

# Surface photovoltage spectroscopy characterization of AlGaAs/GaAs laser structures

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**Abstract.** The characterization of AlGaAs/GaAs laser structures using surface photovoltage spectroscopy (SPS) is presented. The experiments were carried out at room temperature in the simplified variant of metal–insulator–semiconductor (MIS) configuration by means of a lab-made automated experimental setup. With this technique was possible to identify all the layers forming the heterostructure and important parameters have been extracted. The aluminium composition of the layers, obtained in this way agrees very well with the intentional growth parameters. Also from the surface photovoltage spectra was possible to obtain the lasing wavelength in each structure, which is in a good agreement with the values obtained by measuring the electroluminescence spectra. Results underline the power of SPS in characterization of actual laser devices in a contactless nondestructive way.

## 1. Introduction

The Surface Photovoltage Spectroscopy (SPS) is a nondestructive, contactless and versatile technique for characterizing semiconductors structures and devices, which can give important information even at room temperature [1]. SPS is based on the analysis of the induced change in the surface photovoltage (SPV) due to the external illumination. This technique allows determine parameters like: the bandgap energy, minority carrier diffusion length and life time [2], and also can provide a detailed picture of the surface and interfaces band diagrams. A detailed explanation of the basics of this technique can be found in the review paper of L. Kronik and Y. Shapira referenced in [3].

Compared to other spectroscopic techniques such as, Photorefectance and Photoluminescence, SPS has the advantage that is less expensive and simplest since not requires pump laser or detector.

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Moreover, since SPS is intrinsically insensitive to reflection and scattering process, is very useful for the study of micro and nanocrystalline materials.

SPV measurements are usually performed in two configurations: Kelvin probe and the metal–insulator–semiconductor (MIS) operation mode. In the last decade, the SPS has been developed considerably in terms of methods for data analysis and experimental arrangements respectively [4, 5]. However, despite its advantages, this technique has not been fully exploited and its use has been relatively limited.

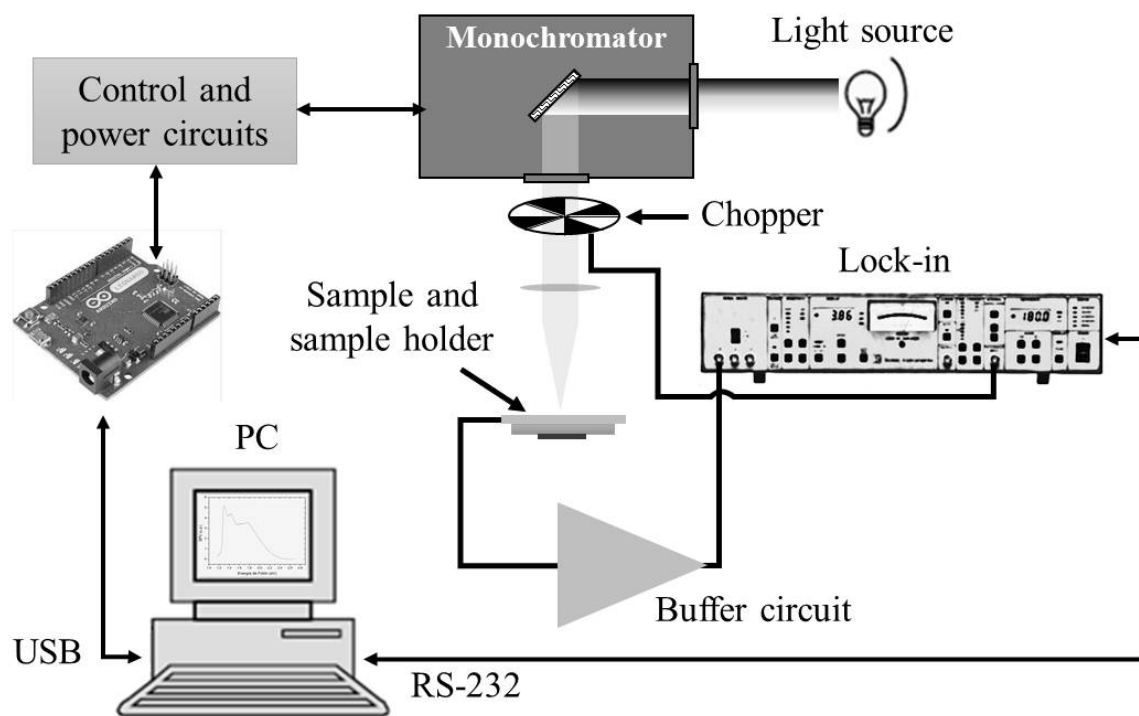
In this paper, AlGaAs/GaAs separate confinement laser structures with different aluminium content in the active region are studied. The experiments were carried out at room temperature by means of a lab-made automated experimental setup. Measurements were performed in a modification of conventional MIS operation mode. In the SPV spectra was possible to identify all the layers forming the laser heterostructure. A proposal of a practical criterion for spectra processing and extraction of the parameters of interest is presented and the extracted parameters are in a very good agreement with the intended growth parameters. The lasing wavelength in each structure obtained from SPV spectra agree very well with the values measured from electroluminescence spectra.

