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Lifetime Measurement of HgCdTe Semiconductor Material

by Uvin Ranawake and James Pattison

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14. ABSTRACT

Mercury cadmium telluride (HgCdTe) is a semiconductor used for detecting infrared radiation. An important method for electrical characterization of HgCdTe is the measurement of minority carrier lifetime using the photoconductive decay method. This experiment was conducted to analyze the minority carrier lifetime of passivated and unpassivated samples of HgCdTe. The lifetimes of the two samples of HgCdTe were measured using a pulse generator, an auto tuning temperature controller, acryostat, a laser, an oscilloscope, and a computer. The lifetime was measured from 80 K to 300 K. A longer lifetime of minority carriers in HgCdTe is desirable for sensing applications.

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Mercury cadmium telluride, molecular beam epitaxy, minority carrier lifetime, photoconductive decay.

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1. Introduction

Mercury cadmium telluride (HgCdTe), an alloy of cadmium telluride (CdTe) and mercury telluride (HgTe), is a semiconductor used for detecting infrared radiation in the near infrared (1–3 μm), mid-wavelength (3–5 μm), long-wavelength (8–12 μm), and the very long-wavelength (>15 μm) infrared spectral region. HgCdTe is a very effective infrared detector material because of its different properties. The properties that make HgCdTe an effective infrared detector are its adjustable bandgap of 0.7 to 25 μm, its high absorption coefficient, its moderate dielectric constant and index of refraction, its high electron-to-hole mobility ratio, its non-parabolic band structure, and its moderate thermal coefficient of expansion. Since this material has different properties that make it more effective than others, this infrared detector is needed in different areas of work, such as in the military. It is used in different technologies, including night vision, missiles, telescopes, and satellites. Sensors made out of this material come in various forms—photoconductors, photodiodes, and avalanche photodiodes. Although HgCdTe is found to be beneficial in different applications, this material can be very difficult to grow because mercury (Hg) has a high vapor pressure.

2. Growth Techniques of HgCdTe

There are different methods for growing HgCdTe. These methods include Molecular Beam Epitaxy (MBE) (figure 1), Liquid Phase Epitaxy, Vapour Phase Epitaxy, Metalorganic Chemical Vapour Deposition, and Bulk Crystal Growth. Although there are many ways to grow HgCdTe, MBE has proven to be the most effective method of them all because it minimizes growth difficulties by controlling the growth conditions. MBE occurs when atoms and molecules are shot at a substrate from effusion cells (figure 2). These atoms or molecules are in the gaseous form. Specific types of atoms or molecules are shot at the substrate, depending on the structure being created. These different atoms or molecules that hit the substrate condense and form ultra-thin layers, thus forming the desired crystalline structure.

MBE is also a very effective method for creating samples of HgCdTe because it creates very thin monolayers, it creates a precise composition of the substrate, and it operates at lower temperatures (~200 ºC). Despite these advantages, MBE does have some disadvantages. For example, MBE requires much complex, sophisticated equipment such as a mass spectrometer and an ultra-high vacuum chamber, and it also has a low growth rate. Overall, MBE is an effective technique that can produce II-VI compound semiconductors.

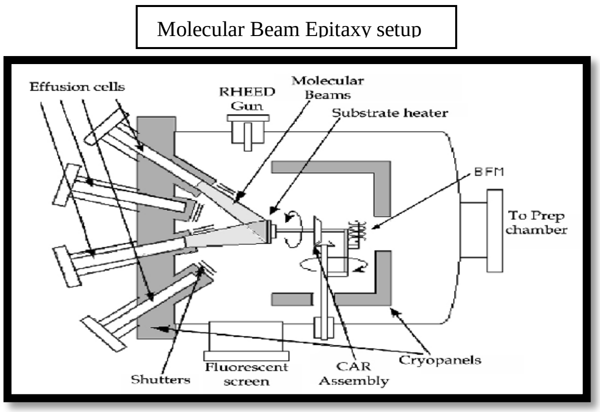

Figure 1. The setup of Molecular Beam Epitaxy.

