

Characterization of ZnSe/GaAs heterostructure using transverse acoustoelectric voltage spectroscopy

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Transverse acoustoelectric voltage (TAV) spectroscopy has been employed to characterize the interface of high-resistivity ZnSe/GaAs heterostructure. Single- and double-beam TAV spectroscopy have been used to study the interface band and impurity transitions of the heterostructure at room temperature. From the TAV spectrum, a conduction band offset of 0.059 eV was found. The spectral behavior of the TAV waveform for single and double-beam cases was different due to the presence of a large number of surface states at the interface. Additional transitions in ZnSe film were also found in the double-beam case when a bias beam of 2.637 eV was used.

Zinc selenide is a II-VI compound semiconductor with a direct band gap of approximately 2.67 eV at 300 K so that it is useful for absorbing and emitting light in the blue spectral region. Its large band gap and closely matched lattice constant to GaAs make it also attractive for use as a passivation layer for GaAs. Furthermore, high-resistivity ZnSe has been used as an insulating layer for metal-semiconductor field-effect transistors (MESFETs).¹ However, the presence of a large number of defects at the ZnSe/GaAs heterostructure interface deteriorates the electronic properties and the performance of these devices. Therefore, many researchers have tried to characterize and improve the interfacial properties of the ZnSe/GaAs heterostructure by various techniques.²⁻⁵

In this letter, the electrical and optical properties of high resistivity ZnSe grown on semi-insulating (SI) GaAs substrate, and the heterostructure interface between ZnSe and GaAs, have been investigated using transverse acoustoelectric voltage (TAV) spectroscopy. TAV spectroscopy has been previously used to characterize various high resistivity semiconductors such as CdS, GaAs, InAs, and InP.⁶ It has also been used to characterize some heterostructure semiconductors such as GaAs/AlGaAs⁷ and GaAs/Si.⁸

ZnSe layers were grown on (100)2° GaAs by organometallic vapor phase epitaxy (OMVPE). A low pressure, 50 mm diam, horizontal reactor with a radio frequency (rf) heated graphite susceptor was used for growth. Dimethylzinc (DMZn) and dimethylselenide (DMSe) were used as the zinc and selenium sources, respectively. The mole fractions of DMSe and DMZn were each kept at 5×10^{-4} . The total flow rate of hydrogen was 2 liters/min and the total reactor pressure was 380 Torr. GaAs substrates were first cleaned in organic solvents and etched in Caro's etch (5:1:1 H₂SO₄:H₂O₂:H₂O by volume) to remove 2–3 μm of GaAs. Just before loading into the reactor, the substrates were dipped in NH₄OH to remove any

residual oxide. The samples were heated to the growth temperature of 525 °C and the growth was started by the introduction of first either DMSe or DMZn sources. A special deoxidation step is not necessary in OMVPE because residual oxides are desorbed by heating GaAs in hydrogen ambient at 525 °C for a few minutes (<10 min).⁹ The thickness of the layer studied is about 0.8 μm.

The semiconductor under study is placed on a piezoelectric substrate (LiNbO₃), on which the surface acoustic wave (SAW) is generated. The propagation of the SAW induces a rf electric field in the semiconductor which interacts with the free carriers, resulting in the development of the TAV. The amplitude of the TAV depends on the near-surface conductivity of the sample under study and its polarity depends on the majority-carrier type.¹⁰ The TAV is positive for *n*-type materials and negative for *p*-type. The advantages of using the acoustoelectric voltage technique compared to the more conventional methods such as Hall and diode capacitance-voltage (C-V) measurements include high sensitivity of the TAV signal for high resistivity semiconductors and the nondestructive nature of the experiment. (For example, this technique does not require ohmic contact formation to measure the carrier concentration and type.)

