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Construction of Economical Dip-Coater for the Fabrication of Hydrophobic Coatings

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Abstract

D.C. motors are considered the basic components for the construction and development of various nanotechnology research equipment due to their constant speed and high efficiency. Spin coater, dip-coater, and spray pyrolysis were a few among them which utilize the above-mentioned component for the production of thin-film coatings on the desired substrates. Conventional spin coater, dip-coater, and spray pyrolysis are expensive to install in research laboratories. In this letter, we report the economical construction of an Arduino-based dip-coater that uses a linear actuator consisting of a D.C. motor for the production of hydrophobic coatings. The dip and drawl rate of the as-constructed machine was estimated to be 3mm/sec and can be varied according to the requirement without any interferences of vibration. Further, the dip-coater was tested with TiO_2 gel for the production of hydrophobic coatings on cotton fabrics. The coated fabrics were characterized using an X-ray diffractometer (XRD), which confirmed the presence of TiO_2, and reflectance analysis using ultraviolet-visible and near-infrared spectroscopy (UV-VIS-NIR) on the coated fabric revealed an increase in the visible and IR range and a decrease on the ultraviolet spectral region. The goniometer investigation with a water droplet on the treated fabric revealed 137^{O} contact angle and the coating is proved as a super hydrophobic coating.

Keywords: Cotton fabric; dip-coater; hydrophobic coatings; UV-VIS-NIR; WCA; XRD.

1. Introduction

Electrical machines are practically essential for the development of novel applications in every field of science and engineering (Agamloh *et al.,* 2020). The low-cost manufacture of these machines, on the other hand, is usually revolutionary. Traditional manufacturers and suppliers impose exorbitant production expenses for the procurement of equipment that works on the same concept. For example, nanotechnology research equipments like spin coaters, dip coaters and spray pyrolysis use a simple D.C. motor, stepper motor, and other electric components for the fabrication of thin films which costs around 3000 to 4000 USD. But this equipment can be constructed with a minimal cost of around 89 USD without disturbing the working principle and operation.

Dip-coater is the equipment for the fabrication of uniform thin films or coatings on the desired substrate which has applications in the areas of photonics, optoelectronics, electronics, etc., it uses a simple gel synthesized by the sol-gel process and can fabricate thin films of varying thickness by simply controlling the dip and with drawl rate (Puetz *et al.,* 2004). Traditional manufacturers use sophisticated lab equipments to produce these machines, however, this type of machine may be built in a basic home environment and made more precise and flexible by using Arduino technology. David *et al*. (2022) designed and fabricated a dip-coater for the rapid production of thin films using a stepper motor. The maximum dip rate of the machine was maintained at about 6mm/sec and tested its performance by depositing copper oxide and iron oxide films on the fluorine-doped tin oxide substrate. Despite its inexpensive construction, the machine has a disadvantage in the higher temperature operation due to its wooden body construction. Yohandri *et al.* (2019) created a microcontroller-based dip-coater with a stepper motor for TiO_2 thin film fabrication. The dip-rate and with-drawl rate were regulated via a keyboard with values ranging from 0.02 mm/s to 10 mm/s, and the machine performance was tested by fabricating TiO_2 thin films, yielding 96.57% accuracy when compared to the standard instrument. Luis *et al.* (2016) developed an open-source dip-coater using mechanical and electronic systems and programmed it with an Arduino microcontroller. The dip-rate and with-drawl speed of the as-developed machine were maintained between 0.6 cm/min to 30cm/min and suggested for large substrates. Furthermore, trials with the machine demonstrated that it can be used to deposit thin films with greater accuracy, which was not possible with conventional machines, and that it is also a more cost-effective construction when compared to regular instruments.

