THE DESIGN OF A HEATER CONTROLLER FOR A THERMAL EVAPORATION SYSTEM

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Abstract - **A compatible heater system is vital for the successful operation of an evaporator for material fabrication process. This thesis describes the method of designing a heater system well suit for evaporation and deposition of amorphous silicon thin film. Several factors must be taken into consideration in the design of the heater to match the use. Analysis of the system before developing the real heater system is Boat. Before this actual circuit is assemble, the simulation by using PSim and PSpice were conduct to get the parameters and the expected result in order to compare with the actual result by experiment. By designing the circuit, the resistances of the boat were obtain, and then the whole parameters were regarded to this value in order to get the expected value of current to used in heating to evaporated process. The calculation of current supply for heater required at 0.295 A for the duration of 1 hour or 3600 s for evaporation of silicon to take place. An air-cored inductor has been used in this circuit to ripple less the wave-form of DC current. By using the Wheeler's formula, the suitable value of inductor at 1.1mH was used in the circuit design to filter or ripple less the wave form current from sinusoidal to constant increase. This is because, the constantly increase current are easy to control, difference to the sinusoidal current waveform.**

Keywords: Bridge rectifier, Boat, coil design, current flowing, evaporator.

I. INTRODUCTION

Thin film is layer of material, which is very small in thickness ranging of several nanometres' to micrometers. The fabrication of thin film onto the substrate is known as deposition techniques. Thermal evaporation, sputtering, electrochemical, metal organic chemical vapour depositions are among the techniques used. The way of depositing the thin film onto the substrate is by thermal evaporation system [1].

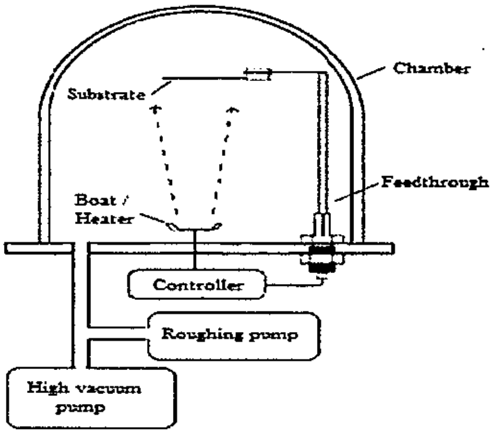

Figure 1: Thermal Evaporator System.

Figure 1 shows the heater system for material processing. It can be called as thermal evaporator system. The boat holds the evaporant or deposition material and when heated suitably by passing through the current, the material will be evaporated. The evaporation of the material will be condensed onto the substrate. The controller consists of current heating circuit, sensor's circuit and pressure gauge [2].

II. LITERATURE REVIEW

Deposition Material

1. Silicon

The Silicon atom has 14 electrons. It belongs to group IV in Periodic Table. The structure of Silicon is crystalline and in diamond cubic crystal. The amorphous silicon can be grown by condensation of Si vapour onto the substrate. One of the methods is thermal evaporation techniques whereby the electrical current is supplied to heat the boat and resulting the silicon to melt and evaporate onto the substrate. The crystalline structure of the silicon was disrupted by the heating process and it will grow as an amorphous or non-crystalline structures and denoted as a-Si.

TABLE 1: HARACTERISTICS OF SILICON

Silicon (Si)	Characteristics
Mass of Wafer (tonne)	500×10^{-6}
Melting Point (°C)	1410
Specific heat (J/Kg/ °C)	175110.6383
Latent heat of fusion (J/kg)	1926000
Latent heat of evaporation (J/kg)	259002000
Temperature at 10^{-5} torr (°C)	1277

2. Water

Water (H_2O) is the most abundant molecule on Earth's surface, constituting about 70% of the Earth's surface in liquid, solid, and gaseous states. It is in dynamic equilibrium between the liquid and gas states at standard temperature and pressure. One of the method to evaporate the water are by using the coil heater, by supplied enough current, the process of heating will complete to evaporate the water.

TABLE 2: CHARACTERISTICS OF WATER

Water (H2O)	Characteristics
Molar mass (g/mol)	18.01528
Mass of water (tonne)	5×10^{-4}
Boiling point (□C)	100
Heat of vaporization (KJ/kg)	2260
Specific heat of water (J/kg/ □C)	418700
Latent heat of evaporation (J/kg)	2270000

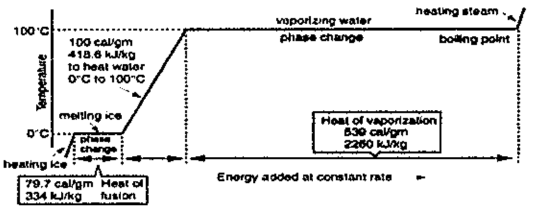

Figure 2: Graph of temperature Vs time.

Transitions between solid, liquid, and gaseous phases typically involve large amounts of energy compared to the specific heat. If heat were added at a constant rate to a mass of ice to take it through its phase changes to liquid water and then to steam, the energies required to accomplish the phase changes (called the latent heat of fusion and latent heat of vaporization) would lead to plateaus in the temperature vs time graph. The graph on Figure 2 presumes that the pressure is one standard atmosphere.

Evaporation Sources

Boat or heater is used as an evaporation source. There are three materials commonly used as evaporation boat.

