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EBIC and IBIC Imaging on Polycrystalline CdTe

Nicolas Baier[a,*], Andrea Brambilla[a], Guy Feuillet[a], Annika Lohstroh[b], Sébastien Renet[a], Paul Sellin[b]

[a]*CEA/Grenoble-LETI, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France*
[b]*Department of Physics, University of Surrey, Guildford, GU2 7XH*

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Abstract

Polycrystalline Cadmium Telluride samples were electrically characterized using two high resolution imaging techniques: Electron and Ion Beam Induced Current. Using different probes, electrons and protons, both surface and bulk transport properties were obtained. The grain structure was observed and grain boundaries effects were studied. The material tends to have a homogeneous response under low excitation, with only few weakly responding grains and no dead areas. Under higher excitation, the material exhibits some particular behavior, like grain sub-structures. The IBIC experiment gives a measure of Charge Collection Efficiency under different sample bias voltages. In addition to the measurement of the response dispersion, it leads to a discussion of the charge transport properties and a mobility-lifetime product calculation.

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1. Introduction

Cadmium Telluride (CdTe) is a widely studied semiconductor for room-temperature radiation detectors, in visible light, infrared, X- and gamma ray ranges. This is due to its interesting properties: a 1.5 eV bandgap, a high radiation stopping power and a high optical absorption coefficient. The polycrystalline CdTe material can be grown on larger surfaces with lower cost than monocrystalline material. Thus it is studied for its use in various applications, such as photovoltaics [1] or X-ray imaging detectors. However, this type of material presents a large amount of structural defects (such as twins or grain boundaries) and impurities.

The aim of this work is to study the material with a high resolution probe. The final goal is to map the transport properties and their homogeneity, to observe the microscopic structures of the material and the grains, and to measure the influence of the grain boundaries.

We used Electron Beam Induced Current (EBIC) and Ion Beam Induced Current (IBIC). These methods give access respectively to the surface and the bulk transport properties with a micrometric resolution.

After a presentation of the experimental conditions and of the principles and specifications of the two experiments, the results obtained on polycrystalline CdTe samples will be described and finally discussed in view of X and gamma ray detection.

2. The beam induced current experiments: principles

2.1. Generalities

The Beam Induced Current techniques consist of using a focused beam of ionizing particles. The interaction in a biased semiconductor material produces a current which is measured with a current amplifier. Knowing the response of the material and the coordinate of the beam impact point, one can scan an area by moving the beam, thus providing a spatial image of the transport properties. The beam can be used in two modes: a high flux beam for

*Corresponding author. Tel.: +33 438 789 321; fax: +33 438 785 164.
E-mail address: nicolas.baier@cea.fr (N. Baier).

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continuous charge generation in the case of electrons or single particle detection in the case of protons.

2.2. Electron-BIC experiment

The first technique used to analyze the polycrystalline CdTe samples is EBIC. It involves the electron beam of a Scanning Electron Microscope (SEM). In this kind of measurement, the electron beam is continuous, thus the signal measured is the current flowing through the sample. The beam exposure at each position is 30 μs, leading to an acquisition time of about 28 s for each 1024×882 pixels scan. With such an exposure length, the electrical afterglow at each point remains small enough that we do not face stacking effects during the acquisition [2].

The acceleration voltage of the electrons was set to its maximum value, 30 kV, in order to have the highest penetration depth of the electrons in the material. Using Monte Carlo simulation for 30 keV electrons with CASINO [3], a penetration depth of about 3 μm is found. This kind of experiment provides the surface response of the polycrystalline CdTe, just under the gold contact. The projected interaction diameter of about 2 μm gives the maximum resolution of the setup.

Since the beam current is adjustable, it is possible to change the generated charge density. With the magnifying possibilities of the electronic microscopes, one can analyze areas of a few mm in side length down to several tenths of μm.

