Device Fabrication from Recycled Electronic Spare Parts: Dip Coating Device and High Voltage Power Supply Adapted for Electrospinning Device

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Abstract. Considering the rapidly increasing amounts of electronic waste, the task of its recycling and disposal is essential and increasingly important all over the world. Recycled components were used to create lab equipment, namely a high voltage power source, an electrospinning device, and a dip coating device. The high voltage power source was created with the purpose of powering the electrospinning device using electronic waste from microwaves, air conditioners, and cars although it can also be modified to power devices such as X-ray machines or ozone generators. On the other hand, the dip coating device was assembled using spare parts from a discarded printer. The validation of their functioning was demonstrated through the presence of sufficiently high voltages and the synthesis of polymeric nanofibers, which were found to be comparable to those produced in a BIOINICIA FLUIDNATEK LE 10. The production of homogeneous films estimated to be of nanometric proportions validated the functioning of the dip coating device. Such equipment can benefit research in locations with a lack of funds, as it is far more economic than the devices from well-established companies.

1. Introduction

Electronic waste is the group of electronic products that are no longer in use for any of multiple reasons such as being unwanted, not working or no longer being useful[1]. Their disposal is currently a large problem society is facing as 53.6 million metric tons of electronic waste were produced in 2019, and the numbers have been increasing ever since[2]. It contains toxic materials, for example, lead, arsenic, and cadmium which can create several problems in humans such as kidney damage, renal lesions, lead encephalopathy, memory deterioration, disturbances in cardiovascular and nervous systems, etc.[3]. Out of the produced amounts, only 17.4% was recycled, although there is potential to recycle far more[2]. There has been an increase in the amount of research on the recycling of e-waste, as it is now the fastest growing domestic waste stream. However, it is not enough, as around 80 million cars were disposed of in 2020[4], six million window air conditioners were disposed of in 2019[5], over 15 million microwaves were disposed of in Europe in 2005[6], and it is estimated that around 57.15 million printers are going...
to be disposed of yearly by 2025 in China alone[7]. The lack of sufficient recycling continues to affect
and worsen the e-waste situation.

The increasing amounts of electronic waste have a huge amount of untapped potential, as their
recycling can help in multiple facets of human life. Large amounts of valuable metals are contained
within this electronic debris, and only a small amount is actually extracted to be recycled. Alongside
that, many components of the discarded appliances remain undamaged and can be extracted to be reused
in other electronic instruments. Electronic instruments are very important for present day research
because they are required in all the existing technological branches. One of the relevant branches in this
project is material sciences, in which equipment to create films, membranes, etc. is required for multiple
applications.

E-waste such as that mentioned above can be utilized to build a high voltage power supply with a
multitude of applications such as X-ray machines[8], electrophoresis[9], corona poling on piezoelectric
materials[10], and ozone generators[11], however, they can also be used to create nanofibers through
electrospinning. Electrospun nanofibers can be produced in electrospinning devices and have a wide
range of applications in scientific and medical research. These fibers have been used in sensors[12],
actuators[13], cellular growth and tissue engineering[14], air filtering[15], etc. Another essential device
in material sciences, a dip coating device, with the purpose of producing polymeric films, with
applications in anticorrosion barriers[16], electrochromic devices[17], microneedles[18], etc. can also
be constructed.

The construction of high voltage power supplies, while dangerous if managed incorrectly, is a
simple yet useful process that can teach people from a variety of ages several electronic concepts. It
can teach the basics of the workings and purposes of components such as capacitors, diodes, and
transistors. Other concepts covered are multiplier/rectifier circuits, conversion between alternate and
direct currents, etc. Each one of these devices contains basic components, and this creates restrictions,
restrictions that once surpassed help the designer and creator develop mechanical and electrical intuition.
The devices themselves, on the other hand, due to the ease of construction and low production cost, have
the potential to be used in practical teachings of the creation of certain types of filters, nanofiber
production, material processing, thin-film formations, etc.