The cost-effective fabrication of hydrophobic coatings is in high demand these days. Ordinary fabrics can be transformed into hydrophobic fabrics by applying a simple TiO_2 coating that repels water molecules on the surface while simultaneously acting as an oil-water separation coating (Tudu *et al.,* 2016). Glass furniture can also be made maintenance-free without affecting their optical transmittance by applying a thin TiO_2 layer to the surface (Shahzadi *et al.,* 2021, Li *et al*., 2021) increased the circuit board's water-proofing and mildew resistance by covering it with a SiO_2 and ZnO composite thin layer. The contact angle of the as-developed coating was calculated to be around 169.47^{O}, and it also demonstrated alkali corrosion resistance. Sutha *et al*. (2017) created superhydrophobic coatings on glass substrates for solar panel cover glasses using aluminum oxide [9]. When examined with water molecules, the coating's thickness was estimated to be around 300 nm and it displayed a 161^{O} contact angle. Furthermore, the optical investigations of the coating confirmed that there were no transmission losses and that the created hydrophobic coating restored 91 % efficiency. Maharjan *et al.* (2020) developed and evaluated a TiO_2-based solar reflective hydrophobic coating for heat reduction in buildings. When tested using a photothermal measurement setup, the coating's application inside the cement mortar composite resulted in a 4°C temperature differential, which can be attributed to light scattering caused by the TiO_2 nanoparticles. Furthermore, a water repellent test on the coating demonstrated a water repellent efficacy of 98.5 %, indicating that it can be used as a solar reflective coating.

This paper focuses on the development of an affordable dip-coater for the fabrication of hydrophobic coatings on cotton fabrics. In this article, the construction of new dip-coater and the method of developing hydrophobic TiO_2 coating are explained. Finally, the experimental results of the fabricated coatings are explained and discussed.

2. Methods and materials

The procedures for building a dip-coater are shown in the construction, along with its block diagram and a digital photograph of the developed dip-coater. The materials and dip-coating of cotton fabric are explained in the sol-gel synthesis and fabrication sections.

2.1. Construction

Figure 1 (a) and (b) depict the block diagram and digital image of the proposed dip-coater. The dip coater construction comprises simple electronic components like a linear actuator, Arduino board, driver board, switched-mode power supply (SMPS), exhaust fan, switches, and a timer module system, which are connected as shown in figure 1 (a).

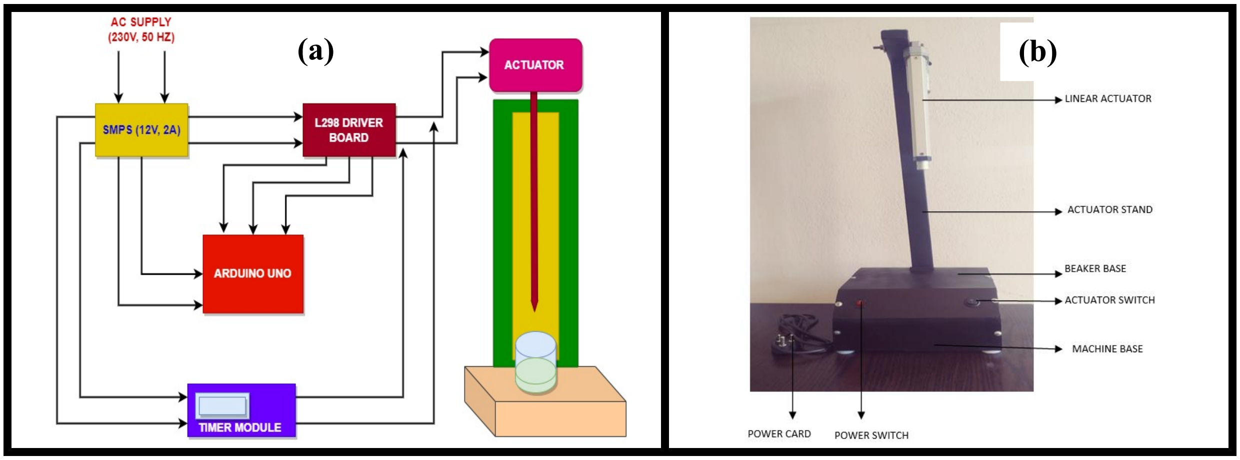

Fig. 1. Block diagram of the proposed dip-coater (a) and a digital image of the constructed dip-coater (b).

A linear actuator with a 106 D.C. motor was chosen for dipping and with a drawl that was paired with 1mm lead because of its high torque delivery and enhanced efficiency. The operation of the dip-coater system was entered by the keypad in the form of dip, drawl rate, and time, which was translated by a microcontroller in the form of delay, which was used to determine the motor rotation speed. The circuit featured a timer delay module setup and a drive controller board to regulate the event time and D.C. motor speed control, respectively. A 12V D.C. switched SMPS was utilized to convert the power utilizing the switching device and for venting the surplus temperature, a simple C.P.U fan was employed to the coater. Limit switches and power switches were connected finally for the movement of the motor and to provide conducting path to the machine respectively.