## 2. Experimental

The surface photovoltage signal is defined as the difference between the surface potential under illumination and in the dark:

$$SPV = V_s (light) - V_s (dark)$$

The experimental set up used to measure the SPV spectra comprises a monochromator, a lock-in amplifier, a chopper, and a sample holder. In Figure 1 it's schematically represented.



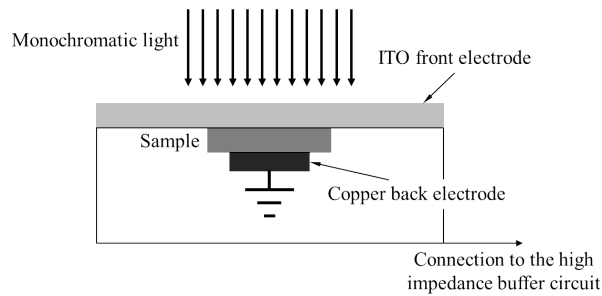
**Figure 1.** Sketch of the experimental setup for Surface Photovoltage Spectroscopy measurements.

The system is fully automated and allows measurements in a wide spectral range. The monochromator is controlled from the PC through an Arduino Leonardo, a power circuit and a stepper motor. The whole experimental setup is interfaced with a PC through a RS232 serial port and the control software.

The light coming from the lamp passes through a monochromator, and is focused onto the sample after being modulated by an optical chopper with a variable frequency. Thus, the photon flux impinging on the sample causes a periodic generation of excess carriers and their subsequent redistribution change the surface potential inducing the SPV signal. This signal goes through to a high impedance preamplifier and is registered by a lock-in amplifier. The SPV is measured as a function of incident photon energy providing the SPV spectra.

For measurements, the sample is positioned between a transparent indium–tin–oxide (ITO) electrode and a copper plate with a spring which acts as a sample holder and the bottom ground electrode. Figure 2 shown a simple diagram of the used sample holder.

Unlike the conventional configuration of MIS where it is left a thin air gap between the sample and the ITO electrode to form a capacitor, in our setup the ITO is directly in contact with the sample. This allows the direct measurement of the SPV signal, whereas in conventional MIS method the voltage measured is affected by the capacitance and must be corrected in some way to obtain the real SPV signal.

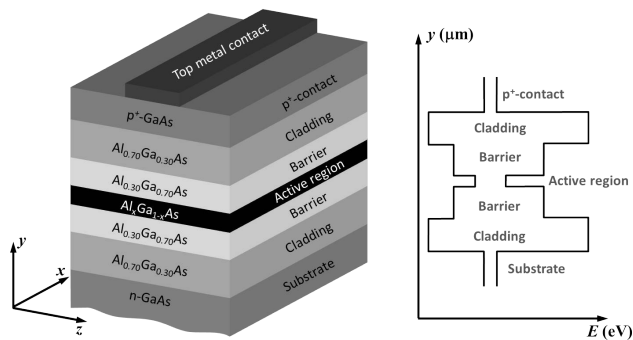


**Figure 2.** Schematic diagram of the sample holder used in SPV measurements.

The ITO plate acts as both the top electrode and a window for light to pass through it. The copper bottom contact is covered with conductive silver paste to improve the electric contact. Experiments were performed at room temperature and in air ambient.

### 3. Results and discussion

The AlGaAs/GaAs laser diodes studied here are separate confinement heterostructures in the metal stripe configuration, and consist of layers of different compositions, thicknesses and doping level respectively. In Figure 3 it is shown the schematic of the laser structures with the corresponding energy band diagram.

