Electrical measurement of barrier energy to ionic current in indium sulfide films

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Abstract

The present work is a study of electrical current in In_2S_3 polycrystalline thin films. The current-voltage plots indicated that the conduction mechanism was due to ion transport. The barrier height to the transport of S^{2-} ions was calculated as 0.496 volts.

1. Introduction

This paper concerns a study of ionic electrical conduction through polycrystalline indium sulfide In_2S_3 films. An ionic current results in ionic semiconductors when, under the action of an applied electric field, an ion in a potential energy well surmounts an energy barrier to jump into another well. The distance between barriers may be that between two adjacent crystal lattice sites or the distance between two grain boundaries. In_2S_3 is used in electric power sources. The jump distance between energy wells, and the potential difference of the potential energy barrier to the motion of ions in In_2S_3 films was calculated.

2. Theory

Consider an ion at the bottom of an energy well separated from another ion or a group of ions, by a potential energy barrier. An ion then has to surmount a potential difference of U volts to jump into the adjacent well. Without an externally applied electric field, the material is at equilibrium, and the number of ions moving in any net direction, and the current, are zero. The application of an electric field E lowers the potential energy between two wells, a distance a apart, by eEa where e is the ionic charge. This lowers the barrier height for ions moving to contribute to the forward current by $0.5eEa$ electron volts and increases the barrier by the same amount for ions moving in the opposite direction[1]. The net electrical current in an ionic conductor with a potential difference V applied across its thickness d is then

$$I=I_0\sinh(eaE/2kT) \tag{1}$$

where a is the jump distance between potential wells, $E=V/d$ is the electric field, k is Boltzmann's constant and T the absolute temperature.

For large fields, when $eaE \gg kT$, the barrier for ions tending to oppose the forward current is large enough to make this component of current negligible, compared to the forward current, and the net current is then given by

$$I=0.5I_0\exp(eaE/2kT) \tag{2}$$

The semi-log plot of the current versus the applied voltage V for Equ. 2 appears in Fig. 1. It shows that taking the logarithm of both sides of Equ 2 gives a linear relationship between $\ln I$ and V, for large E, with a straight line of slope

$$\Delta(\ln I)/\Delta V=ea/2dkT \tag{3}$$

The jump distance a is determined from Equ 3.

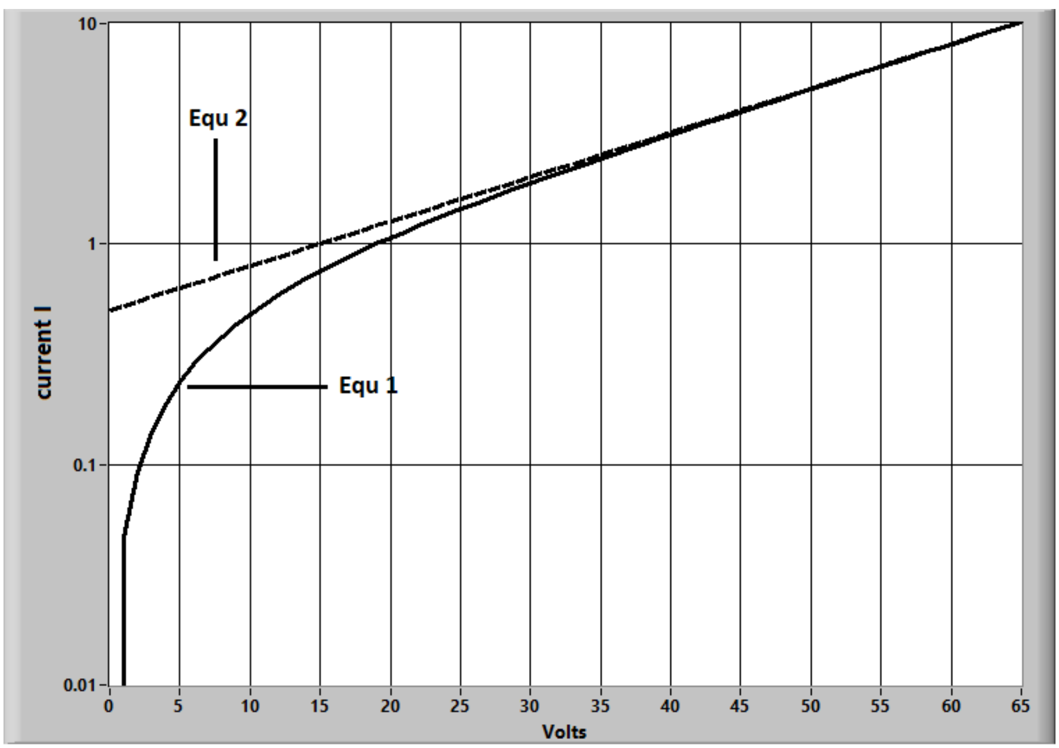

Fig 1 *Log-linear plot of current vs voltage showing linear relationship at high electric field*