2.2 Sol-gel synthesis and fabrication

To synthesize TiO_2 gel, 20 ml of solvent ethanol (Changshu Hongsheng Fine Chemicals) was added in a properly cleaned beaker and 1 ml of chelating agent acetic acid (Sisco Research

Laboratories) was added on continuous magnetic stirring. To complete the synthesis process, 1 ml of precursor titanium isopropoxide (TTIP, Sigma-Aldrich) was added to the mixture, with a drop-by-drop gap of 1 minute, and allowed for stirring for one hour to derive a thick translucent gel. All the chemicals purchased are of analytical grade and require no further purification. Figure 2 shows the schematic of the sol-gel and dip-coating process on the cotton fabrics. Cotton materials were obtained from a nearby textile store and extensively washed with detergent, ethanol, and distilled water before drying at room temperature for 24 hours. The dried fabric was dipped in the synthesized gel, at a dip and drawl rate of 3mm/sec and dried at room temperature for 2 hours. The final dried cloth was tested by sprinkling water droplets on its surface.

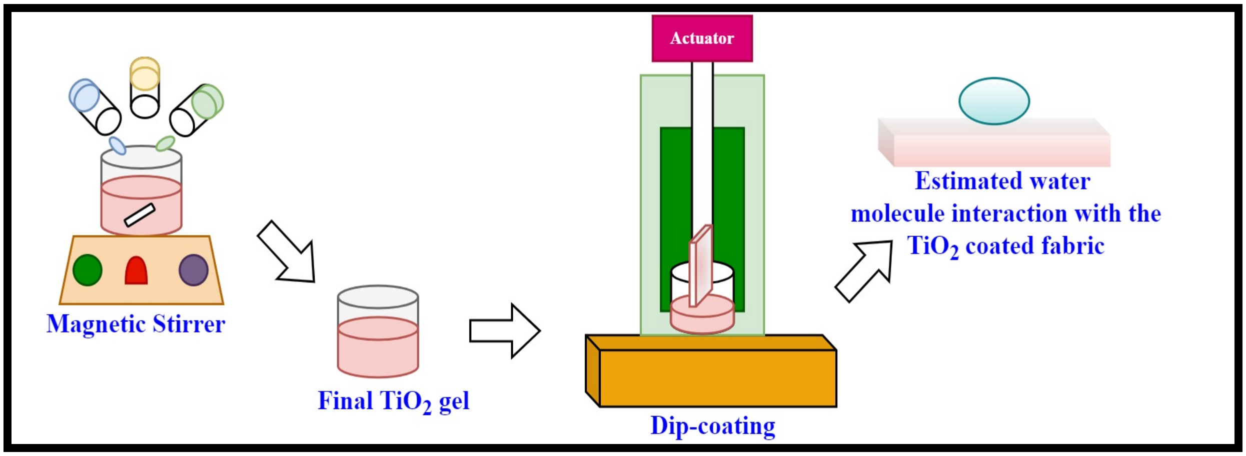

Fig. 2. Schematic of sol-gel synthesis and dip-coating of TiO_2 on cotton fabric.

3. Results and Discussions

Figure 3 depicts the X-ray diffraction pattern of the cotton fabric dip-coated with the synthesized TiO_2 gel.