In this project, the successful fabrication of a high voltage power supply and its application in an
electrospinning device has been demonstrated, utilizing recycled materials from cars, air conditioners,
and microwaves. In addition, a dip coating device has been constructed using a damaged old printer
and a step-up motor. Both devices were constructed at prices far inferior to company manufactured
devices as they are made from electronic waste. This can be especially helpful in developing countries
due to the lower economic demands of the construction of these devices.

2. **Inner Workings**

2.1. **Electrospinning device**

An electrospinning device is made with the purpose of creating a layer of nanofibers. The device is
based on a high voltage power source which charges the polymer, breaking its surface tension and
allowing it to form a Taylor cone (Figure 1a) reducing the diameter of the expelled fluid, making it reach
nanometric dimensions [19]. The fibers are then attracted to the oppositely charged surface, attaching
itself to said surface and then drying[19]. This forms a layer of nanofibers on the surface.

2.2. **Dip coating device**

This device works by lowering the substrate into the solution. This could be done manually but would
result in a non-homogeneous film. The homogeneity of the film depends mainly on the precise control
over the immersion and extraction time of the substrate. The extraction of the substrate from the solution
causes a layer formation which (in some cases) can be increased by increasing the number of times it is
immersed and extracted from the solution. The substrate takes a shape as shown in figure 1b, forming a
thin layer on the substrate[20]. The excess solution drains out, followed by drying (under the required conditions), leaving a thin layer of the polymer on the substrate[20].

![Figure 1](image1.png)

**Figure 1.** (a): Taylor cone produced by the polymer at the tip of the needle (b): layer of polymer formed on the substrate after being pulled out of the solution.

3. **Methodology**

3.1. **Materials**

A 12V ignition coil from a car, a 17µF 250V capacitor from an air conditioner, a variac dimmer switch, 40 1nF 20kV polyester capacitors and 8 RG711 high voltage diodes from microwaves. If necessary, to increase aesthetics, reduce size, and make it easier to use, one can use switches, a fuse and a box. For the production of the samples, a syringe, a copper plate and a stand made of non-conductive materials were utilized.

A stabilizer bar, belt, and print head assembly from a printer, a MEGA 2560 Arduino programmed in Arduino ID using the LabView interface, a ULN2003A breakout board, a 5VDC step motor, a clamp that can be adjusted to the printer head assembly and an aluminum stand were used to create the dip coating device.

3.2. **Construction**

The electrospinning device is powered by a high voltage power source that provides between 15 and 30kV to be effective. The device can be divided into four portions: the control circuit, the step-up transformer, the voltage multiplier (that also acts as a rectifier), all of which are parts of the high voltage power source. The final part of the device is composed of the needle and collector.

Two possible circuits were considered to be viable. The first one needs a 12VDC input and works using a flyback circuit[21] based on a NE555 integrated circuit and the ignition coil (figure 2a) while maintaining the voltage multiplier (figure 2b) to obtain the required 20kV. This circuit was discarded due to the necessity of an additional heat dispersion system for the power transistor, causing the equipment to be more complex and less durable.

![Figure 2](image2.png)

**Figure 2.** (a): Flyback circuit based on a NE555 integrated circuit (Thick-line rectangular section) (b): voltage multiplier (Thin-line rectangular section)
The second one, which is shown in figure 3 and is the one utilized, works by taking electricity from the power grid (which in this case works at 120V 60Hz). It is connected to a dimmer switch (figure 3a) that in turn is connected to the ignition coil (figure 3b) [22]. The ignition coil works using short voltage pulses. In the demonstrated circuit, the dimmer acts as a switch that cuts the 60Hz synodal signal in a certain part of the wave. Due to this, it delivers higher or lower voltages to the 17uF capacitor which then discharges into the primary winding of the ignition coil 60 times per second. Due to this, we can control the output voltages. The output of the circuit until this point (including the 17 µF capacitor) is still a pulse wave. This output is then directed to the voltage multiplier (figure 3c), where the voltage is amplified to up to 20kV and converted into direct current.