For small electric fields, when $eaE \ll kT$, the current vs voltage curve is linear, and the conduction ohmic, with a conductance G. The barrier height, in volts, to ionic conduction is then given by

$$U= -(kT/e)\ln(GdkT/ne^2va^2A) \tag{4}$$

where ν is the attempt-to-escape frequency of ions, n the density of ions, and A the active device area.

3. Experimental

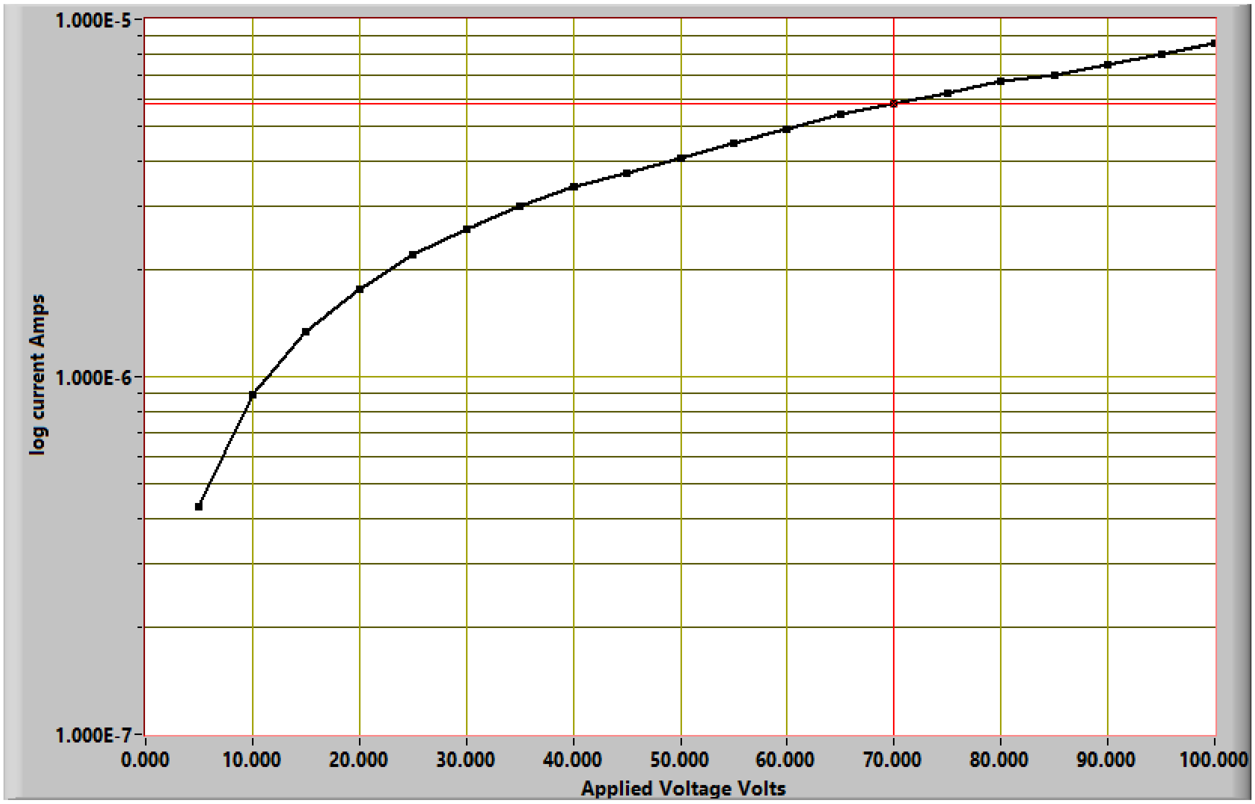

Fig 2 *Semi-log plot of current vs voltage for an* In_2S_3 *film*

Fig 2 shows the semi-log plot of the experimentally determined current-voltage values for an In_2S_3 films at room temperature. It follows the hyperbolic function of Equ 1 and Fig 1. The curve in Fig 2 shows a linear relationship between ln$I$ and and V for voltages higher than 65 volts. The average jump distance a for S^{2-} ions, determined using Equ 3, for the films examined, was 170 nm.

