DEVELOPMENT OF AN ELECTROSPINNING DEVICE FOR NANOFIBER PRODUCTION

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Abstract. *The electrospinning device is designed exclusively for use in a research center, operates with meticulous precision and incorporates comprehensive safety features, mitigating any potential risks associated with its high-voltage operations. This devise stands at the forefront of materials research, offering researchers opportunities to produce nanofibers with desired diameters and lengths. The modular structure of a device allows for easy assembly and disassembly of interchangeable parts or modules. This design offers flexibility, scalability, and ease of maintenance, as faulty modules can be quickly identified and replaced. It also promotes cost-effectiveness by enabling users to invest in only the modules they need initially and upgrade gradually over time. Its ability to generate nanofibers opens avenues for breakthroughs in fields such as biomedicine, electronics, energy storage, and filtration. As a crucial tool in science, this electrospinning device pushes nanotechnology forward, sparking new ideas and shaping the future of materials science.*

Keywords: *Electrospinning, nanomaterials, high-voltage source, nanofibers*

Introduction

Semiconductor nanowires are considered one-dimensional (1D) nanomaterials with diameters of less than 100 nanometers and with lengths of several micrometers. Due to their unique size-dependent properties, semiconductor nanowires have attracted significant attention for various applications including nanoelectronics, sensors, photonics, optoelectronics and energy conversion. Among the important parameters can be mentioned: (i) high surface-to-volume ratio, for applications where surface chemistry plays a critical role, including catalysis and sensing; (ii) quantum confinement effects, due to the small dimensions which can significantly change the electrical, optical, and thermal properties of the semiconductor nanowires; (iii) controllable properties due to the possibilities to change their composition, dimensions, and shape opening possibilities for wide range of applications [1-4]. There are several main methods for semiconductor nanowires synthesis: vapor-liquid-solid (VLS) growth, solution-phase synthesis, and template-assisted synthesis. VLS Growth represent the most common method, requiring a noble metal acting as catalyst to initiate the growth of nanowires, at the same time gives very good control of the diameter and crystal structure, while the method Solution-Phase Synthesis provides versatility in terms of materials and allows for some control over the nanowire properties [5]. A lot of attention gained template-assisted synthesis of one-dimensional nanostructures such as nanowires and nanotubes by means of chemical or electrochemical deposition in porous templates [6]. Template-assisted synthesis can be used to for nanowires and nanotubes obtaining with controlled morphology and complex shapes, but it is a more expensive and time-consuming process [7-13]. At the same time, a significant drawback of template-assisted synthesis is that the achievable length of the nanowires is inherently limited by the thickness of the template itself. This can be a major constraint for applications requiring long nanowires.

A more cost-effective approach was found to be electrospinning using an electric voltage to extrude a polymer solution from a nozzle, forming thin nanofibers [14-16].

The first arrangement of particles through the magnetic or electromagnetic process was achieved by William Gilbert as early as the 16th century. With technological advancement, this effect became automated and realized on a much smaller scale. The electrospinning process was patented by J.F. Cooley in May 1900 and February 1902, and by W.J. Morton in July 1902 [17-20].

The resulting size of a fiber from electrospinning can be at the nano scale, and the surface texture of the fibers can also be at the nano scale, leading to different interactions with other materials compared to macro-scale materials. Ultrathin fibers produced by electrospinning are expected to have two main properties: a very high surface-to-volume ratio and a relatively defect-free structure at the molecular level. These properties make materials obtained by electrospinning suitable for activities requiring a high degree of physical contact, such as providing sites for chemical reactions or capturing small particles through physical entanglement - filtration. Additionally, they allow electrospun fibers to approach the theoretical maximum strength of the spun material, opening up the possibility of producing composite materials with high mechanical performance.

There are many areas of application for the process, but we aim to combine polymers with semiconductor materials and obtain a semiconductor through electrospinning.

The project's goal is to create a device that offers a wider variety of laboratory processes, automated and at a reasonable price, thereby facilitating the research process.

Device implementation

In the electrospinning process, precise control and integration of various components are vital for successful operation. The electrospinning setup detailed in this study incorporates the following components:

Electrospinning Device Components

1. *Power Supply:* In the electrospinning setup described herein, a power supply with an output voltage of 24 V and a current rating of 10 A is used. This power supply is employed not only for general operation but also for creating a high-voltage output necessary for electrospinning processes, achieving high voltages of up to 30 kV.
2. *ZVS Driver:* Zero Voltage Switching (ZVS) driver circuitry is incorporated to facilitate efficient and controlled switching of the power supply. This technology minimizes energy losses and contributes to maintaining stable operation throughout the electrospinning process. Notably, the ZVS driver is designed to handle power levels up to 1 kW, ensuring robust performance under demanding electrospinning conditions.
3. *Flyback Transformer:* The flyback transformer plays a crucial role in transforming the input voltage from the power supply to the required high voltage suitable for electrospinning applications.
4. *Arduino Control Unit:* An Arduino microcontroller serves as the central control unit for process automation, providing functionalities such as voltage monitoring, substance dosing control, and process duration setting.
5. *2.8" ILI9341 Touchscreen Display*: Integration of a touchscreen display allows for intuitive user interaction and real-time feedback on electrospinning parameters, enhancing ease of operation and monitoring.
6. *Syringe Pump*: In order to precisely control the liquid dispersion from the needle to the collector (positive to negative electrode) by the high voltage arc, a servo motor is used which is calibrated initially.
7. *Collector (negative terminal).* The formed nanofibers are collected on the negative terminal which consist of a rotary drum made of aluminum. The collector speed is also controlled by a servo motor controlled by the Arduino unit through a L293D Motor Driver Shield.

