Design and Construction of Home-Made Source Measure Unit

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ABSTRACT: The voltage values used in an IV measurement often depend on the specific electronic components being tested. For example, to test a solar cell, voltage values in the range of -3 V - 3 V are sufficient, while for an LED this value is in the range of 0 V - 12 V. However, sometimes applying a voltage can change the electronic properties of a system under test. For example, the voltage applied to a diode changes the capacitive values of the diode. Therefore, the parameters of the tested system should not change the current-voltage values of the testing system during the test. In this study, a software-controlled current-voltage device was designed and built to overcome this problem. We interpreted the accuracy of this system by measuring the turn-on voltage of an OLED device we produced in the laboratory.

1. INTRODUCTION

An I-V plot is divided into regions around the axes as shown in Figure 1. If a suitable PN junction is operated in region I of the I-V curve, electrons and holes can combine in the junction region above a certain threshold voltage and emit light with a wavelength equal to the band gap. This is electroluminescence. The wavelength of the produced light is a function of the band gap of the semiconductor material used. Materials such as gallium arsenide and others with various trace additives are used to produce different colours of light, and because these materials have a high refractive index, they have design features such as special optical coatings to diffuse light efficiently.

If a forward voltage is applied to the PN junction of a led made of any direct band gap material, light generation occurs. In a forward polarized PN junction, electrons in the conduction band pass through the n-type semiconductor and recombine with holes from the p-type semiconductor in the valence band, resulting in the release of energy corresponding to the forbidden energy gap. This energy is emitted in the form of heat and light, but in gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP) semiconductors, electrons disperse the energy by emitting photons. If the semiconductor is translucent, the junction becomes the light source and thus a light emitting diode. The materials used for making LEDs today have a direct bandgap with energies corresponding to near infrared, visible or near ultraviolet light [1].
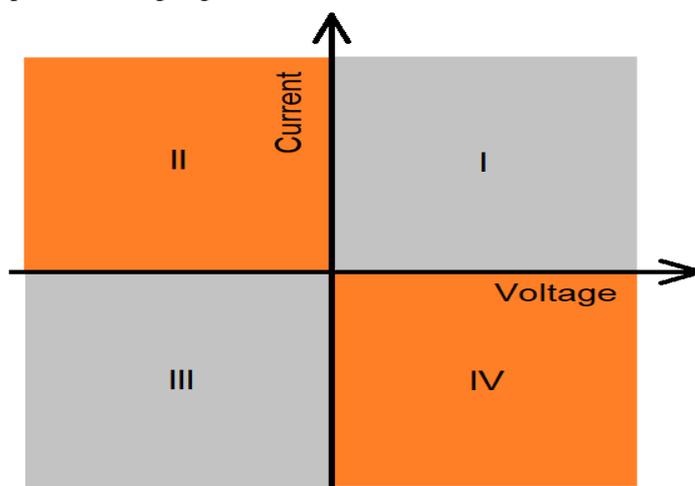
Fig. 1 Quadrants of an I-V curve.

2. IMPLEMENTATION

2.1. I-V Curves

An I-V curve, known as a Current-Voltage curve, is a graphical representation of the relationship between the voltage applied to a circuit and the current flowing through the circuit. It is one of the most common methods used to determine the basic properties of electrical/electronic systems today.

From the shape of the curve obtained, it can give more information about the properties of the system. Moreover, there are many different types of I-V curves for electronic circuits and their elements, and their forms and data can be very different. The voltage values used in an I-V measurement often depend on the specific electronic components being tested. For example, to test a solar cell, voltage values in the range of -3 V - 3 V are sufficient, while for an LED this value is in the range of 0 V - 12 V. However,

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For example, the voltage applied to a diode changes the capacitive values of the diode. Therefore, the parameters of the tested system should not change the current-voltage values of the testing system during the test. In this study, a software-controlled current-voltage device was designed and built to overcome this problem.