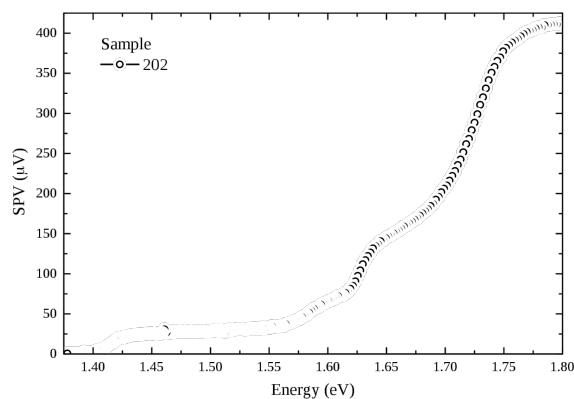


**Figure 3.** Left, schematic of AlGaAs/GaAs laser structures. Right, approximately energy band diagram.

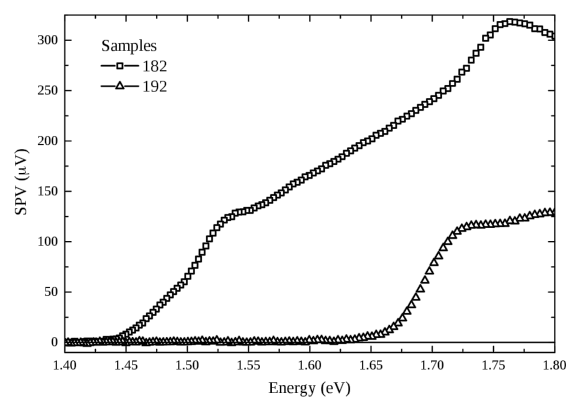
In Figure 4 the features corresponding to: the GaAs substrate (1.42 eV), the  $\text{Al}_{0.18}\text{Ga}_{0.82}\text{As}$  active region ( $\sim 1.63$  eV) and the  $\text{Al}_{0.3}\text{Ga}_{0.70}\text{As}$  barriers ( $\sim 1.73$  eV) are identified.

Figure 5 shows the SPV spectra for two laser structures with different aluminium content ( $x$ ) in the active region. As can be seen the contribution of the different layers forming the heterostructure can be clearly distinguished. The band gap of each layer can be identified as the slope changes in the SPV spectrum. This can be understood by the abrupt change of the absorption coefficient in the vicinity of the bandgap energy in semiconductors, causing a significant change in the signal SPV. In this case, only the signature of the active region and barriers was seen. Peaks corresponding to the active region

in each structure can be clearly differentiated and appear at 1.46 eV and at 1.66 eV respectively. The band gap is higher in sample 192 indicating the higher Al content in this structure, whereas, in both spectra the peak corresponding to the  $\text{Al}_{0.3}\text{Ga}_{0.70}\text{As}$  barriers are at the same energy, around 1.73 eV.



**Figure 4.** SPV spectra measured for sample 202. Features corresponding to the GaAs substrate, the  $\text{Al}_{0.18}\text{Ga}_{0.82}\text{As}$  active region and the  $\text{Al}_{0.3}\text{Ga}_{0.70}\text{As}$  barriers are visibly identified.



**Figure 5.** SPV spectra of structures with different aluminium content in the active region. Energy peaks of the active region are clearly different in the two structures.

The band gap energies obtained in this way was used for estimation of the Al mole fraction in the structure active region. The intended growth parameters are:  $x = 0.05$  and  $0.2$  for structures 182 and 192 respectively, which according to the dependency of the band gap with the mole fraction Al for of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  for  $x < 0.45$ [6]:

$$E_g(x) = (1.42280 + 1.31804 \cdot x) \text{ eV}$$

results in transition energies of 1.48 eV and 1.68 eV in each case, which is in very good agreement with the values extracted from SPV spectra.

With the values of the transition energies of the active region obtained in this way the emission wavelength of the structure was estimated and compared with that obtained from the electroluminescence (EL) emission spectra of laser diodes coming from these structures. In Table 1 these results are presented.

**Table 1.** Comparison of the lasing wavelength obtained from SPV and electroluminescent emission spectra.

Sample	Lasing wavelength (nm)	
	SPV	Electroluminescent spectra
182	844	849
192	743	750

The electroluminescence spectra were measured by forward biasing the laser diodes by pulsing the current source at 1Hz with a 0.1% duty cycle square wave. The emission resulting from radiative recombination is collected by a lens and focused into the monochromator. The detection was made with a Silicon photodiode and a lock-in amplifier registers the signal.

