Maximum entropy mobility spectrum analysis of LPE-grown and anodic oxidated Hg$_{1-x}$Cd$_x$Te($x=0.237$)

Z Y Song$^1$, L Y Shang$^{1,*}$, T Lin$^2$, Y F Wei$^2$, J H Chu$^{1,2}$

$^1$Key Laboratory of Polar Materials and Devices, Ministry of Education, East China Normal University, Shanghai 200062, China
$^2$National Laboratory for Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy of Science, Shanghai 200083, China

$^*$The corresponding author: lyshang@ee.ecnu.cn

Abstract. In this paper, magneto-transport properties of the LPE-grown and anodic oxidated p-type Hg$_{1-x}$Cd$_x$Te($x=0.237$) films have been studied by using maximum entropy mobility spectrum analysis (ME-MSA) technique. It can be found that the high-mobility electron ($\mu_e \sim 2 \times 10^{4} \text{cm}^2/\text{V}s$) has considerable contributions to the conduction of anodic oxidated Hg$_{1-x}$Cd$_x$Te($x=0.237$) film, but not in LPE-grown Hg$_{1-x}$Cd$_x$Te($x=0.237$) film. The high-mobility electron maintains dominant contributions from 11k to 150k, which can be attributed to two-dimensional electron gas in the inversion layer of anodic oxidated p-type Hg$_{1-x}$Cd$_x$Te($x=0.237$) film. In addition, we also observe the nonphysical contributions of low mobility electrons ($\mu_e \sim 0.08 \times 10^{4} \text{cm}^2/\text{V}s$) in mobility spectrum of both LPE-grown and anodic oxidated p-type HgCdTe films. The low-mobility electrons, so-called mirror peaks, can be interpreted as a consequence of magnetic freeze-out of holes in vacancy-doped HgCdTe, which disappeared at T=150k.

1. Introduction

HgCdTe(MCT) is the most important modern semiconductor alloy system for infrared application. Nevertheless, owing to the relative instability of Hg atoms in HgCdTe, the surface treatments play a crucial role in determining the performance of the devices. The most common method to protect the surface of HgCdTe is anodic oxidation[1,2,9], which still introduce some positive oxidation defects, such as oxygen vacancies, in anodic oxidated p-type MCT films[2]. These positive oxidation defects, limiting the detector’s performance, lead to inverted surface of p-type HgCdTe films providing us a two dimensional electron system which could carry on many basic physics research. In addition, due to the narrow band of HgCdTe, thermal excited electrons, light holes tend to make significant contributions to the conduction of MCT samples[3,6,7]. Multicarrier transport studies[7] were performed on a set of MCT samples by using mobility spectrum with changing temperature[6,7]. But, little quantitative research has been performed on transport properties of anodic oxidated MCT system.

Standard measurements of the resistivity and Hall coefficient at a single magnetic field provide only
averaged values of the carrier densities and mobilities[5], which can not give the actual individual species and their accurate mobility. To overcome this shortcoming, Beck and Anderson[3] proposed in 1987 an approach known as the mobility-spectrum analysis(MSA).

Furthermore, Maximum entropy mobility spectrum analysis(ME-MSA)[5] approach minimizes the fit deviation from measured data with the principle of entropy maximization. It doesn’t allow nonphysical negative conductivities and every probable distribution is concerned, with the help of maximum entropy principle. ME-MSA estimates the mobility spectrum by assigning “an entropy” to each probability distribution and choosing the one with the highest entropy.

In this paper, we investigated magnetotransport properties of LPE-grown and anodic-oxidated HgCdTe materials. First, we will introduce the experimental details of sample processing; Then the mobility spectrums of LPE-grown and anodic oxidated p-type Hg_{1-x}Cd_{x}Te(x=0.237) films will be given and we find that the high-mobility electron maintains the dominant contribution to the conduction of anodic oxidated MCT until T=150k, which can be attributed to two dimensional electron gas in the inversion layers of anodic oxidated p-type Hg_{1-x}Cd_{x}Te(x=0.237).

2. Experiments

A set of p-type HgCdTe wafers were grown by standard liquid-phase epitaxy (LPE) on a lattice matched CdZnTe substrate. The surface was passivated by anodic grown native oxidase. The samples were cut into 7 × 7μm squares and then indium was used to make Ohmic contacts. The magneto-transport measurements were performed by using Vander Pauw configuration with an applied magnetic field between 0 T and 9 T and from 11k to 300 K in a liquid-helium-cooled continuous-flow cryostat.