The essential properties of a tested electronic component can be deduced from its position on the plotted I-V graph. The regions where the test curve passes reveal whether the component is active or inactive. A component with a curve in quadrants I and III where both current and voltage are in the same direction is passive. Devices whose curves are in these zones are a passive device and use the electrical power of the circuit. A component with a curve in regions II and IV where current and voltage have opposite poles is active. An active device generates electrical power while in these zones [2].
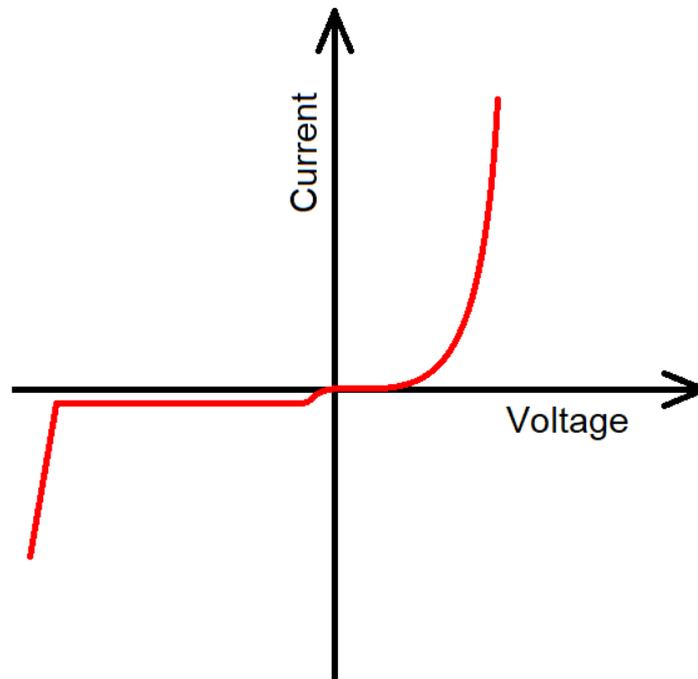
Fig. 2 I-V curve of a diode.

2.2. I-V Curve of a diode

The diode is a semiconductor device that allows current to flow in only one direction, and this feature is seen in the first quarter of the I-V curve, Figure 2.

The diode, which carries a very weak current up to the threshold voltage when it is forward polarized, suddenly starts to pass current above the threshold voltage, so the curve increases exponentially. This indicates that the current flows freely. At negative voltage values, the current remains almost zero. However, if a large enough negative voltage is applied, the diode will be "punctured" and damaged, causing it to conduct in the reverse direction. It becomes a passive device just like a resistor.

2.3. I-V Curve of a solar cell

Solar cells, also known as photovoltaic cells, are semiconductor devices that directly convert solar energy to electrical energy. Its behavior in the dark is the same as that of a diode. However, when illuminated, the I-V curve shifts towards the IV region. While the solar cell works in this region, it turns into an active device as it provides electrical energy to the circuit it is connected to. The basic properties of solar cells can be deduced from the I-V curve. For example, open circuit voltage and short circuit current are the values at which the I-V curve cuts the x and y axes, respectively. Also, the gradient of the curve at each point can be used to find the series and shunt resistances. The main feature of a solar cell is its ability to convert light into electricity.

$$\text{Fill Factor} = \frac{J_{MP}\, V_{MP}}{J_{SC}\, V_{OC}}$$
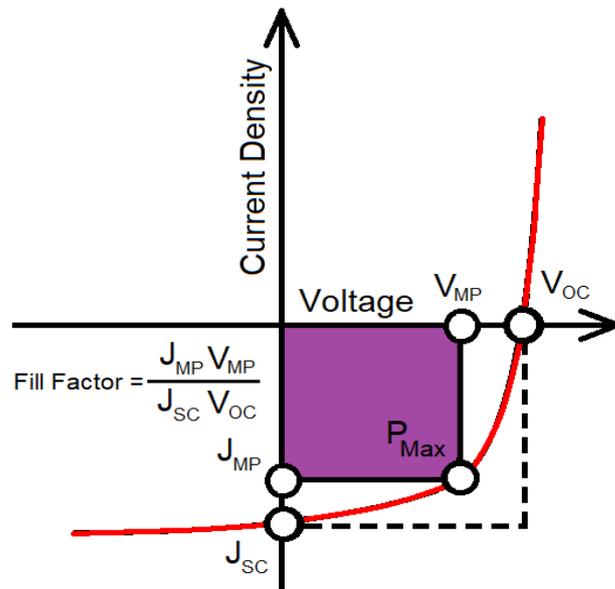
Fig. 3 Typical I-V curve of a solar cell emphasizing its maximum power point (J_{MP}, V_{MP} - current density and voltage at maximum power, P_{Max} - maximum power point, J_{SC} - short-circuit current density, Voc - open-circuit voltage).