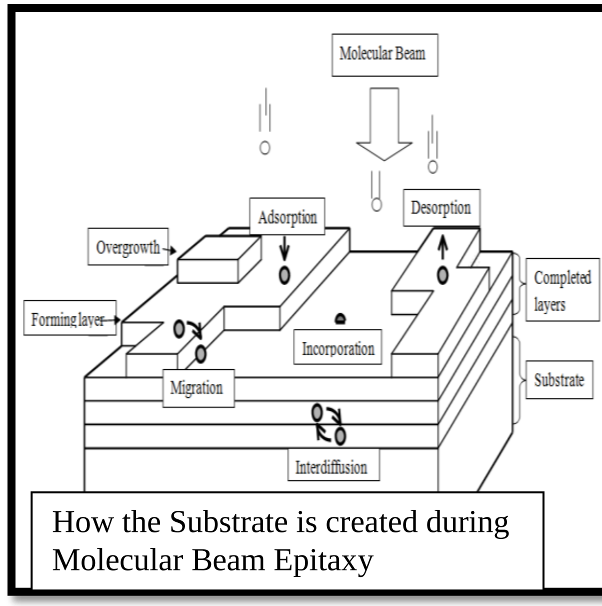

Figure 2. How the substrate is created from the molecular beams in MBE.

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3. Minority Carrier Lifetime

Minority carrier lifetime (lifetime) is the time taken for an electron and hole to recombine. This is important because the longer the lifetime of charge carriers in HgCdTe, the better the material, as it will have higher specific detectivity and lower diffusion current. $D^*J_{O\ Diff}$Specific detectivity is given by the equation, $D^* = \frac{R\sqrt{A}}{N}$ and the diffusion current is given by the equation, $J_{O\ Diff} = \frac{q{n^2}_i d_n}{N_d \tau_p}$. The specific detectivity is a performance metric that compares photodetectors by standardizing flux, detector area, and frequency response across dissimilar experiments. Usually, high performance photodetectors have a higher specific detectivity because of a lower background noise, ($N = \sqrt{2q\left(I_o + I_o e^{\frac{qV}{K_B T}} + I_L\right) + {I_{excess}}^2}$). A greater lifetime is needed to have a more effective material because specific detectivity and the diffusion current are dependent on lifetime.

There is more than one process that affects the lifetime (figure 3). The lifetime of a given material can be expressed by the equation, $\frac{1}{\tau} = \frac{1}{\tau_A} + \frac{1}{\tau_R} + \frac{1}{\tau_{SR}}$. The Auger lifetime ($T_A$) is when an excited electron in the conduction band recombines with a hole in the valence band. The recombination releases energy, and this energy is transferred to another electron on the conduction band. The Auger lifetime is expressed in the equation, $\tau_A = \frac{2{n_i}^2 \tau_{Ai}}{(n_o + p_o)(n_o + \gamma p_o)}$. The Radiative Recombination lifetime (τ_R) is when an electron and hole recombine. During this process, excess energy is emitted as a photon. The Radiative Recombination lifetime is given by the equation, $\tau_R = \frac{1}{B(n_o + p_o)}$. Finally, the Shockley-Read Hall recombination (τ_{SR}) is the recombination of an electron and hole through defects in the crystalline lattice. The Shockley-Read Hall recombination is given by the equation, $\tau_{SR} = \frac{\tau_{po}(n_o+n_1}{n_o+p_o} + \frac{\tau_{no}(p_o+p_1)}{n_o+p_o}$.

