TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

NATIONAL COLLEGE OF ENGINEERING

A Minor Project Proposal

On

Plant Stress Monitoring Using Laser Induced Graphene Sensor

Submitted By:

Prabhat Bhatta	**(NCE077BEI003)**
Prashamsha Adhikari	**(NCE077BEI004)**
Rohit Karki	**(NCE077BEI005)**
Sajan Maharjan	**(NCE077BEI006)**
Saroj Budhathoki	**(NCE077BEI008)**

Submitted To:

Department of Electronics and Computer Engineering

National College of Engineering

Talchikhel, Lalitpur, Nepal.

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Prabhat Bhatta	(NCE077BEI003)
Prashamsha Adhikari	(NCE077BEI004)
Rohit Karki	(NCE077BEI005)
Sajan Maharjan	(NCE077BEI006)
Saroj Budhathoki	(NCE077BEI008)

ABSTRACT

Monitoring Ethylene gas features a new root to monitoring plant stress, however, the requirement of high sensitivity poses challenges. This work investigates the potential of LIG enabled gas sensor to monitor ethylene gas emitted by a plant thereby, monitoring stress in plant. To implement the proposed sensor, a LIG trace will be patterned by lasing a polyimide substrate and will be employed as a capacitor and resistor in a square wave signal generator. LIG enabled resistor and capacitor alter their values upon exposure to ethylene gas which in turn changes the frequency and duty cycle of the generated signal. These changes in signals properties can be used to detect and monitor ethylene gas emitted by the plants. As a proof of concept, LIG enabled sensor will be applied to monitor ethylene gas concentration ranging from 0.1 ppm to 20 ppm. The measured data will be wirelessly transmitted to a distant readout system (smartphone application). The feasibility of the ethylene gas sensor will be examined for the plant stress monitor.

Keywords*: (Ethylene, Gas sensor, LIG, Polyimide, Square wave signal generator)*

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREBIATIONS

CO_2 - Carbon dioxide
CPU - Central processing unit
DPV - Differential pulse voltammetry
DRC – Design Rule Check
EEPROM - electrically erasable programmable read-only memory
GO - Graphene Oxide
IC - Integrated Circuit
I2C - Inter-Integrated Circuit
ICSP - In-Circuit Serial Programming
IDE - Integrated Development Environment
IG/ID - Intensity ratio of Defect (ID) and Graphene(IG)
IOref - Input-Output Reference
LED - Light Emitting Diode
LIG – Laser-Induced Graphene
miRNA - micro Ribonucleic Acid
NH_3 - Ammonia
NO_2 - Nitrogen Dioxide
PCB - Printed Circuit Board
Pd - Palladium
PI - Polyimide
PWM - Pulse Width Modulator
RC – Resistor and Capacitor
Rx – Receiver
SPI - Serial Peripheral Interface
STEM - Scanning Transmission Electron Microscopy
SRAM - Static Random Access Memory
TEM - Transmission Electron Microscopy
Tx – Transmit
UART - Universal Asynchronous Receiver/Transmitter
USB - universal serial bus
VSM - Virtual System Modeling
VOC - volatile organic compound
XRD - X-ray diffraction
$[Fe(CN)_6]^{3-}$ - Ferricyanide
VIS/NIR - Visible and Near Infrared

1. INTRODUCTION

1.1. BACKGROUND

The integration of plant health into the One Health framework has been limited, despite its crucial role in sustaining human and animal health and its impact on the environment. Recognizing its significance, the United Nations designated 2020 as the International Year of Plant Health to raise awareness of its effects on society. Plants play a vital role in food security, being the primary source of nutrition for both humans and livestock, and thus, their health directly influences public health. However, plant diseases and pests can reduce crop yield, affect food safety, and contribute to the spread of foodborne illnesses. The emergence of new pathogen variants and expanding ranges of pests pose economic burdens and disrupt food production. Effective pest and disease management strategies are essential to prevent and mitigate these issues. Through case studies, the interconnectedness between plant health, food security, and food safety is highlighted, emphasizing the importance of a One Health approach to address these challenges and ensure health equity. Plant stress detection is considered one of the most critical areas for the improvement of crop yield in the compelling worldwide scenario.

Stresses come from a range of factors that limit the potential growth of Plant. Evaluation of the stress level to which plants are subjected is therefore critical information required both for the quantification of consequences on production and for taking action for their mitigation. The journal Plant Stress deals with plant responses to abiotic and biotic stress factors that can result in limited growth and productivity. Plants under drought increase ethylene production as a response to stress full condition. Sensors based on graphene materials have promising applications in the fields of biology, medicine and environment. Graphene is a carbon allotrope that has aroused rapidly growing interest for possible applications in many fields. It consists of a single sheet of carbon atoms arranged in a two-dimensional (2D) hexagonal lattice, where each atom shares with neighbor's three in-plane σ-bonds and an out-of-plane π-bond. A laser-scribed graphene provides a versatile, low-cost, and environmental friendly method for stress, bio, gas, temperature, humidity and multifunctional integrated sensors. The laser induced graphene (LIG) has been more and more prevalent for developing sensors. It shows great potential in biochemical sensors and physical physiological sensors. These sensors have great potential in monitoring the normal life activities.

1.2. PROBLEM STATEMENT

Conventionally, to monitor stress in plants, quantitative methods such as metabolomics and qualitative methods such as florescence, thermography and VIS/NIR (Visible and Near Infrared) reflectance are used. These provide a non-disruptive view of the action of the stressors in plants, even across large fields, but with the drawback of poor accuracy. Despite being widely used, these methods aren't consistent and require professional hand on approach. Obtaining accurate and up-to-date data on various environmental parameters, such as temperature, humidity, solar radiation, and soil moisture, can be challenging. Inaccurate or insufficient data can lead to inaccurate stress calculations. The equipment used to measure environmental parameters may have inherent errors, leading to inaccuracies in stress calculations. Calibration and maintenance of these instruments are crucial to ensure reliable data. Environmental conditions can vary significantly within a plant's growing area and over time. Capturing this variability accurately is essential for precise stress assessment, but it can be challenging due to limited resources and monitoring capabilities. Defining stress thresholds for different plant species and growth stages is a complex task. These thresholds can vary based on genetics, environmental conditions, and management practices, making it challenging to establish universal standards.