This is known as the power conversion efficiency (PCE) and is the ratio of the incident light power to the output electrical power. To determine PCE and other measurements, current values are measured by applying a series of variable voltages while the solar cell is illuminated. The I-V graph in Figure 3 is a visual representation of these measurements. In general, current density J (C/m^2) is used instead of current when characterizing solar cells, because the magnitude of the current produced is closely related to the size of the surface area of the solar cell [3].

2.4. Source measure unit

The Source Measurement Unit (SMU) is a device that can precisely produce current and voltage, and can simultaneously measure voltage and current. It is like the ultimate evolution of the digital multimeter [4]. The versatility and high accuracy performance of this device provides great convenience in drawing I-V curves of semiconductor components. In particular, knowing the electrical I-V characteristics of a solar cell is critical in determining solar efficiency. It offers a detailed explanation of solar energy conversion capability and efficiency. These curves provide the configuration information needed for a solar cell to operate as close to its optimal peak power point (MPP) as possible [5].

Not all experiments graphed need negative voltages, but in some cases many different types of devices to which negative voltages are applied work differently. To fully understand how such devices work, we need to be able to change the sign of the applied voltage. In its simplest form, consider the operation of a diode. When polarized in the opposite direction, there should be no conduction, but there is conduction. This will tell you that the junction structure of the diode is damaged [6].
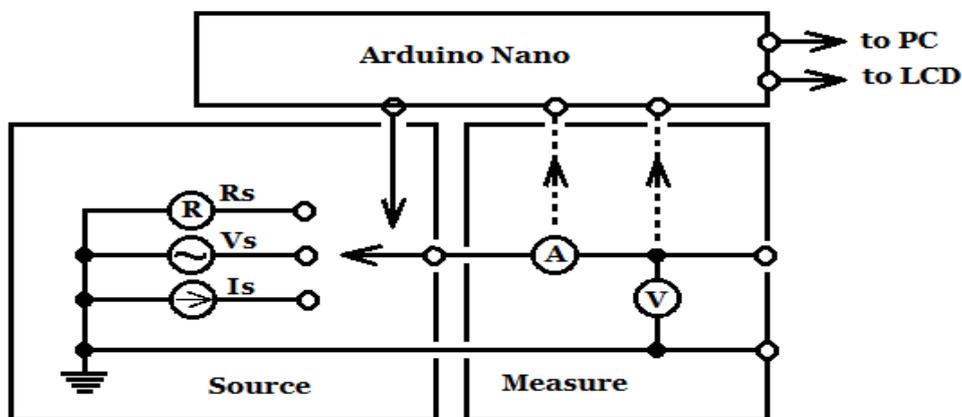
Fig. 4 Block diagram of home-made SMU

2.5. Material and equipment

Since the home-made source measurement unit, whose block diagram is shown in Figure 4, is microcontroller-based, real-time monitoring and recording of all measurements can be made on a screen and data analysis can be performed if desired.

Arduino Nano is an Atmega328 based microcontroller board. Detailed information about the operation of this board, which has 14 digital input/output pins, 6 of which can be used as PWM outputs, 8 analog input pins, 16 MHz crystal, USB socket, ICSP connector and reset button is available on its web pages. It controls data flows from the peripherals.

In order to plot the I-V graph of a semiconductor component, a series of voltages is applied and the current values corresponding to each voltage value are measured. The voltage values on the tested component are measured with a voltmeter connected in parallel, and the current with an ammeter connected in series. Using these measurements we can also do some simple math, such as yield calculations.

2.6. Programing 4 channel 16-bit ADC

ADS1115 4-channel analog digital converter with 16-bit resolution and programmable gain was used to measure voltage and current values. Operating in continuous conversion mode, the ADS1115 has an input multiplexer that allows two differential or four single-ended input measurements. The converter, which can sample at 860 sampling/second rates, can measure input ranges between ±256 mV and ±6.144 V with its programmable gain option.

In the test studies, the current and corresponding voltage values measured in the nano-ampere range were transferred to a computer via the I2C compatible serial interface.