3. MS of LPE-grown and anodic oxidated Hg_{1-x}Cd_{x}Te (x=0.237)

Table1. Selected transport parameters extracted from MS of LPE-grown HgCdTe and anodic oxidated HgCdTe at 20 k.

| Name         | E3   | E1   | T1   | T1b  | E2   | T2   | T2b  |
|--------------|------|------|------|------|------|------|------|
| LPE-grown    | 0.09 | 2.76 | 0.08 | 0.29 | 0.036| 0.064| 0.051|
| HgCdTe       | 0.98 | 35.2 | 1.54 | 0.21 | 1.51 | 2.68 | 2.13 |
| Anodic oxidated | 6.73 | 7.97 | 13.76| 0.46 | 3.06 | 37.19| 6.06 |

Figure.1 shows the mobility spectrums for electron(Fig.a) and hole(Fig.b) at 20 k of as-grown HgCdTe(black circles) and the anodic oxidated one(red triangles). It can be identified that three kinds of carriers in MS of electrons(Fig.1a) at 20K: the low-mobility electron (E2, E3) and high-mobility electron E1. Notably, the high-mobility electron was only found in the anodic oxidated HgCdTe, and the percentage of E1 electrons to the conductivity is 84% . The contributions of E2 and E3 electrons are not expected to the conductions of two samples at 20k. And the E2 and E3 peaks disappear at 150k, as is shown in figure. 2a. But the high-mobility electron(E1) still maintain the dominant contribution to the conductivity in anodic oxidated HgCdTe at 150k (figure.2a), Furthermore the concentration of
E1 electron was almost constant with the increasing temperature (figure.4), which could be the typical characteristics of two dimensional electron gas. We deduced that a two dimensional electron gas appears in the surface layer of MCT since the process of anodic oxidation would introduces some optimistic oxygen vacancies which have positive charges[1,2].

There were four kinds of holes which contribute to the conduction of two samples, as is shown in figure.1b. The low-mobility holes(T1 and T2) are the expected heavy holes. The light holes were easily excited due to the narrow bandgap($E_g = 0.118eV$) of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}(x=0.237)$ and ME-MSA also gave the mobility of light holes(T1b and T2b) which consisted with the results of past reports[6,7,8,9].

We could also find that the low-mobility electron(E2 and E3) disappeared at 150K. The mobilities of E2 and E3 electrons are very low in HgCdTe. Similar features have been observed in other studies of HgCdTe[10]. A possible origin of the low-mobility electrons is the magnetic freezeout of the carriers. The magnetic freezeout[4,10] was to be induced by an increase of the activation energy through a localization of the impurity states, which causes a reduction of the number of carriers as the magnetic field increases. Figure.2b shows that heavy holes(T2) appear in the conducting system with the increasing temperature.

Figure.1. MS of electrons(a) and holes(b) for LPE-grown(black circles) and anodic oxidated(red triangles) HgCdTe at T=20k.

Figure.2. MS of electrons(a) and holes(b) for LPE-grown(black circles) and anodic oxidated(red triangles) HgCdTe at T=150k.

Figure.3 shows the temperature dependence of mobility of heavy holes (T1) of as-grown HgCdTe. It can be shown that the mobility of T1 holes increases until 77k and then decreases as the temperature is increased from 77k to 200k. The iconized-impurities scattering is the dominated
mechanism below 77k since the mobilities and temperatures satisfies the relationship of $\mu \sim T^{3/2}$. As temperature is increasing, phonon scattering becomes the predominated scattering mechanism, which gives a decrease of the mobility of T1 holes. The dominated phonon scattering also gives a slight decrease of the mobility of E1 electron, as is indicated in figure 4.

![Figure 3](image3.png)  
**Figure 3.** Temperature-dependent of hole mobility for LPE-grown HgCdTe.

![Figure 4](image4.png)  
**Figure 4.** Temperature-dependent of electron concentration (black circles) and mobility (red squares) characteristics for anodic oxidated HgCdTe.

4. Conclusions
Mobility spectrum analysis has been employed to study transport properties of as-grown and anodic oxidated HgCdTe films. It shows that electrons are the main contribution to the conduction of anodic oxidated p-type HgCdTe films. We think those electrons were 2DEG located in the invert surface of the anodic oxidated p-type HgCdTe films. The low-mobility electrons found in both two kinds samples can be assigned to magneto freeze-out carriers. MSA based studies of electronic transport properties of HgCdTe films can be employed to determine carrier transport parameters, enabling identification of the main defects limiting the properties of infra HgCdTe detectors.

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