The voltage multiplier is composed of 4 sets of 10 1nF capacitors each, connected with each other to make each set have a capacitance of 2.5nF. The sets are then connected to form the whole part, as shown in figures 2c and 3b.

Figure 3. (a): Circuit of a dimmer switch (thick black rectangular section) (b): ignition coil (thin grey rectangular section) (c): voltage multiplier (thin black rectangular section) (d) Constructed high voltage power source

Once the high voltage power supply is created it is connected to a needle and a conductive copper plate. The needle is placed vertically on a Teflon stand that allows it to vary the height while not disrupting the process thanks to its lack of conductivity. On the other hand, an aluminum foil covering is placed on the copper plate, which is then placed horizontally under the needle to act as the collector as shown in figure 4a.

Figure 4. (a): Schematic external setup of the electrospinning device (b): physical setup of the electrospinning device
For the construction of the dip coating device, the printer is disassembled and the relevant parts are extracted. The step motor is adjusted so as to have the belt around the gear attached to said motor. A hole is drilled into the printer head assembly and a clamp is placed into the hole. The setup is then attached to the aluminum base (figure 5a). The step motor is connected to the Arduino which is programmed as shown in figure 6. The mechanism works due to the fact that the step motor, which is attached to the belt through the gear, rotates in the direction commanded by the LabView interface. It then rotates the belt which causes the printer head assembly to move up or down depending on the direction of rotation of the motor. The substrate is now ready to be attached to the clamp and submerged in a polymer to form a thin film.

**Figure 5.** (a): schematic of the setup of the dip coating device (b): physical setup of the dip coating device

**Figure 6.** (a): Circuit and connections between the Arduino, the breakout board and the step motor (b): Flow diagram and interface of the LabView program
4. Results Obtained Upon Validation of Device Functioning

The high voltage power source was tested for 90 minutes at 20kV, successfully verifying its functionality as it maintained the voltage for the full period of time.

After the fabrication of the device, the functioning of the electrospinning device was validated by verifying the formation of the expected nanometric thickness of the fibrous film different polymers at two different distances. The formed samples were viewed under a Scanning Electron Microscope (SEM). Similarly, the functioning of the dip coating device was validated by monitoring the uniform thickness of the layer formed on the substrate (scanning the cross section of the sample through SEM).

The tests were done with typical Polyvinyl alcohol (PVA) at a 20% weight percentage in a water ethanol solution of a 70/30 proportion respectively (it was also tested with a PVDF-Ag polymer, though the results are not shown). Two samples were made with the solution, with the needle at a 10cm distance from the receptor, and with the needle at a 15cm distance from the receptor. Then, the PVA solution was used in a BIOINICIA FLUIDNATEK LE 10 electrospinning device. The results are shown in figure 7.

![Figure 7](image-url)

**Figure 7.** Surface of the film seen through Scanning electron microscope (a) PVA at 10cm with a 10k magnification in constructed device (b): PVA at 15cm with a 10k magnification in constructed device (c): PVA at 10cm with a 10k magnification in manufactured device (d): PVA at 15cm with a 10k magnification in manufactured device.

The diameter distribution of the nanofibers (Figure 8) was quantitatively analyzed by using a plugin of ImageJ software called DiameterJ[23]. The PVA based fibrous membrane obtained using the proposed electrospinning device reveals that the fibers produced indeed have nanometric diameters (Figure 8). Furthermore, when compared with the fibers produced in the manufactured devices, the range of diameters in the fabricated electrospinning device is smaller than the range in the manufactured device.
Similarly, the functioning of the dip coating device was validated by monitoring the thickness of the layer formed on the substrate (scanning the cross section of the sample through SEM), and verifying its uniformity. These samples were fabricated with the PVA solution at 5 and 20 wt% in a water ethanol solution of a 70/30 proportion respectively. The results of the 20 wt% are shown in figure 9. The layer formed was around 2 µm thick, and relatively uniform along its length.