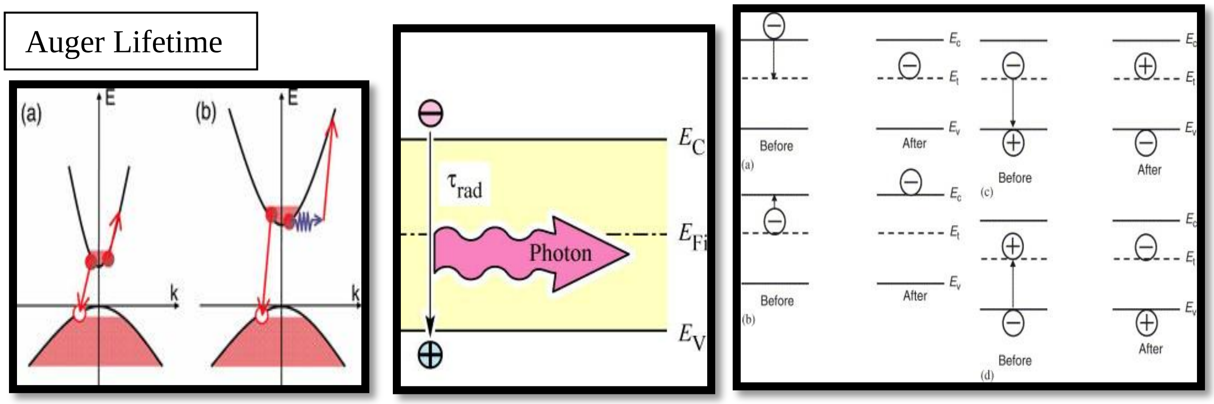


Figure 3. The three processes that can affect the lifetime of HgCdTe.

In order to measure the lifetime of different HgCdTe samples in my experiment, the photoconductive decay method was used. To measure the lifetime of the HgCdTe samples using the photoconductive decay method, samples of HgCdTe were prepared using MBE. After creating samples of HgCdTe using MBE, the samples were annealed. Annealing fills any Hg vacancies in the sample of HgCdTe using Hg overpressure. After the samples were annealed, the samples were etched. Etching removed <1 μm of the surface of the HgCdTe using a 1:400 v/v $Br_2/MeOH$ solution. After etching, one sample was passivated and one sample was unpassivated. Passivation is the deposition of a layer of an oxide to eliminate surface recombination. In my case, I used aluminum oxide to passivate the sample of HgCdTe by atomic layer deposition (ALD). After the passivated and unpassivated samples were ready, indium contacts were deposited.

To measure lifetime, the following equipment was used (figure 5):

- Pulse generator supplies trigger for oscilloscope and laser
- Temperature controller supplies negative feedback loop for temperature measurement and sample heating
- Cryostat is used to keep mounted sample under vacuum and provide electrical contact
- Oscilloscope measures photoconductive decay curve, synchronized with pulse trigger
- Computer provides analysis and graphics from data

To measure the lifetime using this setup, first the sample was placed in the cryostat and pumped to better than 1 mTorr vacuum. The sample was then cooled to 80 K. Electrical contact was made, and the sample biased at 1.5 V. A laser was pulsed on the sample to generate carriers. The electrical signal across the sample was measured by the oscilloscope, and the data was scaled to appear similar to the graph in figure 4. The data was saved at 80 K, and the temperature was raised by 5 K. The temperature was allowed to stabilize for about 5 min, and then the signal was again saved to disk. This was repeated until reaching 300 K. Once all of the data was collected, Microsoft Excel was used to graph log (V) versus time, and calculate the slope of the resulting lines of each graph of each respective temperature. The value that is $\frac{-1}{slope}$ is the lifetime of that respective temperature. Once I calculated the different lifetimes of each temperature, I graphed the lifetime of the respective temperature with a log scale, versus 1000 divided by the temperature. Once the data is graphed, the lifetime data will be analyzed.

Lifetime Setup

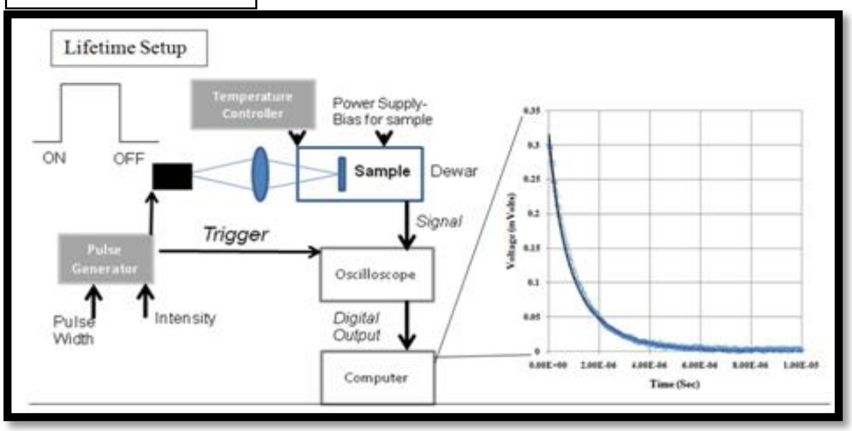


Figure 4. The setup of lifetime.