1.3. OBJECTIVES

The main objective of our project is to develop a gas sensor based on LIG to measure plant stress. Other specific objectives are:

- To investigate the potential of LIG to detect & characterize ethylene.
- To develop a square wave generator using Arduino microcontroller & RC tuned circuit where RC is implemented using LIG.
- To investigate impact of operating frequency (square wave frequency on the resulting sensitivity of LIG to monitor gases).
- To develop a mobile application for stress monitoring through wireless connection with gas sensor.

1.4. SIGNIFICANCE

The significance of the project report on "Plant stress monitoring using LIG sensor" is multifarious. Gas sensors based on Laser-Induced Graphene (LIG) offer several significant advantages and have the potential to revolutionize gas sensing technology. Our plant stress detection system helps in early detection of plant health issues which helps farmers to ensure better crop yields. LIG gas sensors have demonstrated high sensitivity to a wide range of gases, including volatile organic compounds (VOCs), ammonia, nitrogen dioxide, carbon monoxide, and methane. This high sensitivity allows for accurate and reliable gas detection even at low concentrations, making them suitable for various applications, such as environmental monitoring and industrial safety. Identifying and quantifying plant stress is crucial for optimizing crop yields, ensuring plant health, and implementing timely interventions to prevent crop losses. LIG-based sensors can detect subtle changes in gas emissions even before visible signs of stress appear in the plants. Early detection enables timely intervention, helping to prevent or mitigate stress-related damage. Incorporating LIG-based gas sensors into precision agriculture practices can enable targeted interventions, optimizing resource use, and minimizing stress-related losses. In a nutshell, LIG-based gas sensors have the potential to revolutionize the way plant stress is calculated and managed, leading to improved crop productivity, sustainable agriculture practices, and a better understanding of the impact of environmental factors on plant health.

2. LITERATURE REVIEW

2.1. Related Theory

Laser-assisted processing techniques have emerged as powerful tools in various applications ranging from materials manufacturing to surgical pathology. In 2014, the conversion of commercial polymers into porous graphene by direct laser scribing with a commercial CO_2 infrared laser system was found in most machine shops, the product being termed laser-induced graphene (LIG). LIG exhibits a high surface area (≈340 m2 g−1), high thermal stability (>900 °C), and excellent conductivity (5–25 S cm−1). The entire process can be performed in ambient air without any solvents, thereby making it exceedingly attractive for industrial use. This protocol combines the 3D graphene synthesis with writing into a single step process that has stimulated research ranging from fundamental studies on the transformation process to the development of a large variety of engineering applications . The formation of 3D porous graphene has been the interest of researchers in various fields due to its high surface area along with the intrinsic excellent chemical, physical, and electronic properties of graphene [1].

In 2014, it was found that direct writing on commercial polyimide (PI) films under ambient conditions using a CO_2 infrared laser generates 3D porous graphene, LIG (Figure 1a). This was a serendipitous discovery when J. Lin of our group was attempting to lase GO dispersed upon a PI film. The laser missed the GO target and the PI was lased, becoming black. Upon checking the Raman spectrum, Lin noticed that the PI-bound black material was graphene! Under computer control, the LIG can be patterned into various shapes (Figure 1b), providing a simple approach to printable electronics. The LIG exhibits a porous structure (Figure 1c,d); the pore size is tunable by controlling the laser power. A critical fluence of ≈5.5 J cm^{-2} is required for the formation of LIG. The identity of LIG can be inferred from the transmission electron microscopy (TEM; Figure 1e) image that displays a few-layered structure with a characteristic 3.37 Å d-spacing of graphene. The graphene structure is also substantiated from the Raman and X-ray diffraction (XRD) analyses. The high IG/ID ratio in Raman spectra and the sharp (002) XRD peak suggests the highly crystalline graphene structure (Figure 1f,g) and the D-band can result from the bent graphene layers. The I2D/IG ratio is ≈1, which indicates the graphene is few-layered and consistent with the structure observed from TEM (Figure 1e). Unlike the traditional honeycomb structure of graphene, scanning TEM (STEM; Figure 1h,i) images show that LIG contains abundant five- and seven-membered rings. Such an unusual graphene structure could result from the rapid formation and cooling of the graphene, trapping it in the higher energy state. It can therefore be termed kinetic graphene[2].

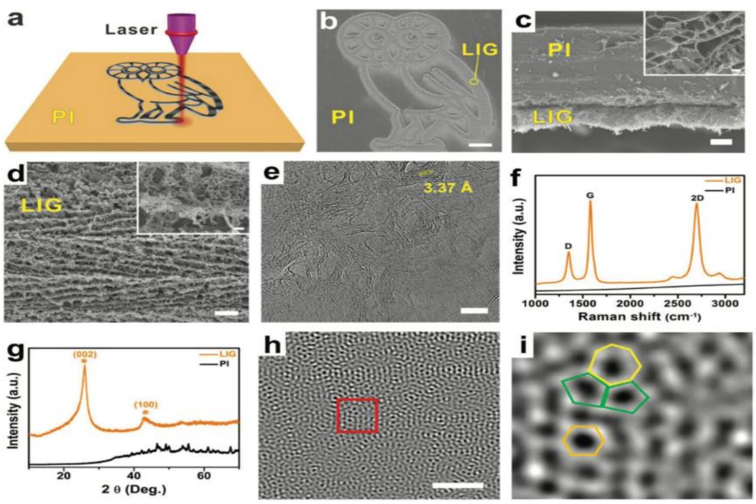

Figure 1: Scribing Graphene in PI Surface

2.2. Related Works

A possible application of bare LIG on PI in sensing was reported by Wu et al.[3] who fabricated an ammonia gas sensor that exploited both the electrical and physical properties of the material. The resistance of a LIG track was monitored as a test gas flowed through a chamber housing the sensor, and a correlation between the variation of resistance and concentration of NH_3 in the air was found. In order to enhance sensor performance, the LIG track was heated by the Joule effect to favor desorption of NH_3 from the sensor surface and restore the initial conditions.

