Acceptor State Activation Energy of Tin Monosulfide

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Abstract:

The positive (*p*)-type semiconductor tin monosulfide (SnS) was studied as a potential solar cell absorber material. Temperature-dependent Hall measurements were taken on tin sulfide thin films to determine the film's resistivity as a function of temperature over a range of 200°K, from which the carrier concentrations at each temperature were obtained. By fitting the carrier concentration data to a model and assuming a single activation energy, an acceptor state activation energy of 0.109 eV was calculated for tin sulfide.

Introduction:

Current research in the development of solar cells for clean energy production seeks to mitigate the cost of high-efficiency solar cells resulting from material scarcity. To this end, earth-abundant, non-toxic materials are being studied as an alternative for use in solar cells.

Tin (II) sulfide has attracted considerable attention due to its desirable optical and electrical properties. It is a *p*-type semiconductor with a direct band gap of 1.30 eV. In order to evaluate the viability of using tin sulfide as an absorber material, it is necessary to study the characteristics of its charge carriers—in this case, holes in the lattice. An important property of a semiconductor material is its donor or acceptor activation energy, or the amount of energy required to dislodge an electron or hole.

Experimental Procedure:

Tin sulfide thin films were created by depositing 300-600 nm of SnS on a glass substrate using atomic layer deposition (ALD). The resistivity data were obtained by performing temperature-dependent Hall measurements over a 200°K temperature range. Starting at 125°K, and in 25°K increments up to 325°K, resistivity, mobility, and carrier density were obtained at each temperature for each of the films.

Results and Conclusions:

Since SnS is *p*-type, charge is carried primarily by holes in the lattice. Hall measurements yielded the density of holes as a function of temperature. Mark Thomas Winkler proposed the following model to describe non-degenerate *n*-type semiconductors [1]:

$$n = \frac{2(N_d - N_a)}{\left[1 + \frac{N_a}{\beta N_c}\exp(\epsilon_d)\right] + \sqrt{\left[1 + \frac{N_a}{\beta N_c}\exp(\epsilon_d)\right]^2 + \frac{4}{\beta N_c}(N_d - N_a)\exp(\epsilon_d)}}$$

where n is the total carrier concentration, N_d is the density of donor states, N_a is the density of acceptor states, β is the spin degeneracy, ε_d is the reduced binding energy (given by Eq. 3), and N_c is the band edge density of states, given by the following:

$$N_c(T) = 2\left[\frac{2\pi m_e^* k_b T}{h^2}\right]^{3/2}$$

where m_e^* is the reduced electron mass, k_b is the Boltzmann constant, h is Planck's constant, and T is the absolute temperature.

$$\epsilon_d = E_d / k_b T$$

Since SnS is a *p*-type material and the model describes negative (*n*)-type materials, the quantities N_d and N_a were switched when performing the necessary calculations (i.e. N_d was used to represent the number of acceptor states and N_a the number of donor states), and the binding energy in this case represented the acceptor state activation energy.

Fitting the data to this model by varying two parameters (N_a and N_d, the number of acceptor and donor states, respectively), a best fit was achieved that yielded an acceptor state activation energy of 0.109 eV. The resulting curves are plotted in Figure 1.

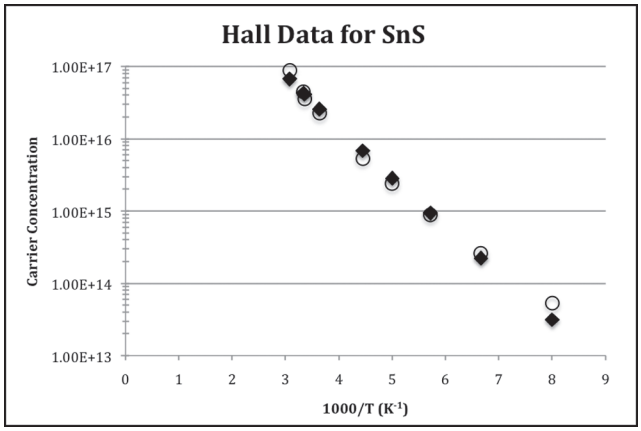

Figure 1

References:

[1] Winkler, M.T. "Non-Equilbrium Chalcogen Concentrations in Silicon: Physical Structure, Electronic Transport, and Photovoltaic Potential." Harvard University Press. October 2009.

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