CHAPTER IE

DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER
EASED SPIN COATING UNIT

2.1. Introduction

Several techniques are available for the preparation of thin films. The deposition techniques, which have been utilized for thin film solar cell fabrication, include Vacuum Evaporation, Electrodeposition, Sputtering, and Spray pyrolysis, Chemical Vapour Deposition Chemical Bath Deposition, Ion Exchange Reaction and Spin Coating Deposition. Among the various techniques, the spin coating is one of the simplest techniques. There is an increasing interest in the sol-gel synthesis of the TCO thin films /1-10/, due to the following advantages increased capability to tailor complex compositions, simple and cheap technological equipments, low thermal budget for film consolidation and specific controlled porosity properties and ease of doping. In the present work the sol-gel route is used for spin coating of thin films. For this a precision spin coating unit is necessary. The development and fabrication of such a spin coating unit and its operation are presented in the following sections.
**2c2o Principle Of Spin Coating Techniques**

The technique makes use of centrifugal force for the film coating/11-13/. A few drops of a liquid/solution containing the material to be coated as the solute are dropped at the centre of a substrate; when the substrate is spun/rotated at a high speed, the centrifugal force on the drops, drives the liquid/solution outwards radially in all directions. Excess material on the substrate is driven off the edges (rim) of the substrate; but the remainder stays on the substrate as a very thin uniform layer due to the viscous and surface tension forces. When the layer on the substrate is allowed to dry, the solvent evaporates, leaving a thin film of the solute. The coated substrate is to be subjected to heat treatment for obtaining oxide films. The entire process can be repeated until the desired film thickness is achieved. An instrument utilizing this principle for developing thin films can be called a spin coating unit.

**2.3,, Essentials Of Spin Coating unit**

To facilitate the high speed spinning of the substrate, the substrate has to be fixed onto a flat turntable, which is capable of rotating at a uniform high speed. For this a suitable motor is to be used. The spinning speed and time of coating of the substrate are to be controlled and set at desired values. For controlling the spinning rate of the turntable, the motor speed has to be controlled and set at the desired rate; so also the duration of rotation is to be controlled and set at the desired
value. For this a suitable timing control device is necessary. There must be provision for the motor to stop at the end of the preset time. It is necessary to have an input device to feed the selectable turntable spin rate and time and a readout/display to display them. It is essential that the substrate is secured firmly and flatly fixed onto the turntable for coating and after coating there should be the possibility of its easy removal from the turntable. So a spin coating unit will have the following basic components.

1. a flat turntable capable of rotation about a vertical axis
2. a suitable high-speed motor suitably coupled to the turntable
3. a control system for speed and time control
4. an input device
5. a readout/display system
6. a substrate holder arrangement to fix the substrate on to the turntable

It is further essential that the turntable must be spun at a high speed to get quality films. As a matter of fact a high turntable spin rate of 2000 - 6000 or 7000 rpm has been found necessary for obtaining good coating of the films/14/ and the spin rate has to be maintained constant for the entire duration of coating. Hence it is essential that the turntable is accelerated very quickly to the predetermined high spin rate (in the range of 2000 to 6000 rpm) held at this speed for the entire preset spin
time and then brought to rest. The spinning of the turn table has to be smooth and uniform without wobbling and jerks to obtain quality films. These essential points are also to be kept in mind while developing a spin coating unit.

A good number of spin coating units have been developed and are available in the market. But almost all low cost units make use of analog controls with not too quick a spin rate rise and fall times, and the turn table spin rate and time are not properly controlled and using such instruments one can not expect much accuracy. There are sophisticated ones that are free from these shortcomings, but are expensive. So in this work, an attempt has been made to design and fabricate a precision low cost spin coating unit with digital control for turntable spin speed and duration of spin selectable so that good quality films could be prepared. This spin coating unit that has been designed and developed has been used for preparing device quality TO, IO and ITO films studied and reported in the present work.