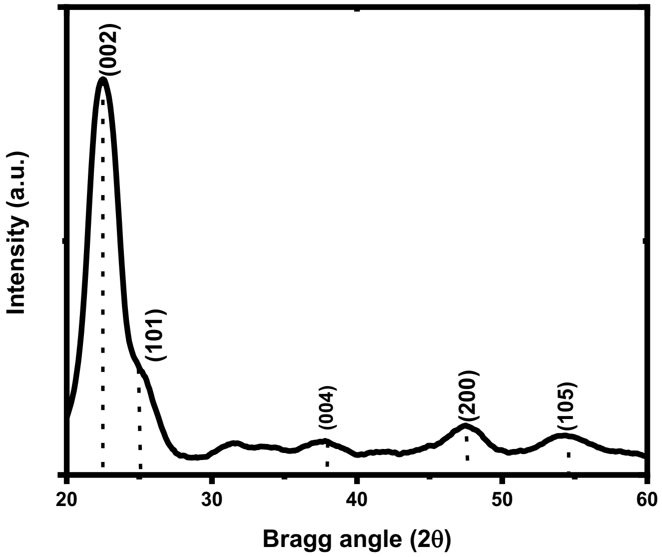

Fig. 3. XRD spectra of TiO_2 dip-coated cotton fabric

To observe the crystalline surface of the dip-coated cotton fabric, an X-ray diffractogram pattern was recorded between 20^{O} to $60^{\ O}$ Bragg angle. The obtained XRD pattern of the cotton fabric coated with TiO_2 is given in figure 3. Because thoroughly cleaned fresh cotton contains polymeric cellulose chains that are arranged in a specific crystalline phase, this cellulose-based crystalline structure produces a sharp diffraction peak in the XRD spectra that appears at 22.4^{O} and can be indexed to the (002) plane, as shown in figure 3, which is consistent with the work of Zhao *et al.* (2020).

Four more diffraction peaks appeared in the XRD pattern at Bragg angles of 25^{O}, 37.8^{O}, 48^{O}, and 55^{O} after coating the cotton fabrics with TiO_2. These four peaks represent the anatase phase of TiO_2 present on the fabric surface with their planes indexed at (101), (004), (200), and (105) respectively. Figure 3 further shows that there are no rutile diffraction peaks, and the observed result was in good agreement with the reported results by Zhang *et al.,* (2019) and Chen *et al.,* (2016).

Figure 4 (a) and (b) show the reflectance and water contact angle analysis on the dip-coated TiO_2 fabric using UV-VIS-NIR spectroscopy and goniometer. The cotton fabric treated with TiO_2 demonstrated increased reflectance in the visible region (400-700 nm) and reaches the maximum values in the near-infrared region and continues its values throughout the spectrum compared to uncoated cotton fabric, as illustrated in figure 4. (a). Figure 4 (a) also demonstrates the decrease in reflectivity in the UV region as a result of coating with TiO_2, suggesting that TiO_2 is a good absorber of ultraviolet wavelength. This property endorses TiO_2-treated fabrics are the perfect choice for protecting against ultraviolet radiation. The NIR reflectance of TiO_2-treated fabrics exhibits contrast behaviour. As shown in figure 4(a), the NIR reflectance of the fabric improves as a result of TiO_2 coating, making it a good choice for heat-reflecting fabrics and also consistent with the work described by Piri *et al.* (2018).

Water droplet behavior was studied on the TiO_2-treated cotton fabric by impacting a water droplet on the coated surface placed on the solid surface. Figure 4(b) depicts the water droplet impact on the TiO_2-treated fabric, with its digital picture as its inset. After modification, TiO_2-treated cotton fabric resulted in extreme water repellent nature with a water static contact angle of 137^{O} and supports the research conducted by Wu *et al.* (2021). Both studies discovered that a single layer of TiO_2-treated fabric has excellent reflectivity in the near-infrared region and absorbs ultraviolet radiation, implying that the fabric is suitable for heat repelling materials and UV radiation shields. hydrophobic properties. Further, the water contact angle investigation on the TiO_2-treated fabric suggested it was a superhydrophobic coating.