Films made with the 5 wt% PVA solution were too thin to locate and analyze with SEM. It is estimated that the films produced with this sample were of nanometric proportions.

5. Discussion
As the objective of the work was to create an economically viable electrospinning device with recycled spare parts, multiple easily accessible high voltage power sources present in different discarded devices were considered for the creation of the project. Some of the considered sources were the ones present in cathode ray monitors and stun guns. The flyback transformers from cathode ray monitors were discarded due to their reduced availability due to technological advancements, despite it being easier to construct. The stun gun, while more space efficient, is designed to only be turned on for a few seconds and was thus rapidly heated, reducing the voltage and preventing it from lasting a practical amount of time.

The first attempts for the creation of the device with an ignition coil were supposed to have an alternate current output. However, after the initial success in obtaining a high voltage, the results were constantly non-reproducible, producing voltages considerably smaller than the one required, alluding to the possibility of an error in the first measurement. The cause of the variability of the results is yet to be verified. The final product is in fact a modified version of the first ignition coil experiment. However, instead of the alternate current, and low voltage, it was decided to compromise space to create a higher voltage direct current power source.
It is of great importance to properly isolate all the necessary components to get the required voltage as the formation of sparks can cause a loss of current and possible short-circuits to the extent of causing damage to the equipment. Considering the functioning of the electrospinning device, it is of great importance to find a way to correctly ground the collector, alongside the verification of the lack of metallic objects in the surroundings, with the hope of avoiding the deviation of the nanofibers. The high voltage power source can be used in other projects where voltages near 20kV are required. Additionally, it is possible to reach higher voltages by adding more stages to the voltage multiplier. However, it would be far more challenging to isolate the components if that is done.

The dip coating device used a two and a half coil step motor, causing the movement to be relatively slow. This can cause the minimum thickness to be slightly larger as there is a relationship between the thickness of the film, the time the substrate is submerged, and the velocity with which it is extracted. However, this extra thickness is almost negligible considering the results produced by the 5 wt% solution. Another thing to be noted is that if the weight of the clamp is too great, the belt might slip, causing the movement of the sample to be irregular, thus creating undesired irregularities on the film. The best solution for this would be to minimize the weight of the clamp. However, if the problem persists, other viable solutions are adjusting the size of the gear and greasing the stabilizer bar.

The interface utilized for the programming of the dip coating device has two methods of operation in this case. By position or by manual operation. The position in which the substrate is submerged can be calculated, allowing the process to be mostly autonomous. On the other hand, for more irregular cases, the movement of the sample can be adjusted by the person, submerging and extracting the substrate when deemed necessary.

6. Conclusion
Electronic waste, as an increasingly disturbing dilemma on the worldwide scale, has been harnessed and utilized as a tool for the creation of two devices and a high voltage power source. The devices were fabricated using spare parts from multiple previously discarded devices. An ignition coil, an air conditioner capacitor, and diodes from microwaves were used to construct a high voltage power source that was later adapted to an electrospinning device. A dip coating device was made using parts from a printer and a stepper motor that was controlled by an Arduino. Both devices were validated successfully as they produced the desired results. These devices can be extremely helpful in labs with few funds as their costs are around 1% of the cost of company manufactured devices. Another benefit of these devices is the fact that they use recycled materials, helping with the aforementioned e-waste dilemma.

Acknowledgments
S S Kumar Agarwal acknowledges the useful discussions with Dr. Jose Escorcia Garcia (Cinvestav), and the facilities provided by the Center for Research in Engineering and Applied Sciences in the Autonomous State University of Morelos (CIICAp- UAEM), for hosting the summer research facility. We additionally acknowledge the availability of the BIOINICIA FLUIDNATEK LE 10 from Dra. Maura and Dr. Mohan from ICF- UNAM.

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