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CONSTRUCTION OF COST EFFECTIVE HOMEBUILT SPIN COATER FOR COATING AMYLOSE-AMYLOPECTIN THIN FILMS

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ABSTRACT

We report the construction of a cost effective and low power consumption spin coater from a direct current (DC) brushless motor. The DC mechanical component is widely available in the central processing unit (CPU) cooler. This set up permits simple operation where the DC voltage can be controlled manually in order to adjust the spin speed ranging from 1500 to 4500 resolution per minute (rpm). The spin speed stability can be determined by a tachometer against the spinning time. In order to evaluate the performance of the spin coater, 25% Amylose-75% Amylopectin thin films were successfully deposited on SiO_2 substrates. The thicknesses of the films were in the range of 96.1 nm to 225 nm.

Keywords: spin coating; CPU cooler; thin film depositions; homebuilt spin coater.

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1. INTRODUCTION

Spin coating has been widely used as a deposition technique to obtain uniform films on various types of substrates such as single crystal, glass, polymer substrates and wafer. A variety of films made of semiconductors [1-2], magnetic [3-5] and phosphorous [6] materials have been fabricated successfully by using this approach. The deposition technique has gained much attention in the micro- and nanofabrication of novel nanodevices, optoelectronics, biomedical sensors, etc. [7-9]. It involves applying a small drop of fluid material on the center of a substrate and spinning the substrate at high speed. The fluid material consists of desired material dispersed in a solvent. During the coating process, centripetal acceleration due to spinning causes the fluid to spread off the edge of the substrate and thus forming a thin layer of the material. In spite of simplicity for sample fabrication, spin coating offers advantages such as uniform film's thickness, low material consumption, rapid and high yield [10].

To date, some efforts have been devoted to the construction of spin coaters, particular with a few innovations of using touch screen interface, Arduino based control unit [11], arm processor [12], DC motor of hard drives [10] etc. Herein, we present a fairly simple construction of homebuilt spin coater based on brushless DC motor of CPU cooler. This set up is different from the reported spin coater constructed using CPU cooler [13] as we modified the DC input of CPU cooler. Our set up offers the ability to tune the spin speed and time by adjusting the applied DC voltage from 3V to 12 V. We managed to boost the spin speed up to 4500 rpm which is twice the value to that of the reported spin coater constructed using CPU cooler (2400 rpm).

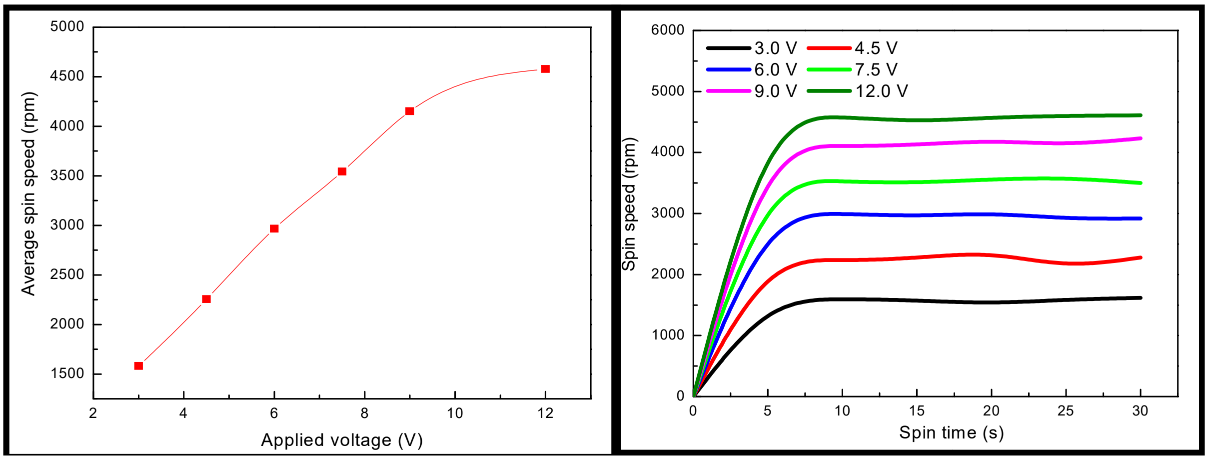
In order to evaluate the performance of the spin coater, we demonstrate the deposition of 25% Amylose-75% Amylopectin thin films on SiO_2 substrates. In addition, the influence of experimental parameters on the flatness, uniformity and thickness of the films were investigated. These parameters are spin speed, spin time and the nature of fluid material. For the nature of fluid material, the experimental parameters involved are viscosities, concentration, drying rate and surface tension, etc. [14-15].