Yang et al.[4] fabricated a wearable sensor to monitor the concentrations of uric acid and tyrosine in human sweat. Microfluidic channels were fabricated by laser lithography in a polyethylene terephthalate layer attached to a PI film supporting the LIG sensor that could be placed in contact with the skin for the simultaneous measurement of the sweat concentrations of the two molecules by electrocatalyzing their oxidation process.

Wan et al.[5] developed an N-doped LIG sensor for the detection of micro-RNA (miRNA) exploiting DPV with $[Fe(CN)_6]^{3-}$ as a redox probe (Figure 3b). Their LIG, fabricated with a CO_2 laser and PI, incorporated a small amount of N atoms from the PI substrate during laser induction, resulting in a slightly improved conductivity of the material and affinity to nucleic acids. Upon the drop-casting of purified miRNA onto the electrode and the performance of DPV measurements, a correlation between the concentration of miRNA and DPV signals was established

Exploiting a different transduction method, Zhu et al.[6] proposed a resistive sensor combining LIG and palladium for monitoring gaseous H_2. Hydrogen molecules are slowly absorbed into Pd, altering the resistance of the sensor. The effect of interfering gases such as NO_2 and NH_3 was investigated. The sensor showed no response toward those interferents. However, no additional analytical parameters were reported, making comparison with similar devices difficult.

Table 1 Main Characteristics of LIG-Based Biosensors [7]

starting material	laser	analyte	transduction method	detection limit	dynamic range	sensitivity
PI	10.6 μm	urea	potentiometry	10^{-4} M	10^{-4}–10^{-1} M	–

Table 2 Characteristics and Comparison of LIG Based Sensors Functionalized with Metal Nanoparticles [8]

starting material	doping material	laser	analyte	transduction method	detection limit	dynamic range	sensitivity
PI	Au and Pt NPs	10.6 μm	dopamine	cyclic voltammetry	75.0 nM	0.95–30 μM	865.8 μA mM^{-1} cm^{-2}
PI	Pt NPs	10.6 μm	H_2O_2	cyclic voltammetry	0.2 μM	0.5 μM to 5.0 mM	248.4 μA mM^{-1} cm^{-2}
PI	Pt NPs	10.6 μm	methane	cyclic voltammetry	9 ppm	1–50 ppm	0.55 μA ppm^{-1} cm^{-2}

3. METHODOLOGY

3.1. Theoretical Background

3.1.1. LIG (Laser-Induced Graphene)

Laser-Induced Graphene (LIG) is a remarkable material synthesis technique that involves using a high-power laser to directly convert certain carbon-containing materials, often polymers, into a three-dimensional structure of graphene. This process takes place in ambient air and eliminates the need for solvents or complex chemical reactions. The laser energy heats the precursor material to a point where it undergoes a controlled transformation, resulting in the formation of graphene-like structures.

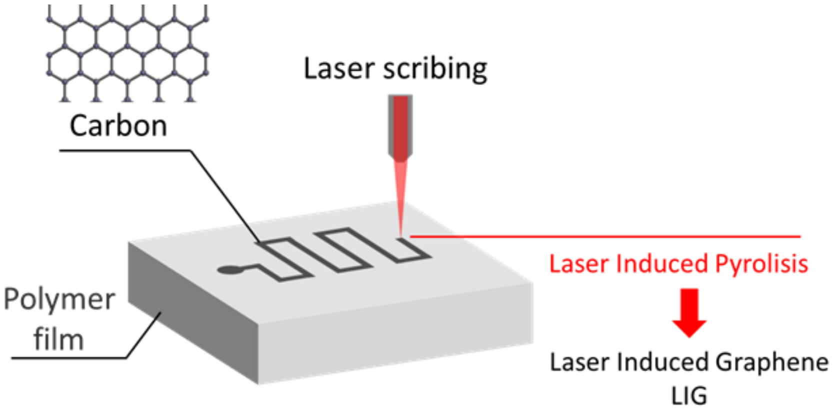

Figure 2: Synthesis of laser-induced graphene (LIG) by lasing a PI substrate using CO2 laser.

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3.1.2. Sensor

A sensor is a device or instrument that detects and measures physical properties or changes in the environment and converts this information into signals or data that can be analyzed, displayed, or recorded. Sensors play a crucial role in various fields, including electronics, robotics, industrial automation, healthcare, environmental monitoring, and more.

3.1.3. Microcontroller

A microcontroller is a small computer on a single integrated circuit (IC) or chip. It contains a processor (CPU), memory, and input/output peripherals, all designed to perform specific tasks and control a particular system or device. Microcontrollers are widely used in embedded systems and servers as the brain of various electronic devices, allowing them to carry out specific functions or processes.

3.1.4. Arduino Uno as Square Wave Generator

The Arduino Uno is configured as a square wave generator with user-selectable control of the frequency and duty cycle. The operating range of the system is up to 10 KHz. The desired frequency and duty cycle of the generated square wave can be produced using a matrix keyboard that is interfaced with the digital pins of the Arduino. The circuit diagram of the square wave generator built around an Arduino Uno board, a matrix keyboard and a few other components is shown in Figure 3.