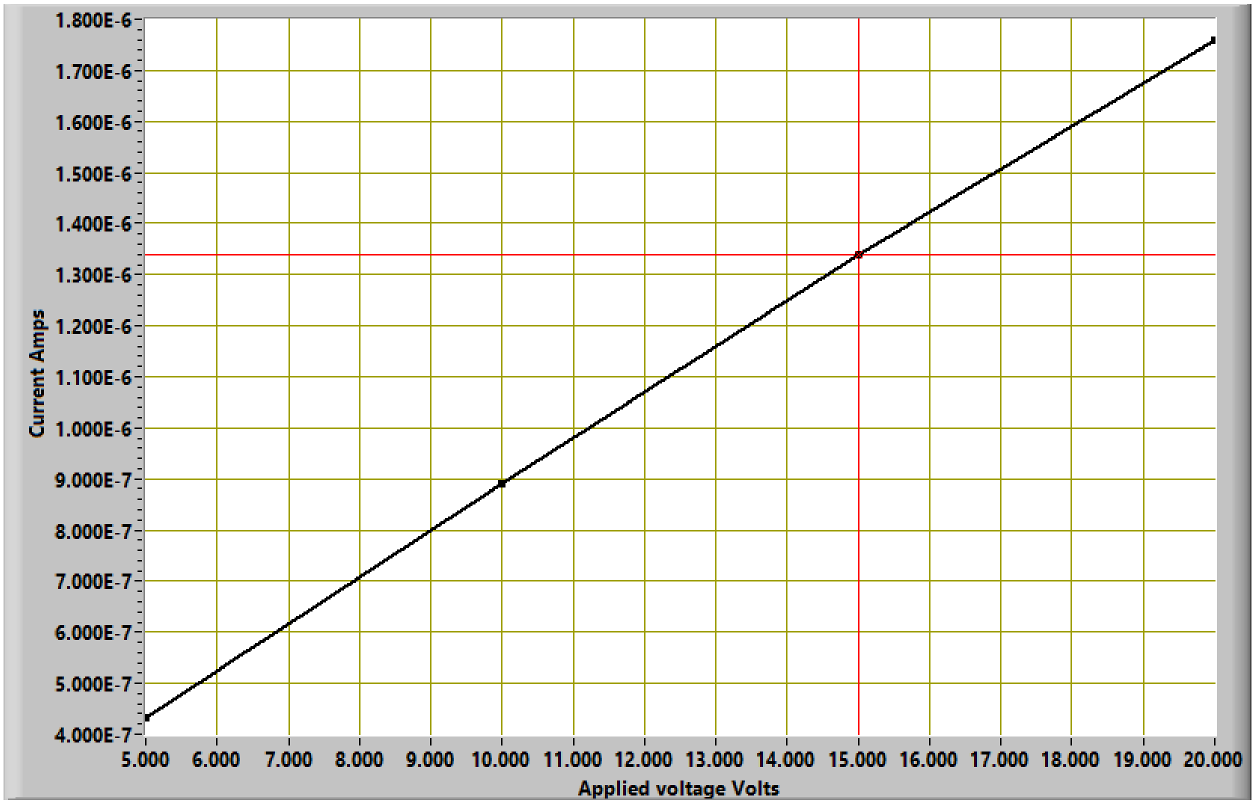

Fig 3 *plot of current vs voltage for* In_2S_3 *film showing linear I-V relation at low voltages*

At low voltages the *I-V* variation was linear, and the film conductance was of the order of 10^{-7} to 10^{-8} mhos. Fig 3 shows the *I-V* curve for an In_2S_3 film at low voltages whence the conductance was calculated as 8.57×10^{-8} mhos. The barrier height U to the transport of S^{2-} ions was then calculated, using Equ 4, as 0.496 volts.

4. Reference

1. N. F. Mott and R. W. Gurney, Electronic processes in ionic crystals, 2nd Edition, Oxford University Press, Oxford, 1957.