High-resistivity ZnSe epilayers and heterostructure interfaces between ZnSe and GaAs were investigated by monitoring the variation of the TAV signal as a function of incident photon energy at room temperature. The single beam TAV spectroscopy is conducted by shining a monochromatic light at the region where the electric field interacts with the free-carriers of the semiconductor. As the incident photon energy is varied, the TAV spectrum reflects the changes in the surface photoconductivity induced by generation or recombination of free-carriers due to band or impurity level transitions. The TAV spectroscopy is similar to photoconductivity spectroscopy except that it is a nondestructive measurement technique. In the double beam TAV spectroscopy a second bias beam is used to enhance or quench particular transitions in order to improve the overall detection sensitivity. This technique is also employed here to determine the trap levels not de-

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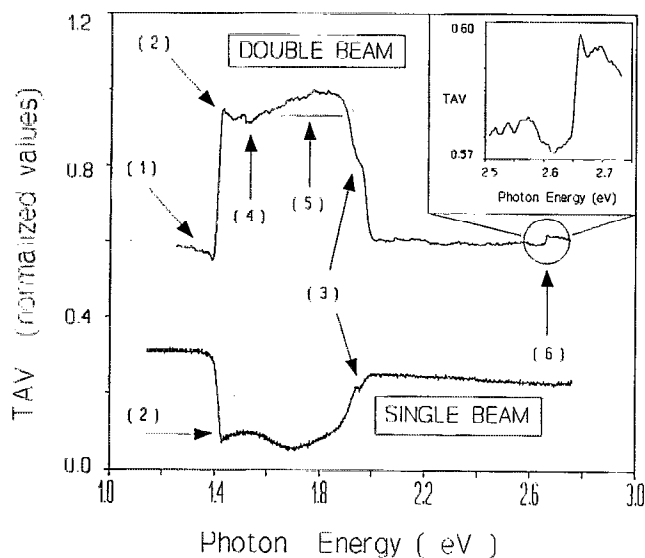


FIG. 1. TAV spectra of the ZnSe/GaAs heterostructure for single- and double-beam cases at room temperature. The ZnSe band-to-band transition is expanded in the inset.

ected by the single beam TAV spectroscopy. A Bausch and Lomb monochromator was used for the bias beam and a high resolution (1 \AA) Jobin Yvon HRS2 monochromator was used for the primary beam.

Figure 1 shows the TAV spectra for the ZnSe/GaAs heterostructure at room temperature. The TAV spectrum for the bulk SI GaAs is presented in Fig. 2. The positive TAV for both curves indicates that n -type conduction is dominant. From comparison of the TAV spectrum of the SI GaAs with the theoretical TAV equation,¹⁰ we estimated the carrier concentration in GaAs to be less than 10^{10} cm^{-3} . From the information presented in the following we also estimated the free-carrier concentration in the ZnSe film to be about 10^{12} cm^{-3} .

The single-beam TAV spectrum shows the same basic transitions found in the SI GaAs sample. However, the TAV amplitude in the case of the heterostructure decreases between 1.35 and 2.0 eV, and increases in the case of bulk

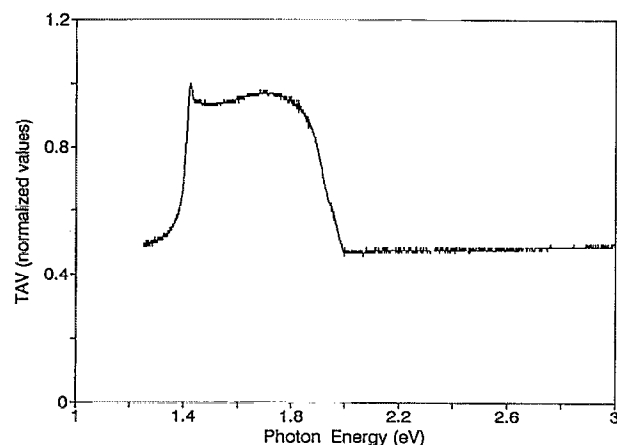


FIG. 2. TAV spectrum of the bulk semi-insulating (SI) GaAs at room temperature.

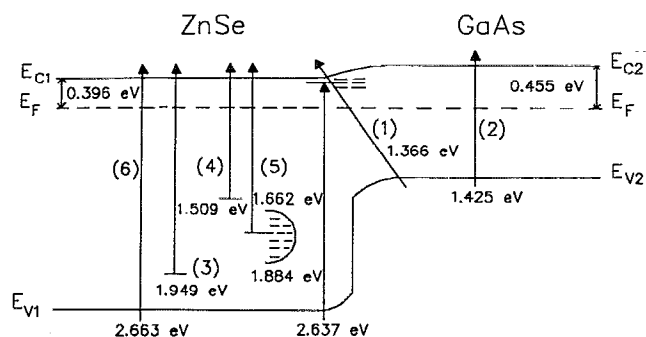


FIG. 3. Energy band structure for ZnSe/GaAs heterojunction under study.