2.7. Waveform generator

The MCP4725 waveform generator was used to obtain the variable voltages required for I-V graph plotting. The MCP4725 is a 12-bit resolution digital-to-analog converter that produces a real-time analog voltage and can be controlled via the I2C serial interface to generate sine, saw or triangle waves. A buffer amplifier is used in series so that the waveform of the voltage received from the analog output is not distorted.

2.8. I-V Characteristic curves of LEDs

Much more detailed information about the ADC and DAC shields used in this study is available on their respective websites. Figure 5 shows the measurement setup using these two ADC and DAC shields, and Figure 6 shows the completed I-V plotter. The I-V characteristic curves of some commercial LEDs measured with this device are in Figure 7. Python programming language was used to transfer digital data to PC environment. The short code snippet below calculates the I-V values of the leds under test. The value of R is dependent on the programmable gain value of the ADC converter.

```
ledVoltage = (getchValue(A1) - getchValue(A2)) * 1000.0;
        ledCurrent = (getchValue(A3)/R) * 100000;
```
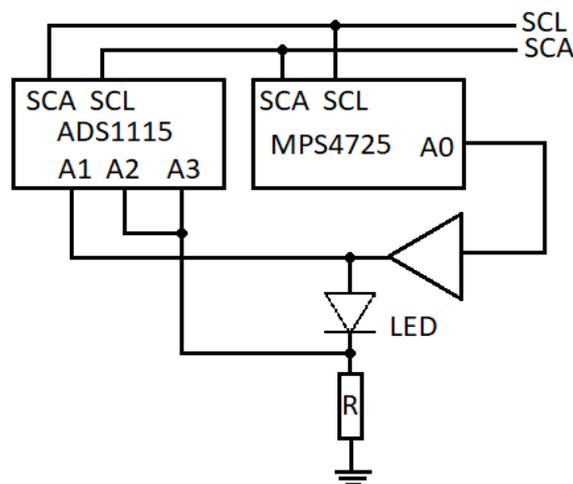

Fig. 5 Setup for measuring I-V curves
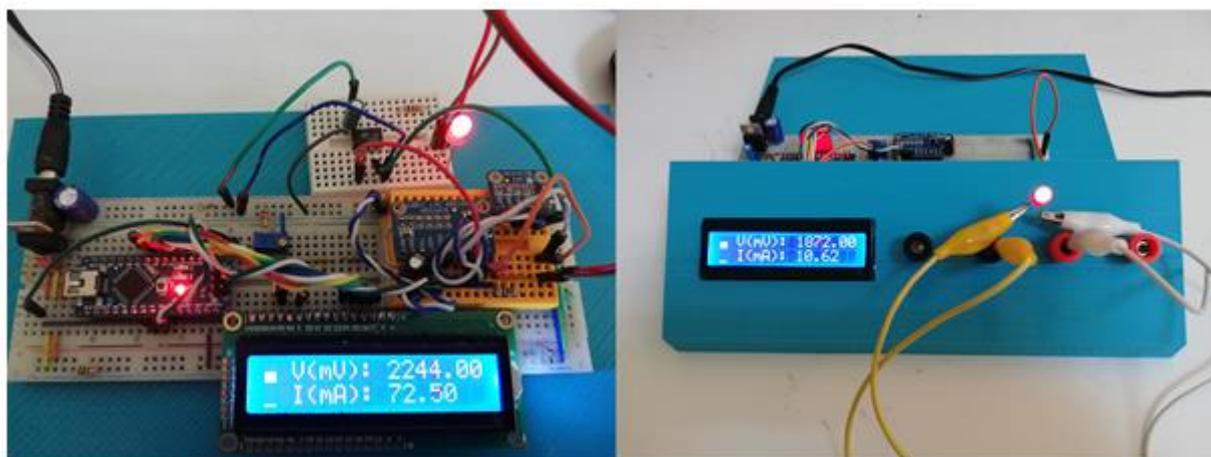
Fig. 6 Source measurement unit, I-V plotter.
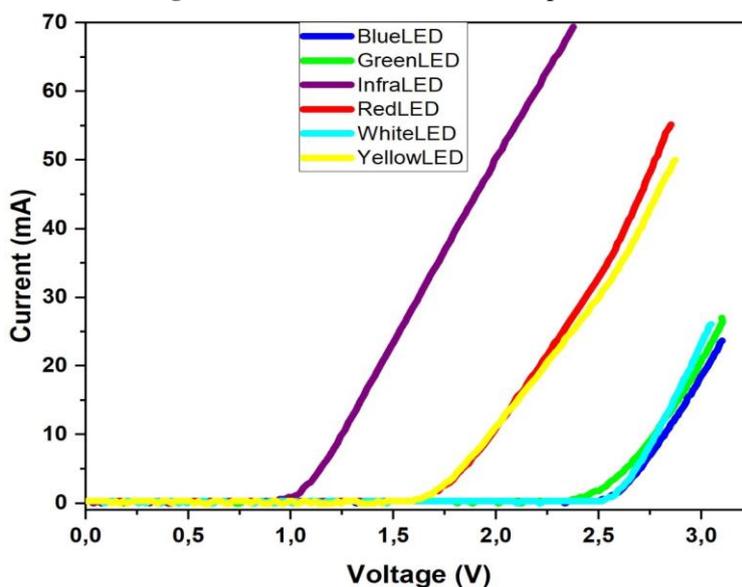
Fig. 7 Measured I-V characteristics of some commercial leds.