2.4.1. Spin Coating Unit

The block diagram of a spin coating unit is given in Fig. 2.1. The spin coating unit needs to be given commands for the spin rate and the duration of spinning. To enable the same a keypad is being used. The input from the keypad is accepted by a processor, which in turn would control the motor. The motor
Fig. 2.1
Block diagram of the microcontroller based spin coating unit
spins at a high speed but direct drive of the turn table by the motor is not desirable, as the vibrations of the motor also would get coupled to the turn table and hence to the substrate that is spinning. To avoid this problem and to give a better stability, the motor is coupled to a flywheel arrangement. To vary the speed of the motor the pulse width modulation (PWM) technique has been employed. As ac motors are slow in gaining speed, a dc motor has been used. To drive the motor a V-MOS based switching circuit is employed. The actual control of the spinner is designed around an 89C51 microcontroller. The relevant hardware and software were developed and they are presented in the next few sections.

2-4.2. Control device

The control of the spinning process can be done with simple electronic circuits. But when it comes to the case of achieving a variable speed and duration the simple electronic circuitry is insufficient. Considering the fact that a microcontroller based system can offer a good degree of flexibility to the designer, it was decided to implement the spin coating unit design around the popular microcontroller 89C51. 89C51 is a versatile 8-bit microcontroller. It is a low power device, with a 4K byte of flash memory that can be used as programmable and erasable read only memory. It has got 4 eight-bit ports for handling of data. In addition it has got two built in 16 bit timers
with on chip oscillator and clock circuitry. The timer can also be controlled by an external clock.

The software to implement the system was designed using the assembler. The software provides for reading a keypad to get the spin rate and the duration. The keyed in values are displayed on an LED display panel. The programming of the duration and speed are done with the help of a two way switch. When programmed and the switch is thrown to the other side the motor starts and runs for the desired duration. According to the data fed in through the keypad the software decides on the pulse width and sends out pulses of constant amplitude but variable duration. The longer the spin rate required, the larger is the pulse width from the spinner. An external clock is used for timing for the motor control. The different sections of the program are written as subroutines, one for reading the keypad, another for sending out pulses yet another for keeping the pulse train duration (decided by the length for which the spinning is to be carried out). The program listing is given in Appendix. 1.

2.4.3. Power control

The duration and the length of the pulse are controlled by the software on the microcontroller. The basic speed is via the control of the average power fed to motor during one cycle. In the implementation it was decided to achieve power control via the pulse width modulation (PWM) technique.
2.4.4. Puls width Modulation (PWM) Technique

The turn table spins because it is coupled to the motor. The speed of the dc motor has to be controlled/varied to control the spin rate of the flywheel/turn table. The speed of dc motors can be controlled using field or armature potentiometers/rheostats. But they are expensive and considerable energy loss is associated with these controllers leading to low overall efficiency of the motor. SCRs (Silicon Controlled Rectifier) can be used as motor speed controllers; but the output of a phase controlled SCR drive is non linear with respect to phase angle and hence has limitations in precision speed control.

In the Pulse Width Modulation (PWM) / (otherwise called Pulse Duration Modulation (PDM) or Pulse Length Modulation (PLM)) systems, the amplitude and starting time of each pulse is fixed, but the width of each pulse decides the average power delivered to a load that is controlled by means of PWM techniques. The PWM method of voltage control is also called the variable duty cycle method of voltage control. This method employs control of conduction duration (or ON time) per cycle to alter the effective voltage (the average of the voltage) applied in one cycle. The lesser the duration of the pulse, the lower would be the effective voltage applied to the motor of the system.
Therefore the voltage applied to the motor has a direct relation to the duty cycle and hence on the ON time $T_{on}$.