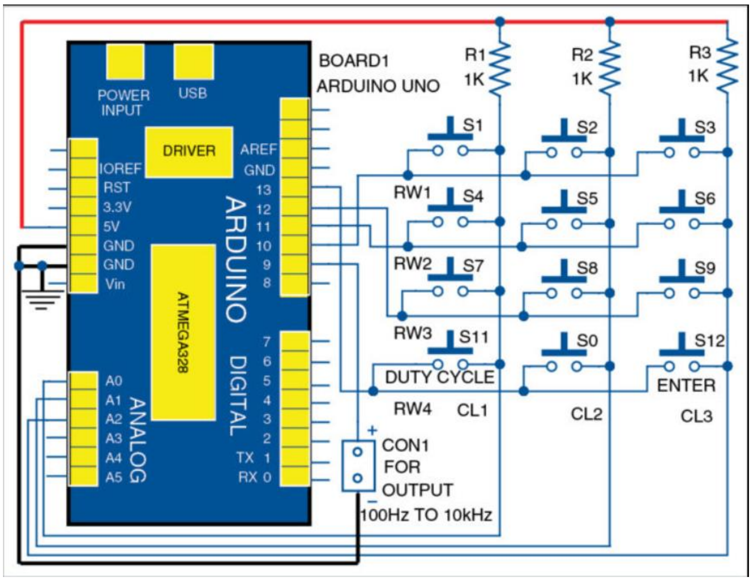

Figure 3 Circuit diagram of Arduino based square wave generator

The 4×3 matrix keyboard is used as an input device. The keyboard's four rows (RW1 through RW4) are connected to digital pins 10, 11, 12, and 13 of the Arduino Uno board. The three columns (CL1 through CL3) of the keyboard are connected to the Arduino analog input pins (A0 through A2). Each column is connected to a 5V supply through a 1-kilo-ohm resistor (R1 through R3). Arduino Uno is an AVR ATmega328P microcontroller (MCU) based development board with six analog input pins and 14 digital I/O pins. The MCU has 32kB ISP flash memory, 2kB RAM and 1kB EEPROM. The board provides serial communication via UART, SPI, and I2C. The MCU can operate at a clock frequency of 16MHz. Here, the digital I/O pins 13, 12, 11, 10, and 9 of the Arduino are configured as output pins. Pins A0, A1, and A2 serve as analog input pins.

3.1.5. Tools Used

3.1.5.1. Hardware

3.1.5.1.1. Gas Sensor Using LIG

Gas sensors using laser-induced graphene (LIG) are an innovative and promising technology for detecting and measuring various gases in the environment. Laser-induced graphene is a type of graphene material created by directly irradiating a solid carbon source, such as polymers, with a laser. This process converts the carbon source into a porous, interconnected network of graphene, which can be used as a sensing material. It works based on the changes in electrical conductivity or other properties of LIG when it interacts with specific gases.

3.1.5.1.2. Arduino UNO

An Arduino is a microcontroller-based kit that can be either used directly by purchasing from the vendor or can be made at home using the components, owing to its open-source hardware feature. It is used in communications and in controlling or operating many devices. It was founded by Massimo Banzi and David Cuartielles in 2005.

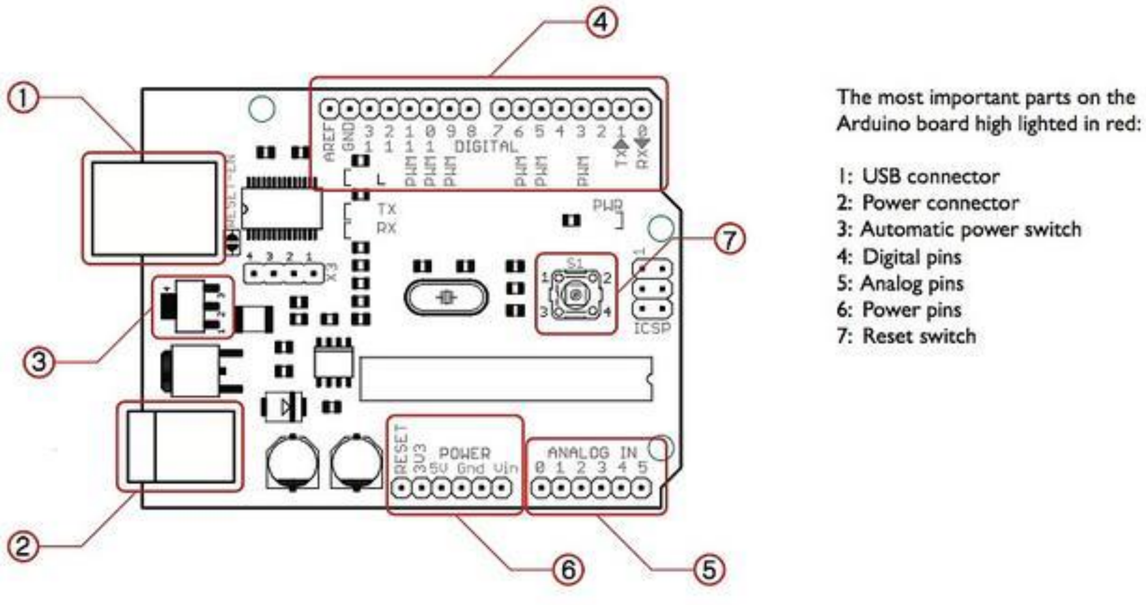

Figure 4: Arduino Pin Diagram

Arduino Uno consists of 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Power Jack: Arduino can be powered either from the pc through a USB or an external source like an adaptor or a battery. It can operate on an external supply of 7 to 12V. Power can be applied externally through the pin Vin or by giving voltage reference through the IORef pin.

Digital Inputs: It consists of 14 digital inputs/output pins, each of which provides or takes up 40mA current. Some of them have special functions like pins 0 and 1, which act as Rx and Tx respectively, for serial communication, pins 2 and 3-which are external interrupts, pins 3,5,6,9,11 which provides PWM output and pin 13 where LED is connected.

Analog inputs: It has 6 analog input/output pins, each providing a resolution of 10 bits.

ARef: It provides a reference to the analog inputs.

Reset: It resets the microcontroller when low.