2.3. Ion-BIC experiment

The main aim of the IBIC is to use a more penetrating probe than the electrons. In our case we used 2.58 MeV (maximum energy achievable) protons provided by the Van der Graaf accelerator of the University of Surrey.

In this experiment, the penetration depth of the protons is 53 ± 2 μm with a projection radius of 2 μm (determined using TRIM [4]), corresponding to their lateral deviation. Since protons deposit energy all along their path, we have access to the bulk response of the material. As a consequence, it is not desirable to change the proton energy as it will lead to a lower penetration depth.

The beam line is equipped with an electrostatic scanning device providing an adjustable mapping size with a maximum size of $2.5 \times 2.5\,\mathrm{mm}^2$. The spatial resolution reached with this scanning device is 4 μm, if no account is taken of the lateral deviation of the protons.

Unlike the EBIC technique, one measures the integrated induced current by single particles. The measured signal is the charge collected for each event, thus giving the Charge Collection Efficiency (CCE) (the ratio between the measured charge and the theoretically deposited charge). Knowing the position given by the scanning device, the CCE map of the sample can be plotted. To avoid event pile-up considering the pulse width and the speed of the read-out electronic, the beam flux was set at about 2000 protons/s. The deposited energy and the charge density are lower than in EBIC, leading to fewer space charge effects.

3. EBIC images

3.1. Sample characteristics

The sample we analyzed is an 18 mm diameter, 350 μm thick polycrystalline CdTe detector. The material has a columnar structure, with ⟨1 1 1⟩ oriented grains. On each face an electroless gold contact was deposited to ensure the electrical contact. The electron mobility in the material is estimated around $500\,\mathrm{cm}^2/\mathrm{V/s}$ [5]. The sample bias voltage was set to 100 V during the measurements and only the electron signal is measured, since holes have very poor transport properties and are created near their collecting electrode.

3.2. Results at low generated charge density

Fig. 1 presents an EBIC scan obtained with the lowest beam current provided by the microscope, 4 pA, in order to have the lowest generated charge density. For this image, the amplitude of the current is imaged with the gray scale and the values are in amps.

One can definitely see the polycrystalline structure of the material, with well separated grains and grain boundaries. The grain size ranges from 10 to 100 μm, but most of the grains have sizes between 70 and 100 μm. In this image, the current ranges from 404 to 428 nA, including the dark current of 402 nA. The sample presents few dark areas, which correspond to weakly responding grains: only 3% of the map has a response below 420 nA. It is important to underline that these areas are not dead since a signal is detected. Apart from these grains, the overall response is quite homogeneous, with a mean value of 24 nA and a

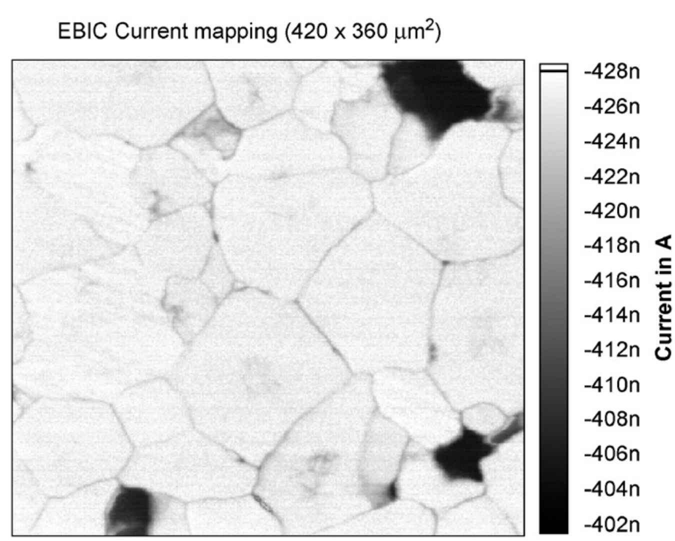

Fig. 1. EBIC current scan of $420 \times 360\,\mu\mathrm{m}^2$ obtained at the lowest beam intensity and a bias voltage of 100 V.