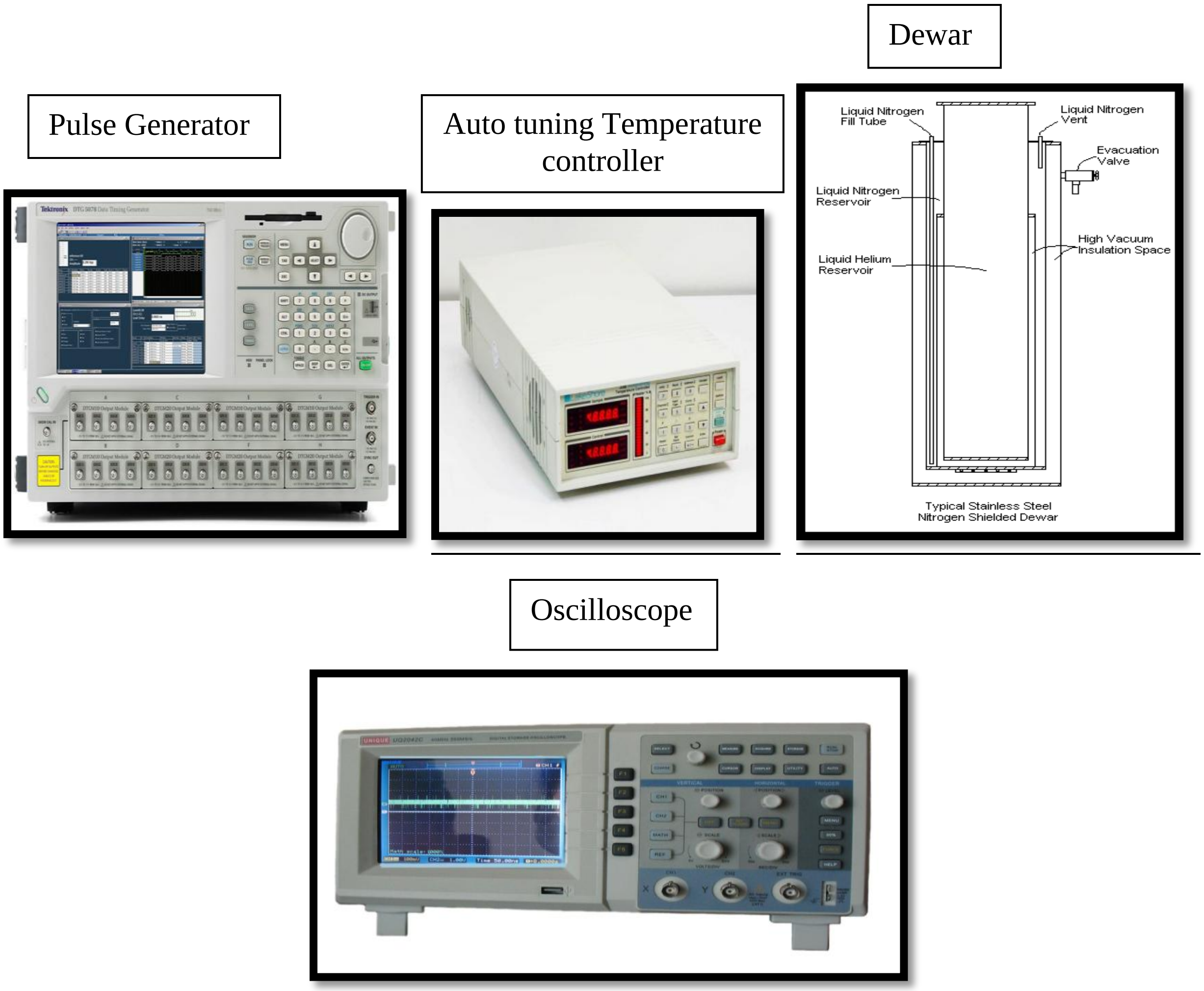
