SETUP

The incident light source was a pulse laser having wavelength tuning range 2.3 ~ 10 μm. The Laser pulse was 30 ps and the frequency was 10 Hz. All mercury-cadmium telluride samples were grown on GaAs substrates with CdTe buffer layers and an abrupt $n^+$-$p$ structure were formed by the ion implantation of $B^+$ in $p$-type material. As ZnS films were formed on the surface for passivation, the measured lifetime values were not influenced by the surface treatment. The detectors were processed into 50×50 μm$^2$ or 28×28 μm$^2$area mesa structures. The composition of Cd in the experiments were $x$ = 0.298 (50×50 μm$^2$), $x$ = 0.3035 (28×28 μm$^2$), $x$ = 0.233 (50×50 μm$^2$) and $x$ = 0.2234 (28×28 μm$^2$). The photovoltage of the photodiode was recorded by a storage oscilloscope. A small resistance (50 Ω) was paralleled with the photodiode to minimize the effect of the equivalent junction series resistance effect.

## III. RESULTS AND DISCUSSION

As it has been proposed, the RC Time Constance of the photodiode often influences the extraction of the minority carrier lifetime in the transient photovoltage measurement. Therefore, if the great resistance can be reduced significant then the RC time constant will be minimized, the decay time constant of the photovoltage will decrease and the decay time constant will close to the minority carrier lifetime, consequently.

It has been reported that the steady-state bias light will compensate the effective junction capacitance and the carrier trapping effect. Either the DC photovoltage or the transient photovoltage are influenced by the bias light in the open-circuit photovoltage decay measurement. In order to determine whether the bias light will influence the small parallel resistance measurement, the bias-light illumination experiment are performed, the results are shown in Fig.1. We can see that the transient photovoltage curves will not be influenced by the bias light comparing with the open-circuit photovoltge decay measurements. This can be attributed that small resistor and the equivalent parallel resistor of the *pn* junction form a parallel circuit, the effect of the equivalent parallel resistor is minimized. Comparing with the traditional OCVD method

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that has no load or is in open-circuit, the difference is a 50 Ω resistance has been connected in the load circuit.

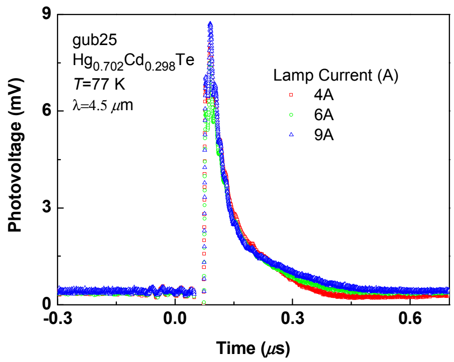


Fig 1 The transient photovoltage of the MCT photodiode with the bias-light intensity and the laser pulses illumination.

Since the bias-light illumination have no influence on the decay curve of the photodiode, it only need to measure the photoresponse without bias-light. Fig 2 is the transient photovoltage curve and the fitting results by using the one-order exponential function and the two-order exponential function. The curves fit well with the experimental indicate that transient photovoltage decay is the relationship of exponential curve. The one-order exponential time constant is 66 ns while the two-order exponential fitting results are 112 ns and 28 ns. These results is very close to the lifetime extracted from open-circuit photovoltage decay measurement. Also the time constant is regarded as the photo-generated minority carrier lifetime in the MCT *pn* junctions. Repeating the measurements, we obtained the minority carrier lifetimes of other pixels of the detector which the Cd component is 0.298. The results are shown in Table 1.

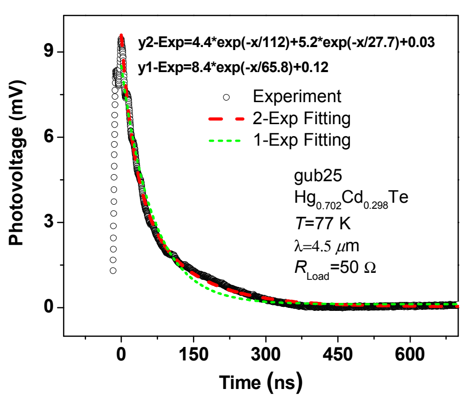


Fig 2. The transient photovoltage curve and the fitting results by using the one-order exponential function and the two-order exponential function.

Table 1. the lifetime extracted from different pixels of the MCT detector which the Cd component is 0.298

| number | lifetime (ns) | |
|---|---|---|
| 1-2 | $t_1$=112, $t_2$=28 | $t$=66 |
| 1-3 | $t_1$=$t_2$=50 | $t$=50 |
| 1-4 | $t_1$=$t_2$=53 | $t$=53 |
| 1-5 | $t_1$=$t_2$=66 | $t$=66 |
| 1-6 | $t_1$=$t_2$=61 | $t$=61 |
| 1-7 | $t_1$=$t_2$=52 | $t$=52 |
| 1-8 | $t_1$=$t_2$=93 | $t$=93 |
| 1-9 | $t_1$=31, $t_2$=110 | $t$=39 |

We also measured the minority carrier lifetimes of other Cd component MCT photodiode using the same method. The results are shown in Fig 3. The experimental results show that the carrier lifetime is in the range of 0.7~110 ns at 77 K for the measured detectors of four compositions. The results indicate that the lifetime become longer with the increasing of Cd composition. On the other hand, the lifetime value become smaller with the decreasing of the junction area, which can be attributed to the surface recombination effect.

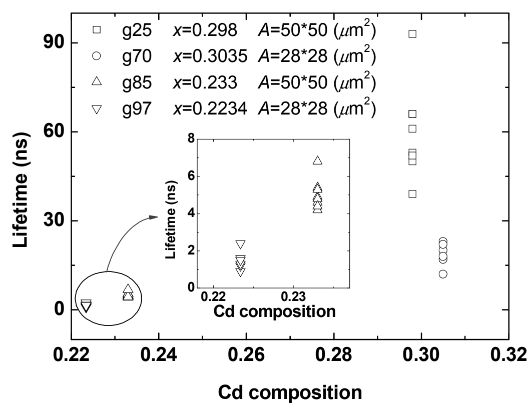


Fig 3.The minority carrier lifetime extracted from the experiment.

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