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Design and development of a semiconductor bandgap measurement system using Microcontroller: MSP430G2553 and ZigBee: CC2500

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Abstract

In this paper, we have designed and developed a microcontroller-based system to measure temperature dependence of the forward voltage drop across the homo- and hetero-pn junction devices (Si, Ge, IR and Light Emitting Diode), at constant current and hence to evaluate the bandgap energies in these devices. Digitized temperature using TSiC 501F as temperature sensor and forward voltage values using the on-chip analog-to-digital converter (ADC) of the MSP430G2553 microcontroller are sent to the remote laptop/desktop using Texas Instruments' CC2500 which works as ZigBee. Measured bandgap energies are compared with standard values of basic diodes and emitted spectral wave lengths in case of Light Emitting Diodes (LEDs), using the standard formula: $E_g = 1.2396/ \lambda$.

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Keywords: Semiconductor bandgap; Opto-electronic devices; Temperature sensor ; MSP430G2553; REF200; ZigBee.

1. Introduction

Based on inter atomic forces, materials are broadly classified into three categories: solids, liquids, and gases. Basing on inter atomic arrangement; solid materials are classified into crystals and non-crystals (amorphous materials). Taking the resistivity into consideration we can divide these materials into metals (conductors), semi conductors and insulators. Continuous research and development in the field of materials (Materials Science) has brought in revolutionary changes in the field of semiconductor physics. The first revolution is the invention of homo pn- junction devices: diode and transistor made up of silicon and germanium. The second breakthrough is the

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invention of the semiconductor hetero-pn junction device: light emitting diode (LED). Thanks to Holonyak and Bevacqua [1] for their invention of such a tiny invaluable solid state light emitter. Microcontroller based systems are developed in our laboratory [2-5].

LEDs are used in different areas of our daily walk of life, e.g., street, traffic, and automotive lights, TV projectors and in electronic appliances such as washing machines, microwave ovens etc. Major advantages in using LEDs include low-cost, low-power consumption and low operating voltage. One of the important parameter that characterizes the LED is its spectral power. This parameter depends on the semiconducting material and the energy gap (E_g) of the formed hetero pn junction material. In such a case, the relationship between E_g and the wavelength (λ) of the emitted light is given by [6]

$$\lambda = hc/ E_g = 1.2396/ E_g$$
$$E_g = 1.2396/ \lambda$$

The exact value of E_g depends on the LED chip material the details of which rarely provided by the manufacturer. As far as the bandgap (energy gap, E_g) measurement is concerned, broadly two types of methods are used; namely, Optical method and electronic method. These methods are listed below:

A. Optical methods:
   - Absorption of electromagnetic radiation method [7]
   - Electron energy loss spectroscopy method [8]
   - UV absorption spectroscopy method [9]
   - Photo acoustic spectroscopy method [10]
   - Optical reflectivity method [11]

B. Electronic methods:
   - Four probe method [12]
   - Constant current method [13]
   - Temperature versus junction voltage measurement method [14]

In the above mentioned methods, optical methods need sophisticated equipment, time consuming and costly; hence we have chosen the electronic method. In this direction, several papers have appeared discussing the fundamentals of diodes and LEDs. Majority of them involves manual intervention. Further, microcontroller based bandgap measurement using the ZigBee communication between data acquisition system and remote computing device (laptop/desktop) is rarely seen in the literature. Keeping this in view point we have designed and developed a microcontroller-based system to measure temperature dependence of the forward voltage drop (at constant current) across the homo- and hetero-pn junction devices (Si, Ge, IR and Light Emitting Diodes), and hence to evaluate the bandgap energies in these devices. Hardware and software description of the present work are given in the following sections. Further, we have compared the experimentally measure bandgap energies with standard values in basic diodes and the emission spectra of LEDs, the experiment carried out elsewhere .

2. Experimental:

The experimental description is divided into two sections:
(i) Hardware description (ii) Software development for data acquisition.