These components are meticulously assembled and interconnected to form a comprehensive electrospinning setup, as depicted in Figure 1. For safety reason, the syringe pump and collector are encapsulated in a transparent plexiglass box. The configuration ensures precise control and monitoring of critical parameters, contributing to the reproducibility and efficiency of the electrospinning process.

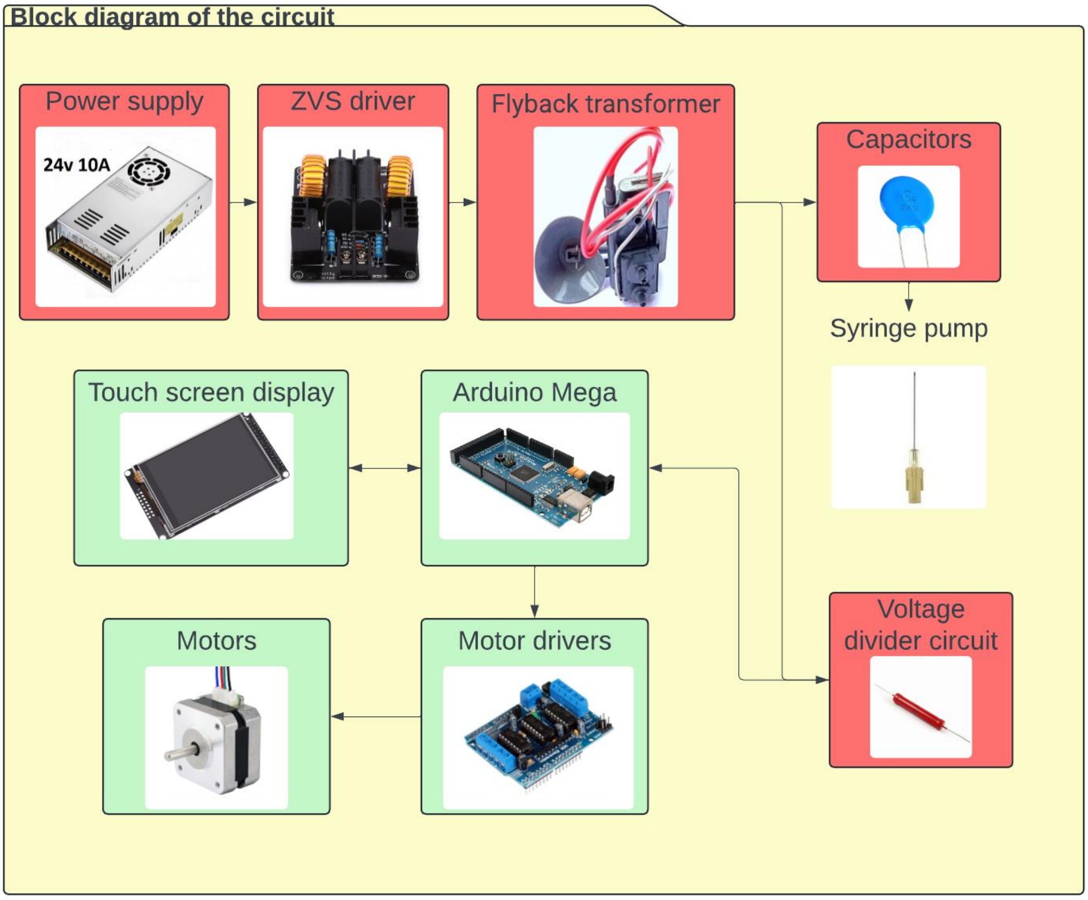

Figure 1. Schematic Diagram of the Electrospinning Device

It can be taken into consideration that, the electrospinning process is influenced by various factors, including:

- Viscosity of the substance utilized;
- Polymer concentration in the solution;
- Molecular weight of the polymer;
- Conductivity of the substance;
- Distance between the device and the collector;
- Ambient humidity;
- Working environment temperature [21].

Understanding and controlling these factors are crucial for attaining the desired outcomes in electrospinning applications.

The developed electrospinning device will represent a leading advancement in nanofiber manufacturing technology, integrating several innovative features to improve efficiency, precision and scalability. It should be noted that the device is designed with modular components, allowing easy assembly, disassembly according to specific application requirements. Monitoring and controlling the critical parameters such as voltage, flow rate, temperature and humidity will ensure precise manipulation of electrospinning conditions for optimal fiber morphology and properties. Real-time monitoring and feedback mechanisms further improve process stability and reproducibility. Greater attention must be paid to safety because it operates with high voltages. The electrospinning device will be equipped with comprehensive safety features, including voltage interlocks, emergency shutdown mechanisms and user-friendly interfaces with clear operational instructions.

Conclusions

The electrospinning process is essential in the research of nano-scale semiconductor materials from two major perspectives. Firstly, its ability to produce thin fibers at the nano level provides researchers with precise control over the morphology and dimensions of materials, facilitating the development and characterization of semiconductor materials with improved nanostructured properties. Secondly, increasing the active surface area of materials through electrospinning promotes maximum interaction between the semiconductor material and the surrounding environment, which can lead to improved performance and efficiency of nanostructured optoelectronic and photovoltaic devices.

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