SI GaAs. This difference in behavior is due mainly to the presence of a broad distribution of empty surface states near the conduction band at the ZnSe/GaAs heterointerface and also to the extremely small conduction band-offset ($E_{C2} - E_{C1}$) between ZnSe and GaAs. When the incident photon energy is above the band gap of GaAs (1.425 eV at 300 K), electrons are excited to the conduction band, leaving free holes in the valence band. These electrons are then quickly recaptured by the empty states at the interface resulting in a reduction of the TAV amplitude. In double-beam TAV spectroscopy, a high intensity monochromatic bias beam at a fixed energy of 2.637 eV was employed to compensate for the decrease of TAV by filling up those empty surface states near the conduction band. This value of energy was chosen because of the necessity to fill all empty trap levels present at the interface below the band-to-band transition of ZnSe (2.663 eV). In this case, when the second monochromatic beam has a photon energy close to the band gap of GaAs, the band-to-band transition dominates, increasing the number of electrons and thus also the amplitude of the TAV signal.

The band structure of the ZnSe/GaAs heterojunction under study is illustrated in Fig. 3. The figure shows various transitions which account for the band-to-band and band-to-impurity levels by the generation-recombination processes. Each transition is also labeled on the TAV spectra shown in Fig. 1. Transition (1) (1.366 eV) corresponds to electron excitation from the valence band of GaAs to the conduction band of ZnSe at the interface. Transition (2) (1.425 eV) represents the band-to-band generation of electron-hole pairs in GaAs. From the difference between the transition labeled (1) and (2) in Fig. 1, we estimated the conduction band offset to be 0.059 eV. Transition (3) (1.949 eV) was also detectable in both single and double beam TAV spectra and represents a donorlike deep trap level in ZnSe. By comparing the TAV spectrum of the SI GaAs and the double beam TAV spectrum of ZnSe/GaAs in the photon energy range from 1.5 to 1.82 eV, it is found that a large number of trap levels are present in this range, which result in an increase of the TAV amplitude. These levels are represented by the transitions (4) (1.509 eV) and (5) (1.662–1.884 eV) in Figs. 1 and 3. Low-temperature photoluminescence (PL) measurements showed the presence of a peak at about 1.9 eV, and a broad shoulder

between 1.6 and 1.8 eV, which may be related to the levels observed by TAV measurements. The last transition (6) (2.663 eV) observed in our data represents the band-to-band optical generation for ZnSe near the band gap; an expanded view of this last transition is shown in the inset of Fig. 1. This transition is very weak in the single-beam TAV spectrum, because any carriers generated in the ZnSe side of the interface are rapidly trapped by the empty shallow impurity levels which are located below the conduction band of ZnSe.

The results mentioned above are observed in many samples when the growth was initiated with DMSe. However, when the growth was initiated with DMZn, a p^+ GaAs forms at the interface by the in-diffusion of Zn into GaAs. This p^+ layer is responsible for quenching the TAV signal on such layers. Growth initiation with DMSe results in an interfacial layer which is nonconducting (as measured by Hall and C-V), thus allowing us to probe both the ZnSe and GaAs. Present results agree with earlier reports^{4,11} in which it was argued that the presence of Ga₂Se₃ is responsible for the high quality GaAs-ZnSe interface.

The presence of deep levels detected by both TAV and PL measurements near 1.9 eV and 1.6–1.8 eV agrees well with As-doped ZnSe layers.¹² It is plausible that growth at 525 °C and the likely formation of Ga₂Se₃ will free As near the interface and can thus diffuse into ZnSe and contribute to the observed deep levels. Unlike PL, TAV can distinguish between acceptorlike and donorlike deep levels.

In conclusion, ZnSe/GaAs heterostructure samples have been characterized using TAV spectroscopy. Single-beam and double-beam TAV methods have been used to study the interface band structure of the heterostructure at room temperature. A bias beam was used to fill empty acceptor states around 2.637 eV from the valence band at the interface. Nondestructively, we have measured the type

and carrier concentration of ZnSe as well as the presence of various trap levels in ZnSe by using the TAV spectroscopy technique. Our work demonstrates the usefulness of this technique for the study of ZnSe/GaAs heterostructures.

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