2.1 Hardware Description:

Block diagram of the hardware developed in the present work is shown in Fig. 1. It consists of three modules. The first module consists of the device under test (DUT) placed in an oil bath whose temperature is measured using TSic501F and maintained constant using a constant current source, constructed using Darlington pair fed to the heater assembly. The constant current source has the provision to vary the magnitude of current and hold it constant during measurement. The second module consists of the microcontroller MSP430G2553 and the CC2500 transmitter. The voltage drop across the junction of the DUT (with a constant current of 100 µA using REF200) at various temperatures are measured by connecting it to the analog input of the on-chip ADC of the microcontroller. The TXD and RXD pins of MSP430G2553 are connected to the ZigBee transmitter module, through which the digital equivalent of temperature and voltage are transmitted. The third module consists of the receive module of the ZigBee connected to the serial port of the laptop/desktop. The software developed in the present work which runs as to laptop receives the data and stores it in a file format useful for computation and graphic representation. The total circuit diagram of the hardware assembly developed in the present work is shown in Fig.2.

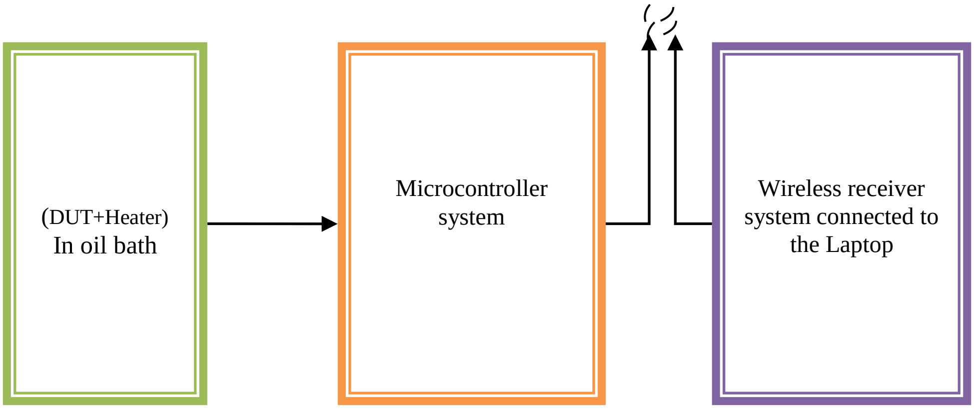


Fig. 1. Block diagram of the hardware

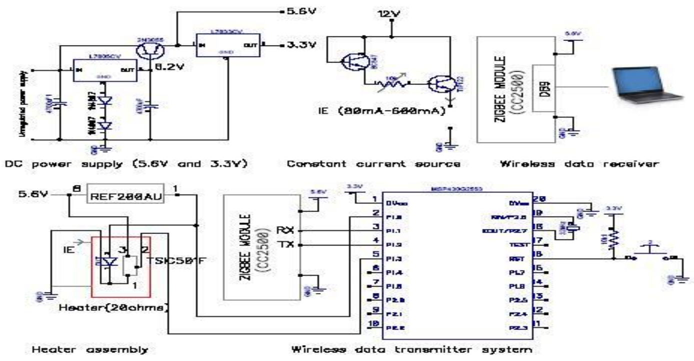


Fig. 2. Schematic diagram of the hardware

2.2 Software Description:

Software for data acquisition, namely, temperature, analog voltage measurement and temperature control are developed using Texas Instruments' IAR WorkBench and the corresponding binary file is embedded in the on-chip ROM of MSP430G2553. Flowchart of the program is shown in Fig.3. ComCap4 software running on the laptop captures the data and stores it in a file format. VEUSZ open source plotting software imports the file, makes a linear fit of the data and displays the slope and intercept values. Bandgaps are computed and the results are displayed on the laptop screen. Screen shots of the IAR Embedded Workbench IDE [15], ComCap4 [16] and VEUSZ [17] software are shown in Fig. 4.