If the duty cycle or $T_{on}$ is increased the effective or the average voltage applied to the motor is increased and hence the speed of motor would increase, on the other hand if the duty cycle or $T_{on}$ is decreased, the effective voltage applied to the motor is decreased and hence the speed of the motor would decrease. Thus the speed of the motor can be controlled, by varying the duty cycle (or ON time $T_{on}$) of the pulse width modulated signals. The duty cycle can be varied over a wide range from 0 to 100%. The salient features of the PWM method of speed control are:

\[
T_{on} = \frac{\delta}{T_{on} + T_{off}}
\]

The average value of the output DC voltage applied to the motor is

\[
= \frac{\delta \times V_{in}}{T_{on}}
\]

\[
= \frac{\delta \times V_{in}}{T_{on} + T_{off}}
\]
1. The dc voltage applied to the motor is proportional to the varying parameter namely the duty cycle, which can be varied over a wide range from 0 to 100%.
2. The switching losses are minimal in these ranges of duty cycle, which is an important factor in applications where precise control of speed is required.
3. It is an efficient speed control technique when compared to the other techniques.
4. It is an economical and a simple technique for the present application. It does not need field rheostat and/or armature rheostat for motor speed control, which are much costlier and lead to increased complexity of operation.
5. It is immune to noise /15/.

Because of these features of the PWM technique for speed control, it has been chosen and implemented in the present work. The duty cycle has been varied and made selectable using the microcontroller 89C51 with the appropriate software/programme developed and mentioned earlier - given in Appendix I.

2.4.5. Switching Device

Once the duty cycle control is designed the next task would be to choose a suitable power switching device for the motor in order to control the motor speed and set it at the predetermined
value. Power BJT’s can be used as switching devices. But there are several performance limitations of the Power BJT’s. The bipolar transistor is a current controlled device. Even large reverse base drive currents are necessary for obtaining high-speed turn off. These characteristics make the base drive circuitry complex and expensive. The bipolar transistor is also vulnerable to a second breakdown failure mode under the simultaneous application of a high current and voltage to the device.

To overcome the performance limitations of power Bipolar Transistors, the power MOSFET was developed. This device is an n-channel enhancement MOSFET: but is fabricated so that the current flows vertically and hence this transistor is designated as VMOS. The control signal is applied to a gate electrode that is separated from the semi conductor surface by an intervening insulator with no significant steady state gate current flow in either the on-state or the off state. The high input impedance is a primary feature of the power (VMOS) MOSFET that greatly simplifies the gate drive circuitry and reduces the cost of the power electronics.

The power MOSFET is a unipolar device. Current conduction occurs through transport of majority carriers in the drift region without the presence of minority carrier injection required for bipolar transistor operation. No delays are observed
as a result of storage or recombination of carriers in power MOSFET’s during turn- off and switching is fast. They have also been found to display an excellent safe operating area; that is, they can withstand the simultaneous application of high current and voltage (for a short duration) without undergoing destructive failure due to second break down. They have high power handling capacity and high voltage range operation. The thermal runaway is no longer a problem to be dealt with. There is no current “hogging” when devices are operated in a shunted manner to increase the current handling capacity. Because of very high input resistance, the VMOS requires extremely small input power and may be driven easily by CMOS logic gates. The power gain is extremely large. They have low noise figures. The VMOS channel is short and hence its output characteristics are linear. These characteristics of VMOS make them candidates for very many switching applications /16/. Considering these features a VMOS transistor has been used in the designed spin coating unit as the switching device for the control of motor speed through the PWM technique.

2.4.6. Motor

The turntable has to spin at a high rate of 2000-6000rpm and its spin must be smooth and uniform without wobbling and jerks. So the motor that is chosen must be a high speed motor capable of running at speeds in excess of 6000 rpm and must run smoothly and uniformly without any vibration. Since an AC
motor produces violent vibrations, and takes good amount of time to gain speed, it is not a good choice for the present design. But a DC shunt motor can attain the desired speed in a shorter duration and produces less vibrations when compared to an ac motor. The dc series motor can be used as a variable speed motor by controlling the power delivered to it. The traditional servomotor is primarily intended to function as position control system and not as angular velocity control system. The shunt motor, on the other hand, has a fairly constant speed for all loads (the drop in speed from no-load to full-load does not exceed 5 to 10% of no load speed) and hence is a constant speed motor; further the shunt motor exhibits extremely stable running. So a dc shunt motor appears to be suited for use in the low load spin coating unit / system and hence has been used in the present design.