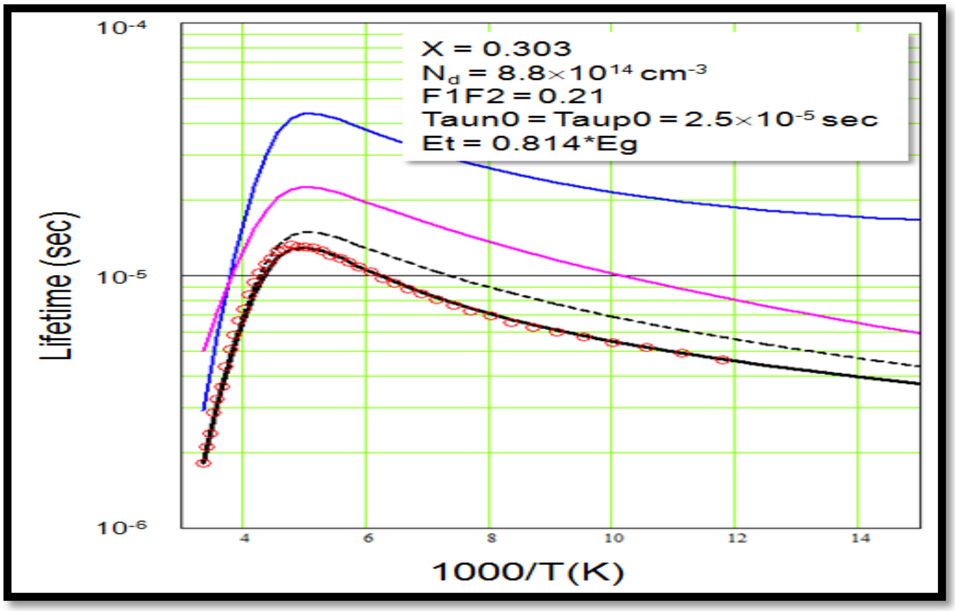