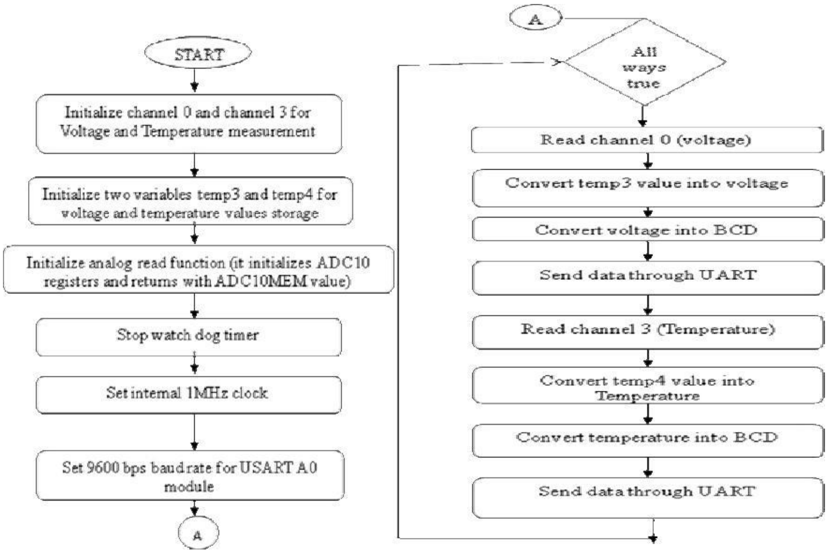
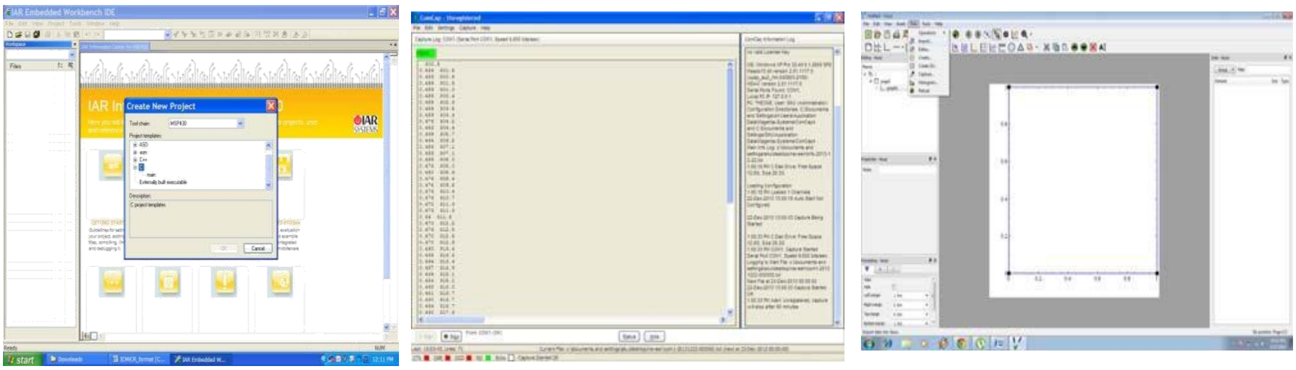


Fig. 3. Flowchart of the program



(a) (b) (c)

Fig. 4. Screen shots of (a). IAR Embedded Workbench IDE , (b). ComCap4 data capturing , (c). VEUSZ open source software.

3. Results and Discussion:

Photograph of the fabricated system, its exploded view and the monitor terminal display are shown in Fig.5. In the present experiment, for homo-pn junction, we have considered 1N4007 (silicon diode), OA 79 (Germanium diode) and OP140A (GaAs IR Diode), and RED, Blue and Orange-LEDs as hetero-pn junctions are used as DUT. The bandgap energies measured for silicon, germanium and IR LED are compared with the literature values. In the case of LEDs, we also have taken the spectral response in order to compute the bandgaps by knowing the peak emission wavelength. Fig. 6 and 7 shows the linear fit (junction voltage vs temperature) for the homo pn-junctions and hetero-pn junctions, respectively. The experimental setup used to record the spectra of LEDs is shown in Fig. 8. Recorded spectra of the hetero-pn junctions (LEDs) are shown in Fig.9. Complete hardware and software are developed in our VLSI and Embedded System Laboratory. Spectra of the LEDs are recorded at the Department of Physics, Sri Sathya Sai Institute of Higher Learning, Puttaparthy. Results obtained in the present study for homo- and hetero-pn junctions are given in Tables 1 and 2, respectively.