MONA make 7500rpm 220v/0.75A dc shunt type motor is chosen for the fabrication of the spin coating unit so that a maximum speed of 6000 rpm could easily be attained.

2.4.7. The spinning flywheel/ turntable

As mentioned earlier to facilitate the high speed uniform spinning of the substrate, it has to be fixed, using a suitable substrate holder, onto a perfectly flat turntable, which is capable of rotating about a vertical axis at a uniform high speed; further
there should be provision to remove the substrate easily from
the turn table after the coating time i.e. when the turn table
stops spinning. For film coating, the coating solution must
spread uniformly on the top surface of the substrate and
therefore the bottom surface of the substrate alone is to be fixed
onto the turntable. The conditions mentioned above cannot be
achieved using adhesive tapes/ clamps, but can be achieved if a
vacuum is created underneath the substrate. Because of the
vacuum underneath, the substrate will be firmly attached /fixed
to the turntable even when it spins at very high rates. Once the
coating is over and the vacuum is released, the substrate can be
easily removed from the turntable. This method of firmly fixing
the substrate onto the turntable is adopted for use in the
designed spin coating unit. An accurately turned flat metal plate
will serve as the turn table. This turn table has to spin smoothly
and uniformly without any wobbling and jerks to obtain quality
films. As a heavy flywheel would have a better inertia and would
reduce the jerks, vibrations and noise associated with the direct
coupling of motor, it has been used in the system and is coupled
to the motor through a belt.

There must be a substrate holding assembly/ system
to fix the substrate firmly to the turn table when it is spun at
high speeds. The flat turntable consists of an accurately milled
flat 4 mm thick 10cm dia mild steel plate. A fine 2 mm hole is
drilled at the centre of the turntable. A 1.5 cm dia 15cm long
axle with a 2 mm central axial hole is fixed to the bottom of the turntable ensuring that the 2mm hole (or passage) runs uniformly from the top of the turntable to the bottom of the axle. The axle passes through a ball bearing fitted suitably on the chasis (Fig.2.4), which ensures the smooth spinning of the turntable.

The axle of the motor and the tubular axle of the turntable are coupled by means of a flywheel arrangement. For this, 8cm thick steel pulley is made and firmly fitted to the tubular axle symmetrically. At the bottom of the tubular axle of the turn table another ball bearing with a small 1 mm bore thick-walled brass tube is provided to facilitate connection to the vacuum pump. When a substrate is placed symmetrically about the central hole of the turntable and the vacuum system switch on, vacuum is created underneath the substrate, holding it firmly, uniformly and flatly to the turntable. The substrate is held so firmly to the turntable that even at a high turntable spin rate of 6000 rpm the substrate does not fly off the turntable. After the coating is over, if the vacuum is released/ turned off, the substrate can be easily removed from the turntable. For the present work, the Hind High Vac rotary vacuum pump model ED30 has been used.

2.4.8. Power supply

For obtaining the d. c supply to the motor, the output of an isolation transformer rectified by a bridge rectifier formed by
1N5218 power diodes is used. As has been discussed earlier, on the designed spin coating unit, the motor speed is controlled by the PWM technique because of its advantageous features. So during the ON time of the duty cycle only the motor has to be energized. As mentioned earlier the switching for ON time is provided by a versatile VMOS device. In this work IRF 840 VMOS has been used for switching purposes. A BJT switch formed by BC547 drives the input to the VMOS.

2.4.9. Timer Clock

The timer to control the duration of spinning required an external clock. A timer circuit using 1444 IC has been used for the same.