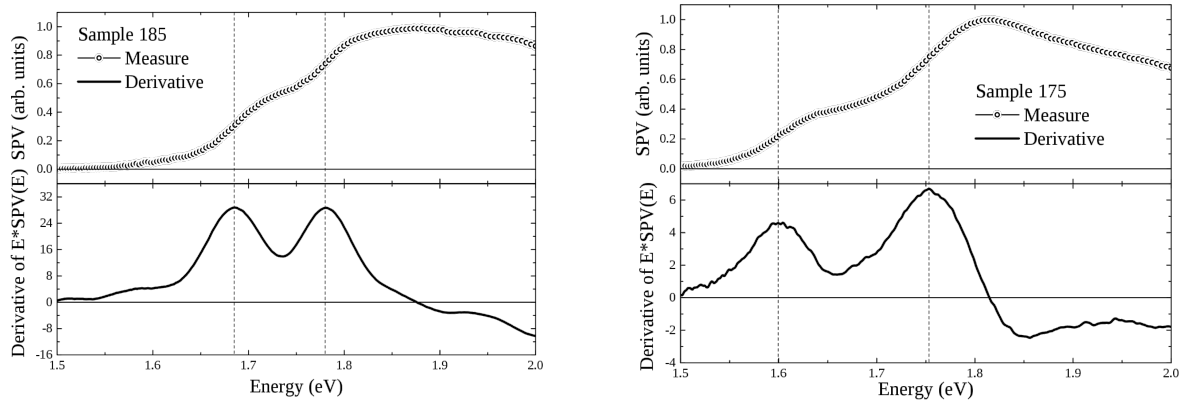
As shown in Table 1, results obtained from both methods are in very good agreement, demonstrating that SPV spectroscopy can be used to obtain performance parameters of actual laser devices in a simple manner.

Recently some authors have reported that, the numerical derivative of SPV spectrum can provide the transition energies in a heterostructure in a more accurately way [4, 7]. In fact, assuming that SPV signal is proportional to the open-circuit photovoltage we can write [4]:

$$SPV \propto V_{oc} \propto \frac{\alpha}{h\nu}$$

$$\frac{d[E \times SPV(E)]}{dE} = \frac{d\alpha}{dE}$$

From Equation (4) it can be seen that a plot of the numerical derivative ( $d[E \times SPV(E)]/dE$ ) versus the incident photon energy  $E$ , provides the transition points in absorption for the different layers. Figure 6 show a comparison between the SPV spectra and the numerical derivative ( $d[E \times SPV(E)]/dE$ ) versus Energy for structures 185 and 175 respectively.



**Figure 6.** Comparison of the SPV spectrum and numerical derivative of SPV versus  $E$  for two structures: (a) sample 185 and (b) sample 175. The transition energies are indicated by dashed lines.

As can be seen, in the derivative spectra is possible appreciate much better the points where the slope changes occur. In this case, the transitions energies points correspond to the maxima in the derivative spectra and results in 1.68 and 1.60 eV respectively.

Is worth mentioning that the SPS has been applied before to the study of both, vertical cavity surface emitting laser (VCSEL) [8, 9] and edge emitting laser diodes [7, 10].

In case of edge emitting lasers, Leibitovich et al [10] used a commercial Kelvin probe unit for SPV measurements on InGaAs QW structures. The authors extracted the structure parameters by a

Lorentzian fitting of the SPV spectra. Muralidharan [7] did SPV measurements in MIS geometry to characterize AlGaAs laser structures and extracts the transition energy points from the numerical derivative of the SPV spectra. In this case, the measurement was done by successively etching of the individual layers and subsequent measurement of SPV. Their results were compared with photoluminescence (PL) measurements.

In our work, the SPV measurements were carried out in a simplified MIS configuration using a lab-made automated experimental setup. Our structures are fully metalized allowing us to do EL measurements to compare results. The results show that is possible to obtain the composition of the layers in the laser structure, without the necessity of complicated procedures such as etching away the individual layers.

#### 4. Conclusions

In this work, characterization of AlGaAs/GaAs laser structures using surface photovoltage spectroscopy (SPS) is presented. Measurements were carried out in a simplified MIS configuration using a lab-made automated experimental setup. The ITO electrode is directly in contact with the sample allowing the direct measurement of the SPV signal. With this technique was possible to get information regarding each layer forming the  $\text{Al}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$  heterostructure and the results are in agreement with the intended growth parameters. Also from the SPV spectra was obtained the lasing wavelength in each structure, which is in a good agreement with the values obtained from the electroluminescent spectra of laser diodes coming from the structures.

Our results show that it is possible evaluates the composition of AlGaAs layers in laser structures without the necessity of a chemical etching process. These results emphasize the potentialities of the SPS as a simple tool for semiconductor devices characterization, compared to other more expensive spectroscopic techniques.

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