Fig. 5. Photograph of the fabricated hardware containing ZigBee, temperature sensor , and monitor view

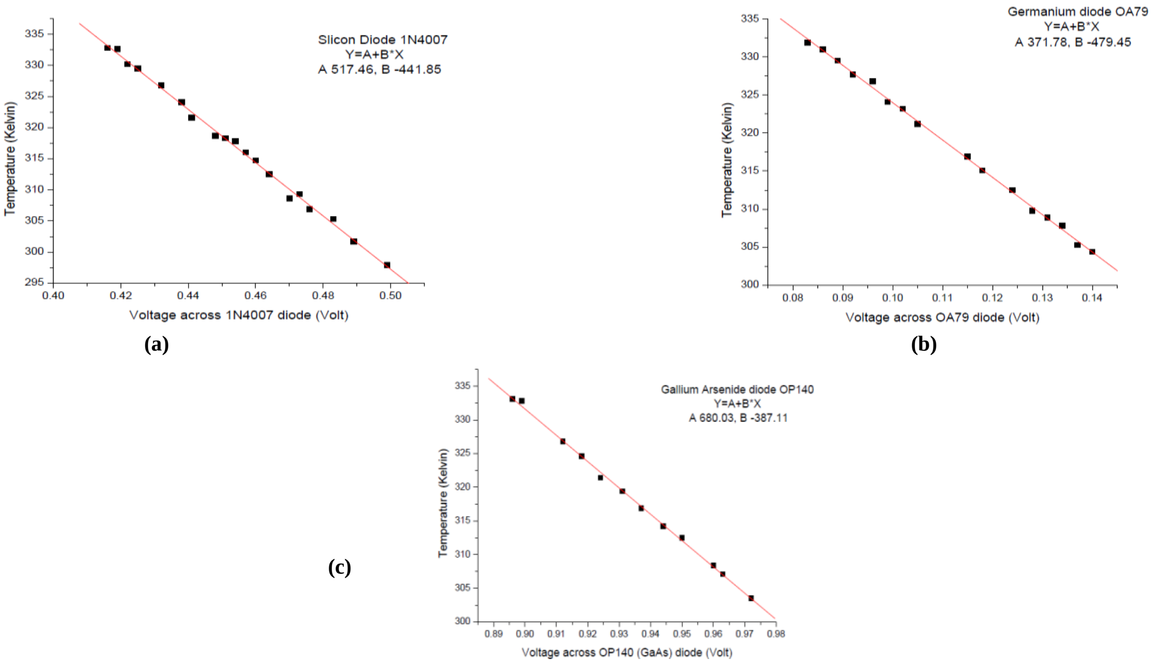
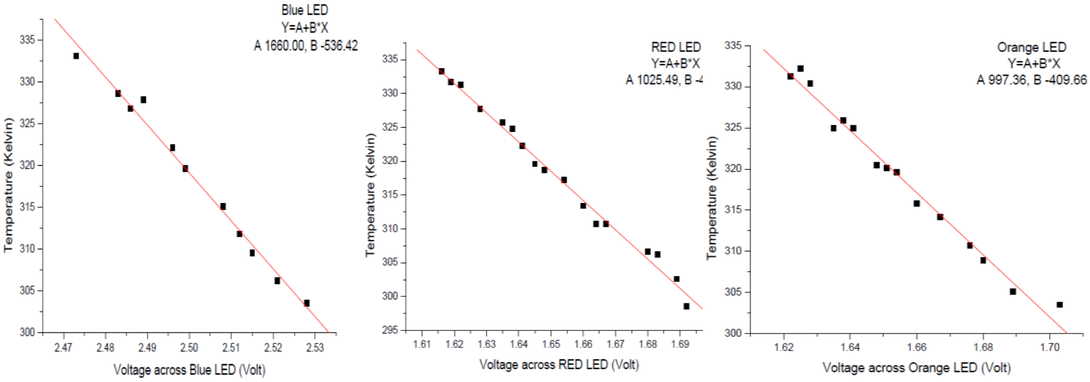