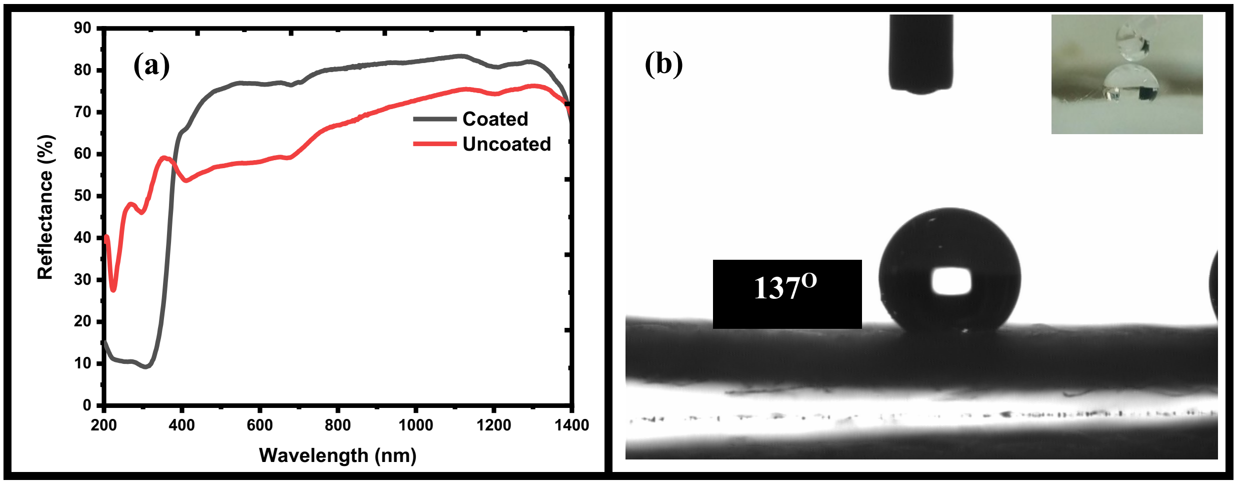

Fig.4. Reflectance spectra (a) and water contact angle analysis on the TiO_2 dip-coated cotton fabric (b).

Figures 5 (a) and (b) show the response of coated and untreated fabric to a gas lighter igniting. When the uncoated fabric was ignited, it took fire in 2 seconds as shown in figure 5(a), and produced excessive smoke shortly after being blown off, whereas the coated fabric did not catch fire for 13 seconds as shown in figure 5(b), and produced no smoke when blown off. This investigation on TiO_2-treated fabric revealed that the fabric could be used for flame-retardant purposes and also supports the work reported by Pakdel *et al*. (2020).

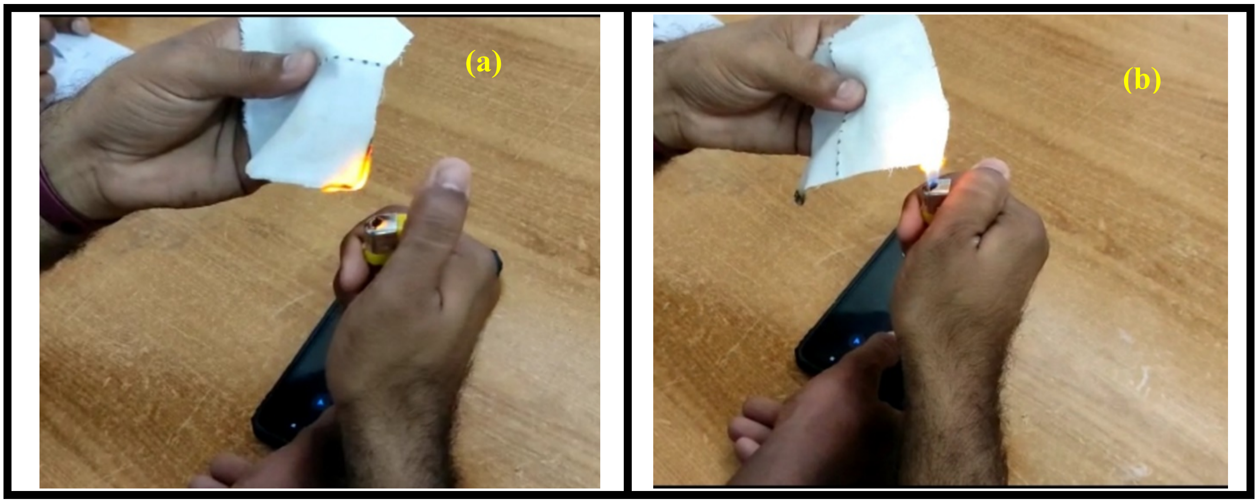

Fig.5. Flame test on the uncoated coated (a) and TiO_2 dip-coated cotton fabric (b).

4. Conclusions

The inexpensive dip-coater was built utilizing simple electronic components such as a linear actuator, an Arduino board, a driver board, a switched-mode power supply (SMPS), and an exhaust fan with a dip and drawl rate of 3mm/sec. After construction, the dip-coater was tested by dipping a cotton fabric in the sol-gel-generated TiO_2 gel. Furthermore, the presence of TiO_2 was confirmed by XRD on the treated cloth, with no rutile or anatase phases present. The reflectance investigation using UV-VIS-NIR spectroscopy revealed a small increase in the visible region and IR regions, which is a promising factor for the creation of heat-reflecting fabrics. The water contact analysis on the TiO_2-treated cotton fabric confirmed the 137^{O} contact angle and demonstrated the coating's capability as a superhydrophobic coating. A flame retardant test was also done on the treated fabric, which revealed an 11-second stand rate upon igniting.

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