In addition, to test the success of our device, an organic light-emitting diode (OLED) device with a basic structure was produced in our own laboratory, Figure 8. The device consists of ITO coated glass as the anode, Poly (3,4-ethylene dioxythiophene) -poly (styrene sulfonate) (PEDOT:PSS) as the hole transport layer (HTL), poly[2-methoxy-5-(2`-ethylhexyloxy)-1,4-phenylenevinylene] (MEH:PPV) as the emitting material layer (EML) and Aluminium (Al) cathode

layers. The holes are injected from the anode (ITO side), while the electrons are injected from cathode (Al side). The injected electrons and holes recombine in the EML layer (MEH:PPV) and recombination causes in to generation light [7]. Figure 9 shows the current (I)-voltage (V) graph of the OLED cell and an inset demonstrating the light emitted from the cell. The voltage across the OLED was applied from 0 V to 3.5 V by a step of 20 mV.
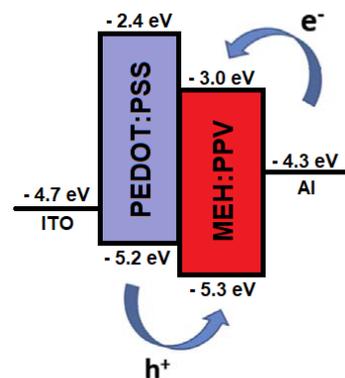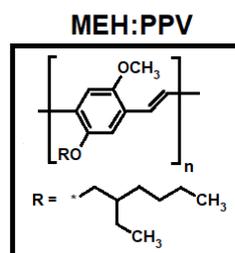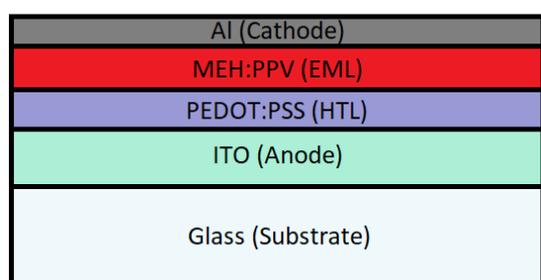
Fig. 8 a) Structure of OLED device and b) energy level diagram.
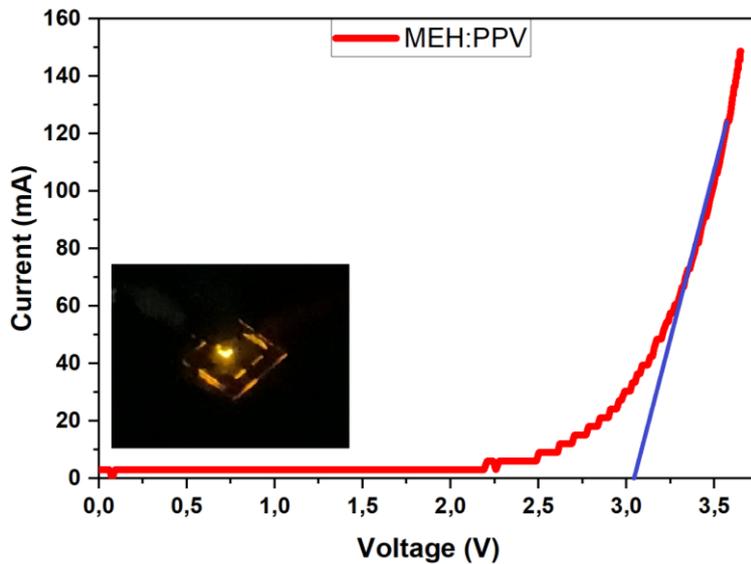
Fig. 9 I-V graph of OLED. Inset shows emission from the OLED.