2.5 **Implementation**

The software was developed with a cross assembler of 89C51. The software gets the inputs for running the spinner from a keypad; the parameters being the spin rate and the spin duration. On getting these details the appropriate pulse width for the PWM is selected and the timer is activated. The trace of output from the micro controller for different spin rates are shown in Fig.2.2. The motor runs for the duration set by the user. The circuit for the designed spinner is shown in Fig.2.3 different sections are indicated by dotted boxes.
Fig. 2.2
The trace of output from the microcontroller for different spin rates fed into CRO.
Fig. 2.3. MICROCONTROLLER BASED SPIN COATING UNIT-CIRCUIT
From the Fig.2.3 it can be seen that the keypad is connected to the microcontroller via port 2 and that the timer clock is connected to port 3 (bit 3.4). The PWM signals are sent out by the microcontroller on port 3 (bit 3.0). The display device is controlled through port 0.

The system clock of the microcontroller is generated by the use of a 12 MHz crystal. The PWM output from the microcontroller drives a BC547 transistor which in turn drives the VMOS device. By controlling the gate potential, speed control is achieved. The program in the assembly language is converted using the assembler and is entered into the 89C51.

The designed spin coating unit/spinner was tested to work properly and all the films reported in the thesis were coated using the spin coating unit/spinner mentioned in this chapter.

2.6. Fitting of components of the system

The key pad and display unit form the front panel of the instrument. The motor, flywheel, axle, micro controller and related electronic circuitry are fitted in a cabinet with the turn table just projecting above the cabinet.

The isolation transformer and the PCB having the Electronic circuitry are suitably fixed to the chasis. The switches are arranged in the front panel. The run and programme modes are selectable by means of a SPDT toggle.
switch. The view of the developed spin coating system is shown in Plate No.2.1. The motor is firmly fitted to a 4mm strong MS plate bent suitably and fitted to a strong MS chasis as shown in the Fig.2.4.

2.7. Working of the spin coating unit

The substrate to be coated is kept symmetrically about the central hole of the turn table and the vacuum system is switched on. As the vacuum is created underneath the substrate, it gets firmly and uniformly attached to the surface of the turn table. The instrument is switched on. The programme mode is switched on and the desired input data namely the spin time and spin rate are fed into the system through the key pad. 5 to 6 drops of the sol is dropped at the centre of the substrate. After feeding the input data the run mode is switched on. The VMOS switch gets the command from the microcontroller and this energize the motor to operate at the desired prefixed speed. Simultaneously the timer starts counting down. It just takes ~ 1 second for the turn table to reach the desired speed. As the turn table spins at a high speed, the centrifugal forces drive the liquid/sol radially outwards in all directions. Excess material is driven off the edges (rim) of the substrate and collected by a suitably mounted PVC vessel; but the remainder is retained on the substrate as a very thin layer by the viscous and surface tension forces/II/. After spinning for the prefixed time the
Plate 2.1. Spin coating Unit
Fig. 2.4
MECHANICAL PARTS OF SPIN COATING UNIT

1. Chassis
2. Turn Table Platform
3. Turn Table
4. D.C. Shunt Motor
5. Spindle for Vacuum Connection
6. Ball bearing
7. Fly wheel Arrangement
8. Cabinet
VMOS de-energizes and the motor stops functioning and stopping the rotation of the turn table.

The vacuum pump can be switched off and the coated substrate can be carefully removed from the turn table. This is how the system functions and the film is formed. This is in a nutshell the process of film forming using the designed spin coating unit. The turn table spin rate can be varied from 100 to 6000rpm and the spin time can be varied from 1 second to 999 seconds.

2.8. Conclusion

A low cost versatile microcontroller based spin coating unit has been developed and implemented with precision control of spin rate and spin time.

The developed spin coating system has all the essential features such as high spin rate and its constancy with spin duration and uniform revolution of the turn table required for achieving good uniform coating.

This spin coating unit has been used to prepare device quality uniform SnO₂, In₂O₃ and In₂0₃:Sn films of the present study (given in chapters IV to VI).
References