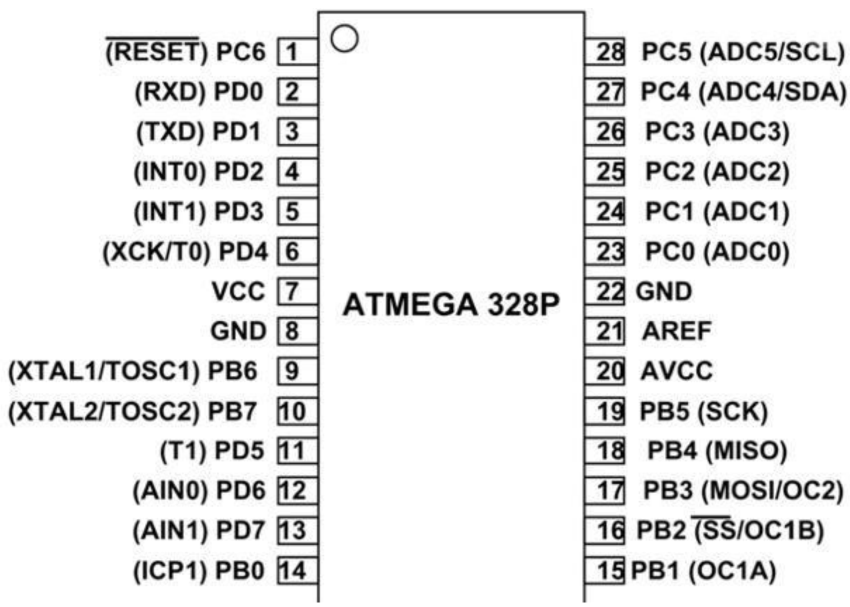

Figure 5: Arduino Pin Configuration

ATMEGA 328P is a very advanced and feature-rich microcontroller. It is one of a famous microcontroller of Atmel, because of its use in Arduino UNO board. The internal circuitry of ATMEGA328P is designed with low current consumption features. The chip contains 32 KB of internal flash memory, 1 KB of EEPROM, and 2 KB of SRAM. The EEPROM and the flash memory are the memories, which save information and that information stillexists the power is disconnected or off but the SRAM is a memory which only saves the information until the power is supplied and when the power is disconnected, all the information saved in SRAM will be erased.
PC6: When this reset pin goes low, the microcontroller and its program get reset.
PD0: Input pin for serial communication.
PD1: Output pin for serial communication.
PD2: Pin 4 is used as an external interrupt 0.
PD3: Pin 5 is used as an external interrupt 1.
PD4: Pin 6 is used for external counter source timer 0.
Vcc: Positive supply of the system.
GND: Ground of the system.
XTAL: This pin should be connected to one pin of the crystal oscillator to provide an external clock pulse to the chip.
PD5: Pin 11 is used for external counter source timer 1.
PB3: This pin is used as master data output and slave data input for SPI.
AVcc: Positive voltage for ADC (power).
AREF: Analog Reference Voltage for ADC.
PC0: Analog input digital value channel 0.
PC1: Analog input digital value channel 1.
PC2: Analog input digital value channel 2.
PC3: Analog input digital value channel 3.
PC4: This pin can be used as a serial interface connection for data.
PC5: This pin can be used as a serial interface clock line.

3.1.5.1.3. PCB

A PCB (Printed Circuit Board) is a fundamental component in modern electronics. It provides a mechanically supportive and electrically connected platform for various electronic components and circuits. PCBs are used in a wide range of electronic devices, from simple household appliances to complex computer systems.

Figure 6: Arduino Pin Configuration

3.1.5.1.4. HC-05 Bluetooth Module

The HC-05 Bluetooth module is widely used for wireless communication between microcontrollers, computers, smartphones, and other devices. It enables serial communication over Bluetooth, making it an ideal choice for creating wireless connections in a range of electronic projects.

Table 3: HC-05 Pin Configuration

Pin Number	Pin Name	Description
1	Enable / Key	This pin is used to toggle between Data Mode (set low) and AT command mode (set high). By default, it is in Data mode
2	Vcc	Powers the module. Connect to +5V Supply voltage
3	Ground	Ground pin of module, connect to system ground.
4	TX Transmitter	Transmits Serial Data. Everything received via Bluetooth will be given out by this pin as serial data.
5	RX Receiver	Receive Serial Data. Every serial data given to this pin will be broadcasted via Bluetooth
6	State	The state pin is connected to onboard LED, it can be used as feedback to check if Bluetooth is working properly.
7	LED	Indicates the status of Module • Blink once in 2 sec: Module has entered Command Mode • Repeated Blinking: Waiting for connection in Data Mode • Blink twice in 1 sec: Connection successful in Data Mode
8	Button	Used to control the Key/Enable pin to toggle between Data and command Mode

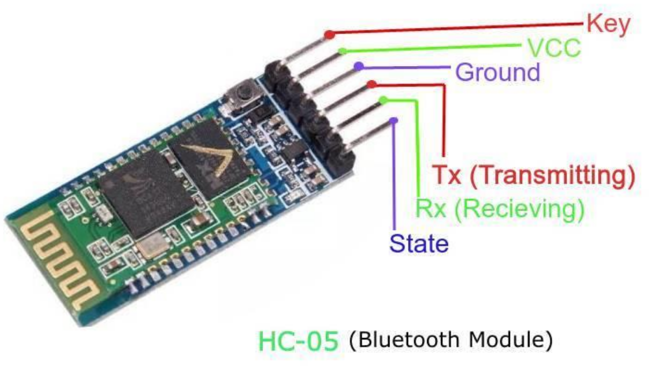

Figure 7 HC-05 Bluetooth Module

3.1.5.2. Software Requirement

3.1.5.2.1. Proteus 8.6 professional

Proteus 8.6 Professional is a software package for creating electronic circuits that are used by engineers, designers, and hobbyists. It includes two main components: Proteus Design Suite and Proteus VSM (Virtual System Modeling).
Proteus Design Suite allows users to create schematic diagrams of electronic circuits by selecting components from a library and connecting them using wires. The library includes a wide range of electronic parts, such as resistors, capacitors, transistors, microcontrollers, and sensors.
Proteus VSM is a powerful component that allows you to simulate the behavior of the circuit in real time. You can run simulations to see how the circuit responds to different inputs, debug potential issues, and understand current and voltage levels at various points. Proteus VSM also supports microcontroller simulation, making it useful for testing and developing embedded systems.

3.1.5.2.2. Arduino IDE 2.1.1

The Arduino Integrated Development Environment (IDE) is an open-source software platform used for programming and developing applications for Arduino microcontroller boards. Arduino IDE provides a user-friendly interface and a set of tools that make it easy for both beginners and experienced developers to write, compile, and upload code to Arduino boards.