The graph in the figure consists of two regions. The first region ranges from 0 V to 2.5 V. In this region, the current is almost constant and cut in voltage for anode is about 2.5 V, i.e. so the anode current start to increase after about 2.5 V. After this point, the current begins to increase rapidly. The turn on voltage of the OLED cell is about 3 volts and reaches a current value of about 150 mA around 3.5 V.

Normalized electroluminescent spectrum of the OLED is shown in Fig. 10a and the chromaticity diagram indicating CIE coordinates is shown in Fig. 10b. The EL spectra were recorded over a wavelength range 200–1000 nm using a spectrometer (Flame, Ocean Optics). The OLED reached a maximum luminescence of 1023 cd/m^2. Emission maxima occurred close to 583 nm wavelength for the device.
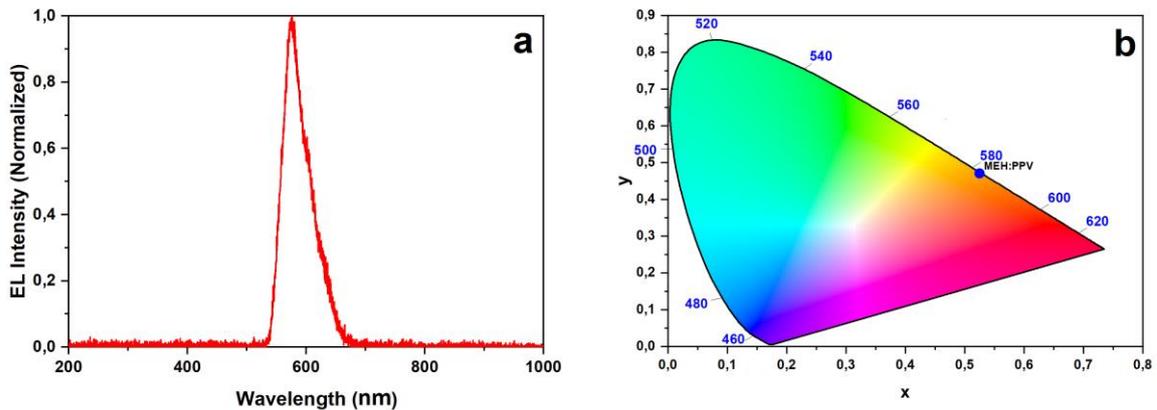
Fig. 10 a) Electroluminescent spectrum of OLED. b) The emission colour of OLED in CIE coordinates.

CONCLUSIONS

In this study, only the I-V plotter of the source measurement unit is described. In order to use the other functions of this device, it is necessary to redirect the subunits whose block diagram is given in Figure 4. Each subunit has its own embedded software. For example, if you want to work in the 3rd region, negative voltages are needed. This negative voltage is generated via software. Let's take a zener diode as an example. When the zener diode is correctly polarized, it works like a normal diode. When polarized in the opposite direction, it does not conduct until the breakdown voltage (zener voltage). When the breakdown voltage is exceeded, it passes current in the form of an avalanche effect and turns into conduction. Therefore, it is sufficient to reverse the

polarity voltage without reversing the terminal connections of the zener diode. To produce this reverse polarity, the software uses two DACs (MPS4725) whose waveforms produce opposite sawtooth. To measure the voltage across the zener diode, the ADC (ADS1115) is pulled into differential readout mode. This device also has some additional equipment. For example, if the leakage current of a reverse-biased diode is to be measured at very low temperatures, the software uses another ADC (HX7111) with 24-bit resolution. The fact that microcontrollers allow cheap and open source software has paved the way for many laboratory devices to be made.

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