2. RESULTS AND DISCUSSION

The constructed spin coater was able to spin the substrate steadily from static to 4500 rpm by varying the applied DC voltages. For the brushless motor, the armature winding with permanent magnets gives high efficiency as it can produce a large torque over a vast speed range. Fig. 1(a) depicts the average voltage dependence of spin speed of the spin coater. The spin speed is directly proportional to the DC voltage up to 10.0 V. However, the spin speed reached a maximum 4500 rpm at 12.0 V which is attributed to the dissipation of heat and marginal loss of magnetic field of the permanent magnet [16].

Fig. 1(b) shows the spin speed stability versus spinning time for various DC voltages. It is clear that the spin speed is stable up to 30 s as tuned by 3.0 V, 4.5 V, 6.0 V, 7.5 V, 9.0 V and 12.0 V respectively. For each of the applied voltage, a stable spin speed was attained after about 8.0 s. The spin speed affects the degree of centrifugal or centripetal forces applied to the solution. During the spinning process, air turbulence above the coating is formed immediately causing the fluid material to dry. Likewise, acceleration plays an equally crucial role in the spin coating process. The spin acceleration can be calculated from the initial and final (stable) spin speed. The spin coater accelerates from 316.2 rpm/s towards its maximum value of 915.5 rpm/s within 5.0 s. These values are lower than that of the spin coater constructed using hard disk brushless DC motor. We also found that the conformity and uniformity of the Amylose-Amylopectin films did not improve for acceleration above 316.2 rpm/s (1600 rpm).

This phenomenon is different from the semiconducting films which require high acceleration coating (> 3000 rpm) to obtain uniformity [17]. In fact, the conformity and uniformity of thin film is not solely dependent on the spin acceleration. Other factors such as viscosity and drying rate of the fluid materials also have a great influence on the quality of films. The drying rate of our films is considerably lower than most of the spin coated films where the desired material is dispersed in volatile organic solvents (toluene, ethanol etc).



(a) (b)

Fig.1. (a) Spin speeds versus input DC voltages and (b) spin speeds versus spin time for the homebuilt spin coater

Fig. 2(a)-(f) show the surface morphology and thicknesses of the Amylose-Amylopectin films. The spin speeds of coating were varied from 1600 rpm to 4500 rpm. The spin durations were set to 5 s and 10 s whereas the viscosity of solution was fixed at 471.2 cP. It was found that the thicknesses of the Amylose-Amylopectin films were gradually decreased from 96.1 nm to 37.2 nm and 131.1 nm to 64.6 nm for the films coated for 5 s and 10 s respectively. None of the films is uniform and conformal except the one coated at the lowest spin speed and shortest spin time (1600 rpm for 5 s). The swirling effect is observable in these films. Such effect occurs when the centripetal forces exerts a twisting motion on the fluid and shear the fluid unevenly [18].

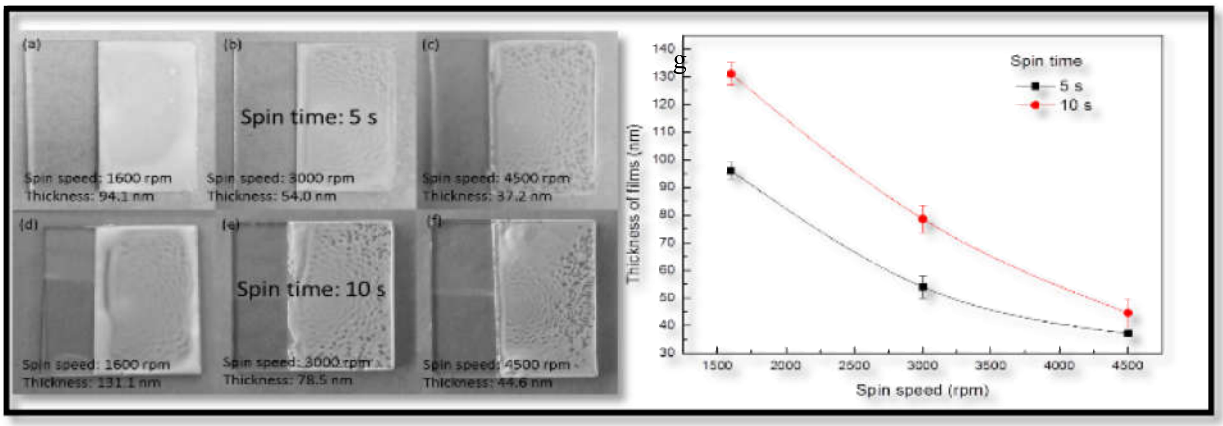


Fig.2. (a)-(f) The surface morphology of the Amylose-Amylopectin films and (g) variation of film's thickness versus spin speeds with a constant viscosity of 471.2 cP and varying spin speeds, thicknesses as well as spin times

Moreover, the increasing spin duration tends to spread off more fluid outside the edge of the substrate. We proved that higher spin speed and longer spin time are essential to obtain thinner films. As shown in Fig. 2(g), the thicknesses of the films scale inversely proportional to the spin speed squared and in good agreement with the expression:

Thickness, $t \propto 1/\sqrt{\omega}$ (1)

where t is thickness and ω is angular velocity [19].