3.1.5.2.3. Visual Studio Code

Developed by Microsoft, Visual Studio Code (VS Code) is a widely used and powerful source code editor. Its extensive customization options, versatility, and range of features have made it a favorite among developers. Supporting a broad range of programming languages, including popular ones like Python, JavaScript, C++, Java, HTML, and CSS, VS Code achieves its flexibility through extensions. These add-ons provide language support, additional tools, and integrations. The VS Code Extension Marketplace hosts thousands of extensions developed by the community, enabling users to customize their coding environment to meet their specific needs.

3.1.5.3. Programming Languages

3.1.5.3.1. Python

Python is a high-level, interpreted programming language known for its simplicity, readability, and versatility. It was created by Guido van Rossum and was first released in 1991. Python is designed with a strong emphasis on code readability, using indentation and whitespace to define code blocks, which contributes to its clean and easy-to-understand syntax.
Kivy Framework: Kivy is an open-source Python framework for developing multitouch applications and user interfaces. It is particularly focused on creating cross-platform applications that can run on various devices, including desktop computers, smartphones, tablets, and even embedded systems. Kivy is known for its ease of use, flexibility, and support for both touch and traditional input methods.

3.1.5.3.2. C/C++

C++ is a versatile and widely used programming language that builds upon the foundation of the C programming language while introducing powerful features for modern software development. Developed in the late 1970s and 1980s, C++ is known for its combination of efficiency, flexibility, and object-oriented programming (OOP) capabilities. It is commonly used for a variety of applications, from system-level programming to application development and game design.

3.2. System Block Diagram

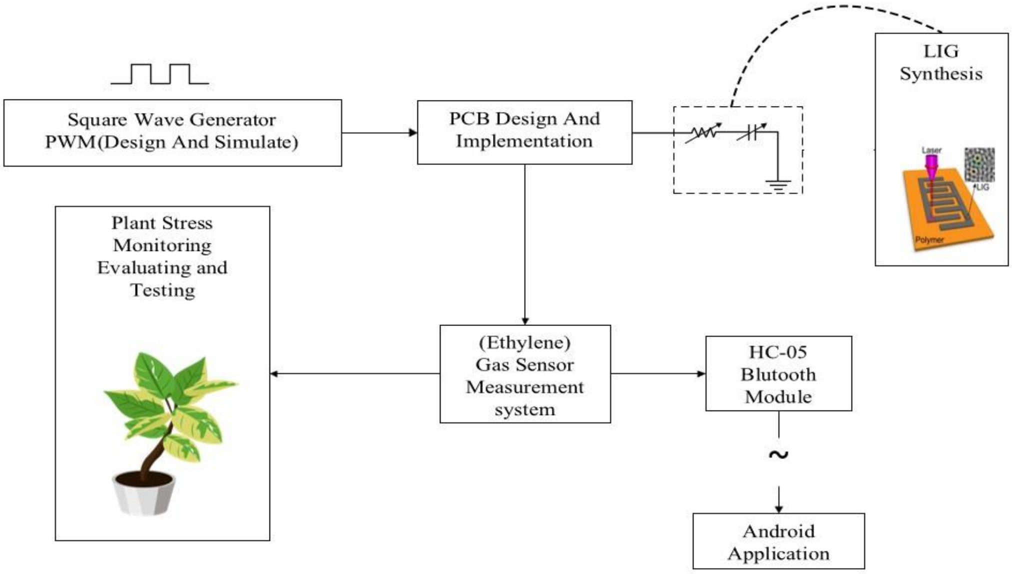

Figure 8: System Block Diagram

3.3. Algorithm:

Step 1: Start.

Step 2: Design and simulate a square wave generator with PWM using a predetermined frequency and duty cycle. This process involves calculating PWM values, setting up a microcontroller or PWM generator IC, connecting to a low-pass filter, and simulating using software for waveform verification.

Step 3: Design, implement, and validate a PCB for a square wave generator and PWM circuit involving software selection, schematic and layout design, DRC, Gerber file generation, manufacturing, assembly, and functional testing.

Step 4: Develop a system for measuring ethylene gas using a selected sensor, involving sensor interfacing, calibration, data acquisition, communication implementation, and accuracy validation through controlled testing.

Step 5: Evaluate plant stress using an ethylene gas sensor by deploying it in the environment, collecting and analyzing data to determine stress indicators and plant health correlation, and validate findings through comparison with established metrics.

Step 6: Integrate Bluetooth Module

In this step, integrate a Bluetooth module into a square wave generator and PWM circuit design. This will allow us to remotely control the generator parameters and receive real-time data on your Android device.

Step 7: Smartphone Application Development

In this step, develop a Smartphone application that communicates with your square wave generator and PWM circuit via the integrated Bluetooth module. The Android app will provide a user-friendly interface for controlling the generator and visualizing the data.

Step 8: End.