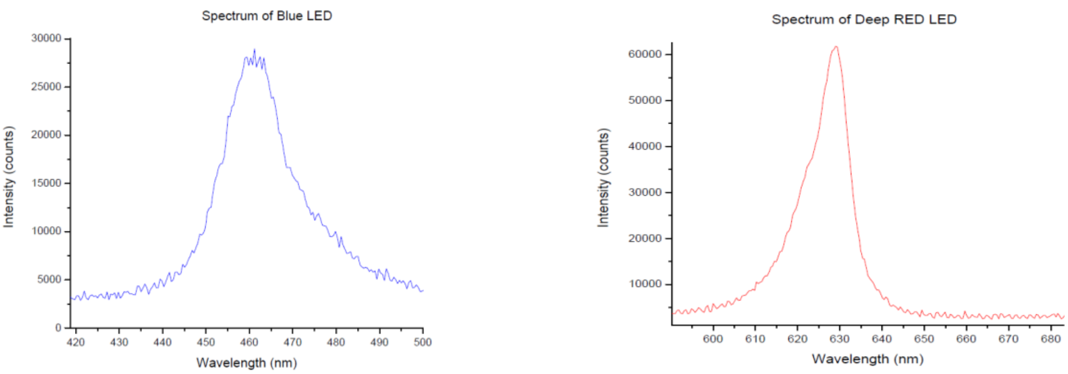
Fig. 6. Junction voltage vs Temperature for (a). 1N4007 (Si), (b). OA79 (Ge) and (c).IR diode.



(a) **(b)** **(c)**

Fig.7. Junction voltage vs Temperature for : (a). Blue LED, (b). Red LED and (c). Orange LED.

Fig. 8. Spectrometer setup used to record the spectra of LEDs



(a) **(b)**

Fig. 9. Spectral distribution of (a). Blue and (b). Red LEDs

Table 1. 1N4007, OA79 and OP140 samples experimental and standard bandgap values

Devices under test (DUT)	Semiconductor bandgap values (in eV)		Error in bandgap measurement (%)
	Experimental values	Standard values[10]	
1N4007 (Si)	1.17	1.107	5.690
OA79 (Ge)	0.77	0.670	14.92
OP140 (GaAs) IR Diode	1.75	1.350	20.68

Table 2. LED samples experimentaland spectroscopic band gap values

Devices under test (DUT)	Semiconductor Band Gap values (in eV)		Error in band gap measurement (%)
	Experimental values	Spectroscopic values	
Blue LED	3.09	2.70	14.44
Red LED	2.39	2.00	19.50
Orange LED	2.43	2.22	9.45

Conclusions:

We have designed and developed an inexpensive microcontroller based constant current technique for bandgap measurement using off-the-shelf components. The temperature sensor has an accuracy of ±0.1K in the temperature range of -10 to 60°C. Inspite of this, one of the possible reason that the experimental values differ with the standard values is that in the case of homo- and hetero- pn juction devices, the plastic encapsulation between fabricated junction and the outside environment wherein the temperature sensor is in contact differ. Further, LED manufacturers rarely provide the full information on material used in the chip fabrication [6].

The hardware and the technique presented in this paper can even be extended to measure variation of I-V characteristics with temperature and Temperature vs Voltage characteristics at constant current for other devices also.

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