Lately, a similar dependency of film's thickness on the spin speed was reported in ZnO films [20]. The thickness of a film is actually a balance between the centripetal force, which shears and spread off the fluid towards the edge of substrate and drying rate. According to [12], the drying process also has an incredible impact on the flow of solution on the substrate. Fig. 3 shows the film deposited using the Amylose-Amylopectin solution of 553.9 cP. The rate of evaporation is higher for the high viscosity fluid. As a result, the flow of the solution is slower leading to conformity where the spin speeds and spin time were controlled at 1600 rpm and 5 s respectively.

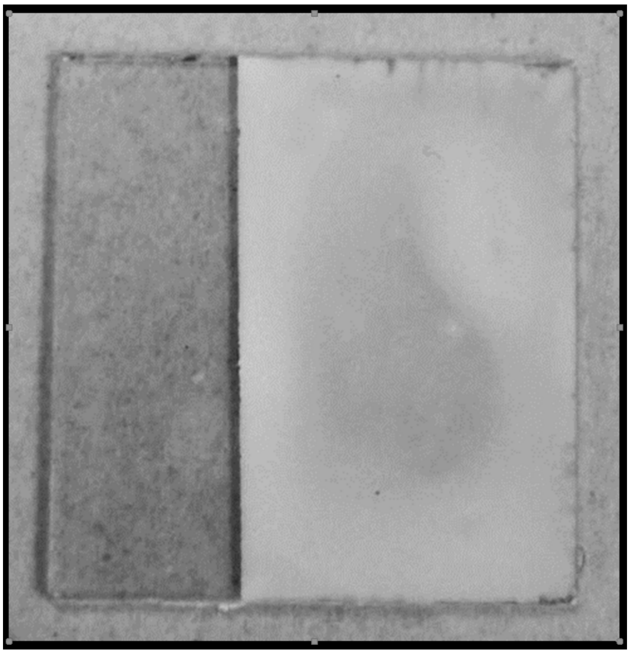


Fig.3. Surface morphology of spin coated Amylose-Amylopectin film with viscosity = 553.9 cP, Spin time = 5 s, Spin speed = 1600 rpm and Thickness = 225.8 nm

The components of the entire part of the homebuilt spin coater are easily available and inexpensive. This spin coater can be assembled with a total cost of less than RM 250 as compared to commercial spin coater with the cost of at least RM 5000 and above, though they are often equipped with additional specifications and automation features. We believe that our set up is versatile, easy to replicate and cost effective.

3. EXPERIMENTAL

TA spin coater prototype was constructed from a commercially available CPU cooler and contained in a 10 cm × 10 cm × 12 cm box made of Polymethyl Methacrylate (PMMA) as shown in Fig. 4. The DC adapter was modified to cater for various voltages ranging from 3.0 V to 12.0 V. The 3 cm × 3 cm SiO_2 substrate was fixed on the flat top of the rotating fan. 10 g - 120 g of 25% Amylose-75% Amylopectin (corn starch) powders were mixed with 100 ml distilled water in order to prepare solutions with varying concentration. The viscosity of the solution was measured by a rotational viscometer (Brookfiled DVIII) equipped with SP-18 spindle. The puddles of the Amylose-Amylopectin solution were dropped on the substrate and then the spin speed was increased gradually. The rpm was determined by a digital laser photo tachometer (Allwin DT2236B). The final thicknesses of the films were measured by a stylus profilometer (AMBIOS XP-200).

Fig.4. A homebuilt spin coater contained in PMMA box with a modified DC adapter

4. CONCLUSION

We have constructed a homebuilt spin coater via DC brushless motor of CPU cooler. Our spin coater is equipped with a wide range of speed (1600 rpm to 4500 rpm) and has high spin stability. The spin coater was used to fabricate the Amylose-Amylopectin thin films successfully. These films were deposited on the SiO_2 substrate in varying spin speed and time using the Amylose-Amylopectin solution with different viscosities. In turn, these experimental conditions influence the flow of solution and drying rate which ultimately control the conformity and uniformity of the films. The main benefits of this equipment are cost effective, easy to replicate and user-friendly.

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