3.4. Flowchart:

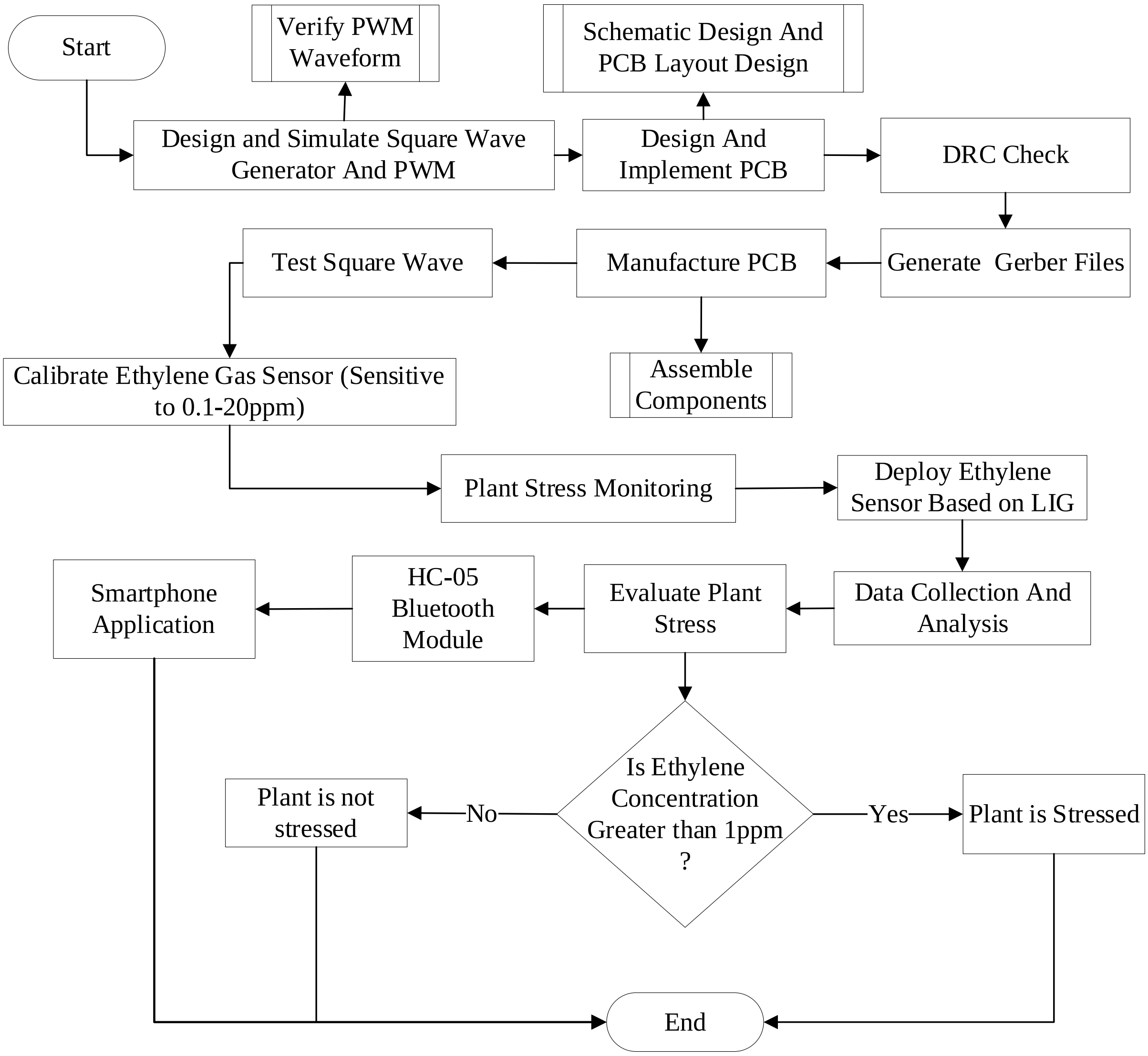

Figure 9: Flowchart for System.

4. EPILOGUE

4.1. Task Accomplished

- **LIG Fabrication:** LIG sensor was fabricated. The obtained result is shown in figure in below:

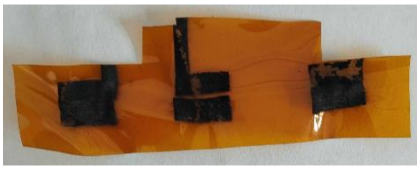

Figure 10: LIG Fabrication

- **Equipments Gathered:** The following components were gathered for the Project experiment:
    1. Multipurpose Transparent Plastic Container with Air Tight Lid.
    2. Humidifier Mist Maker
    3. Temperature and Humidity meter (Hygrometer)
    4. 12V DC Fan
    5. Arduino UNO Kit
- **PCB Fabrication:** The required PCB to mount the LIG sensor was designed. According to design, PCB was etched in $FeCl_3$ solution thus, obtaining the PCB. The figure is shown below.

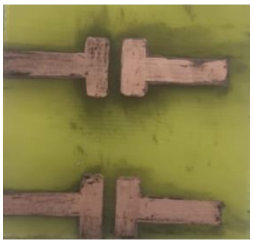

Figure 11: PCB Fabrication

- **LIG Connection to PCB :** The LIG was mounted on wired connected soldered PCB as shown in figure below:

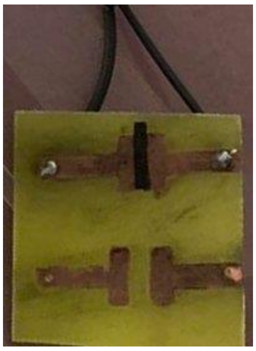

Figure 12: LIG Mounted PCB

- **Measurement System:**
For measurement system, an experimental setup was designed to faciliate the seamless integration of components. This configuration is categorized into sensing unit (Plastic Container) And External unit. A key consideration during the setup was maintaining an airtight environment within sensing unit.
<u>Sensing Unit</u>:
The Sensing Unit encapsulates the core components responsible for data acquisition and environmental control. This unit includes:
Humidifier: Regulating the moisture levels within the controlled environment.
LIG Sensor: Providing precise and responsive measurements crucial for the experiment.
Fan: Contributing to controlled airflow and environmental homogeneity.
Hygrometer: Ensuring accurate humidity measurements for enhanced data reliability.
<u>External Unit</u>:
The External Unit encompasses components that facilitate external control, power supply, and data analysis. This unit comprises:
DC Power Supply: Offering the necessary power to drive the components within the setup.
Function Generator: Providing controlled input signals for a systematic and controlled experiment.
Oscilloscope: Enabling precise visualization and analysis of electrical signals.
The experimental setup is shown in figure below:

Figure 13: Experimental Setup for measurement system.

- **Characterization and Fundamental Tests Under Humidity:**
In the process of characterizing the Laser-Induced Graphene (LIG) sensor, our methodology involved the utilization of a humidifier within a sealed container to induce controlled humidity levels. To ensure uniform distribution of water vapor throughout the enclosure, a 12V fan was employed. Powering these components was facilitated by a dedicated DC power supply, delivering the required voltage.To interface with the sensor-mounted printed circuit board (PCB), the output of a function generator was routed. The ensuing response of the sensor was meticulously measured using an oscilloscope, capturing valuable insights

into its performance under varying humidity conditions. The controlled elevation of humidity within the sealed environment was orchestrated, and the sensor's response was systematically gauged. Throughout the course of the experiment, a comprehensive dataset was meticulously acquired, furnishing invaluable information on the sensor's behavior across different humidity levels.