Figure 5. The equipment used to measure the lifetime of HgCdTe.

4. Discussion of Data

After plotting the lifetime versus the temperature data, it was shown that passivation has an effect on the lifetime of HgCdTe (figure 6). Two of the samples clearly show that the lifetime of the passivated sample is greater than the lifetime of the unpassivated sample over the extrinsic region. However, on the third sample, the lifetime of the passivated sample appears to be slightly shorter than the unpassivated sample over the extrinsic region. Therefore, in order to get more conclusive data, more passivated and unpassivated samples will need to be tested in order to better understand if and how passivation increases the lifetime of HgCdTe.

Sample of a fit of the Unpassivated Data



Comparison of Passivated and Unpassivated Data

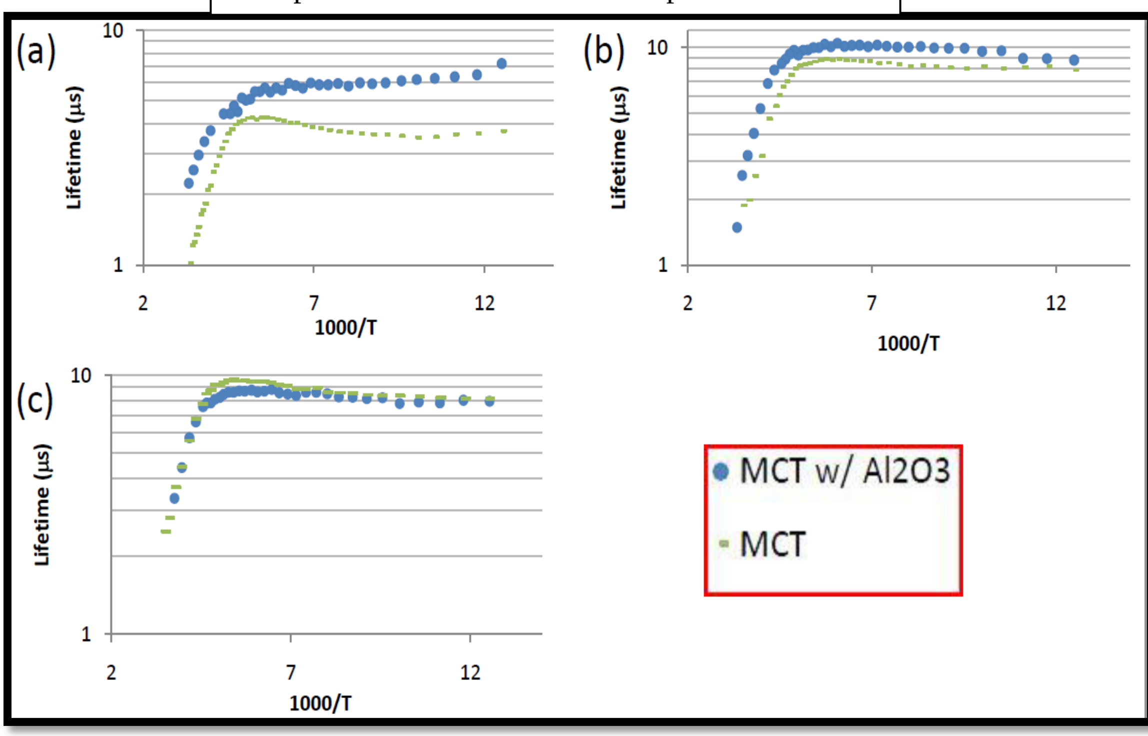


Figure 6. Comparison of the passivated and unpassivated samples.

5. Conclusion

It is very important to develop HgCdTe material that can effectively detect different wavelengths of light. Lifetime can have a great impact on the effectiveness of the material HgCdTe. In order to have a greater lifetime, the sample can be altered; for example, the sample can be passivated or annealed. The altered samples must be tested to see whether they have a positive effect on the lifetime of HgCdTe. With a greater lifetime, the HgCdTe material will be a better material for detecting different wavelengths of infrared radiation. Better material will lead to better applications in different fields of work.

6. References

(2007). In *Epitaxial Growth*. Retrieved Jul. 17, 2011, from http://mxp.physics.umn.edu/s07/projects/s07_graphene/intro.htm

Cooke, M. (2011 Apr. 20). In *UCSB theory blames indirect Auger recombination for nitride LED droop*. Retrieved Aug. 3, 2011, from http://www.semiconductor-today.com/news_items/2011/APRIL/UCSB_200411.html

Honsberg, C. In *Types of Recombination*. (chap. Chapter 3/ LifetimeTypes of Recombination) Retrieved Jul. 18, 2011, from http://pvcdrom.pveducation.org/SEMICON/RECTYPE.HTM

In *Chapter 2: Radiative and non-radiative recombination* . Retrieved Aug. 3, 2011, from http://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap02/chap02.htm

Khanna, V. (2005). In *Physical understanding and technological control of carrier lifetimes in semiconductor materials and devices: A critique of conceptual development, state of the art and applications* . Retrieved Aug. 2, 2011, from http://www.sciencedirect.com/science/article/pii/S0079672705000030#SECX11

Norton, P. (2002). In *HgCdTe infrared detectors*. Retrieved Jul. 17, 2011, from http://www.wat.edu.pl/review/optor/10(3)159.pdf

Wagner, R. J. (1999 Apr. 16). In *Molecular Beam Epitaxy A Simple Introduction*. Retrieved Jul. 19, 2011, from http://www-personal.umich.edu/~wagnerr/IntroMBE.pdf

Woodford, C. (2009). In *Molecular beam epitaxy*. Retrieved Jul. 19, 2011, from http://www.explainthatstuff.com/molecular-beam-epitaxy-introduction.html

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