Output from Experiment:

Performing experiment using water for calibration of Humidity sensor. The output from LIG sensor is passed to oscilloscope for analysis of electric signal. The corresponding outputs from hygrometer and oscilloscope is presented in table below:

Table 4: Humidity and Vrms Reading

HUMIDITY (RH) %	V_{rms}(mV)
66	184
68	216
70	256
72	296
74	328
75	336
77	400
79	416
81	456
83	496
85	544
87	576
89	624

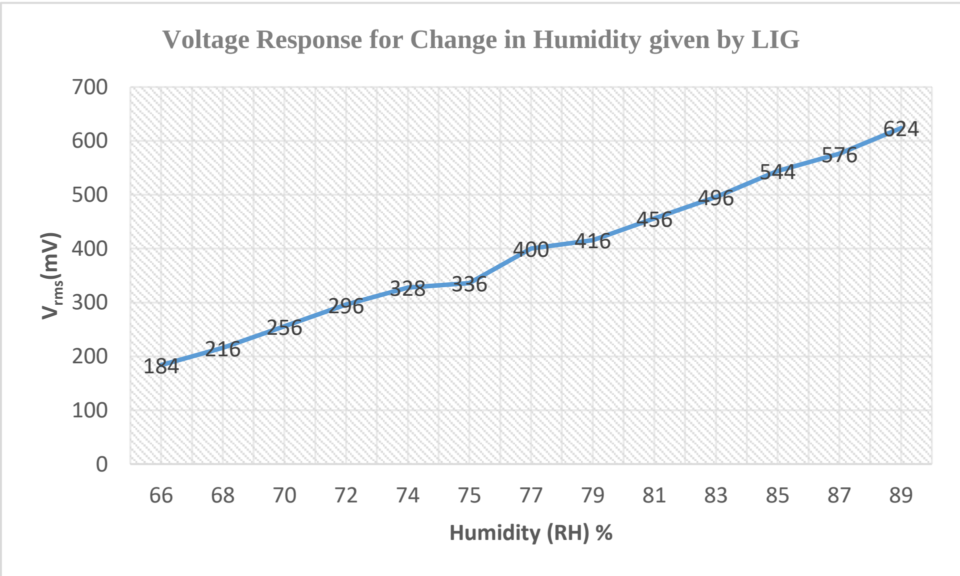

Figure 14: Voltage Response for Change in Humidity given by LIG

4.2. Task Remaining

- **Ethylene gas testing:** conduct the experiment using ethylene gas for evaluation. This simple adjustment will allow us to observe how ethylene impacts our study in the future, providing valuable insights for improved plant stress monitoring.
- **Replacement through Arduino:** Upgrade the setup by replacing the current external components with an Arduino UNO and incorporating a Bluetooth module. This will enable the transmission of sensor data to a mobile device, ensuring a streamlined and efficient process for real-time monitoring in the future.
- **Mobile App:** developing a mobile app for monitoring results from sensor data with a graphical user interface, ensuring a user-friendly and intuitive experience.

5. COST ESTIMATION

After careful research, proposal writing, and buying necessary components, estimated project cost is currently Rs. 8000. It might change later based on project schedule.

Table 5: Cost Estimation

S.N.	Components	Quantity	Total Unit price
1	Arduino UNO	1	1800
2	12 V DC Fan	1	250
3	Humidifier Mist Maker	1	600
4	Plastic Container	1	650
5	Hygrome	1	1800
6	Bluethooth module	1	900
7	DHT11 (Humidity Sensor)	1	800
8	PCB Board	1	200
9	Miscellaneous	1	1000
Total			8000

6. REFERENCE

[1] Geim AK. Graphene: status and prospects. Science. 2009 Jun 19;324(5934):1530-4. doi: 10.1126/science.1158877. PMID: 19541989.

[2] Ye, R., James, D. K., & Tour, J. M. (2019). Laser-Induced Graphene: From Discovery to Translation. In Advanced Materials (Vol. 31, Issue 1). Wiley-VCH Verlag.

[3]Wu, D.; Peng, Q.; Wu, S.; Wang, G.; Deng, L.; Tai, H.; Wang, L.; Yang, Y.; Dong, L.; Zhao, Y.; Zhao, J.; Sun, D.; Lin, L. A Simple Graphene NH_3 Gas Sensor via Laser Direct Writing. Sensors 2018, 18 (12), 4405.

[4]Yang, Y.; Song, Y.; Bo, X.; Min, J.; Pak, O. S.; Zhu, L.; Wang, M.; Tu, J.; Kogan, A.; Zhang, H.; Hsiao, T. K.; Li, Z.; Gao, W. A LaserEngraved Wearable Sensor for Sensitive Detection of Uric Acid and Tyrosine in Sweat. Nat. Biotechnol. 2020, 38 (2), 217−224

[5]Wan, Z.; Umer, M.; Lobino, M.; Thiel, D.; Nguyen, N. T.; Trinchi, A.; Shiddiky, M. J. A.; Gao, Y.; Li, Q. Laser Induced Self-N-Doped Porous Graphene as an Electrochemical Biosensor for Femtomolar MiRNA Detection. Carbon 2020, 163, 385−394.

[6]Zhu, J.; Cho, M.; Li, Y.; Cho, I.; Suh, J. H.; Del Orbe, D.; Jeong, Y.; Ren, T. L.; Park, I. Biomimetic Turbinate-like Artificial Nose for Hydrogen Detection Based on 3D Porous Laser-Induced Graphene. ACS Appl. Mater. Interfaces 2019, 11, 24386−24394.

[7]Mamleyev, E. R.; Heissler, S.; Nefedov, A.; Weidler, P. G.; Nordin, N.; Kudryashov, V. V.; Länge, K.; MacKinnon, N.; Sharma, S.Laser-Induced Hierarchical Carbon Patterns on Polyimide Substrates for Flexible Urea Sensors. npj Flex. Electron. 2019, 3, 2.

[8]Zhang, Y.; Zhu, H.; Sun, P.; Sun, C. K.; Huang, H.; Guan, S.; Liu, H.; Zhang, H.; Zhang,C.; Qin, K. R. Laser-Induced GrapheneBased Non-Enzymatic Sensor for Detection of Hydrogen Peroxide. Electroanalysis 2019, 31, 133.