TABLE 3. CHARACTERISTICS OF THREE COMMON MATERIALS

Material	Melting Point (°C)	Temperature (°C) at 10^{-5} Torr Vapor Pressure
Tungsten (W)	3350	2650
Tantalum (Ta)	3000	2450
Molybdenum (Mo)	2600	2000

III. PROBLEM STATEMENT

The boat component is widely used in the evaporation system. The boat tungsten is one of the heater can be apply in this project. However, the prices of the boat are very expensive. As an alternative, the electrode coil is used as a heater in this project and water as the material to evaporate. This project is to gain the experience and the knowledge in the thermal evaporation system in order to develop the controller to control the current flow in the system and to control the temperature when the process of evaporant occurs.

IV. OBJECTIVE

To designing the controller of the system and identify the current required to supply the heater to enable the evaporation process of Silicon to takes place.

V. SCOPE OF WORKS

A study and an analysis on the design the heat controller to supplied current in the system to evaporate the silicon. Circuit diagram of heat controller and simulation of the circuit in software such as PSim and PSpice will be implemented. This includes the study on bridge rectifier and sensor heating which to be applied in the controller. Hardware for controlling current will be constructed.

VI. METHODOLOGY

The purpose of this project is to design the heat controller to supply sufficient current to evaporate the silicon vapour. The enough current supplied is to get the high temperature on the boat so that the process of silicon evaporation easy to occur. Then, the resistance of heater is measured to get the current maximum can be flow in the heater. After that, the parameter of whole circuit is re-corrected in order to design the appropriate value of current by re-simulate the circuit in Psim. After the required value of current has been obtained by simulation, the coil is designed and fabricated according to the value of inductor chosen. Then, the real circuit of heat controller is assembled and fabricated. Finally, the value of current and temperature is measured in order to be used in the thermal evaporation system. These methods are illustrated in Figure 3:

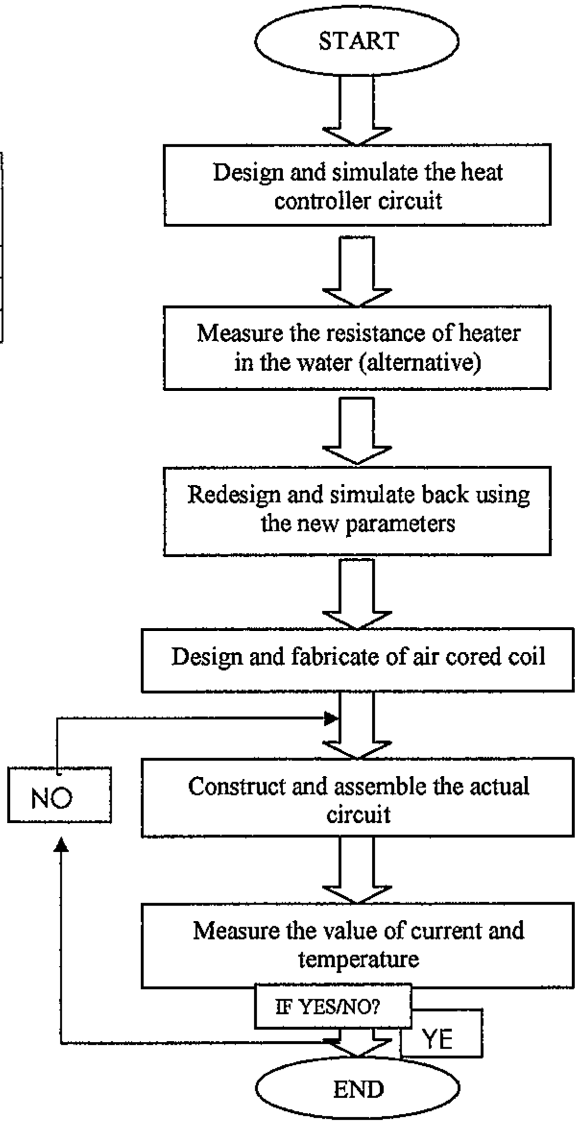

Figure 3: Methodology Flow Chat

VII. EXPERIMENTAL SET UP

1) Circuit controller

A diode bridge or bridge rectifier is an arrangement of four diodes in a bridge configuration that provides the same polarity of output voltage for either polarity of input voltage. When used in its most common application, for conversion of alternating current (AC) input into direct current (DC) output, it known as a bridge rectifier. A bridge rectifier provides full-wave rectification from a two-wire AC input, resulting in lower cost and weight as compared to a center-tapped transformer design. By using the dc voltage, the current flow in the heater will be constant and it is easy to control the heat on boat when the process of evaporate occur.

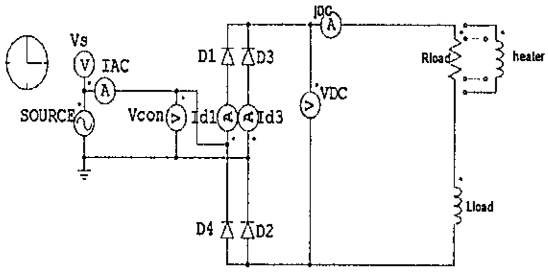

Figure 4: Schematic diagram of heater by using the manual controller.

2) Coil Design

This main inductive circuit is developed by air cored coil of inductor and to realize this fabrication, the Wheeler's Formula is used to produce multilayer coil of inductor. The design using this formula will be in cylinder type of inductor where the coil is wrapped to the former and the formula is stated below;

$$L(\mu H) := \frac{\left[0.0315 \cdot (N)^2 \cdot (Ravg)^2\right]}{6Ravg + 9l + 10B}$$

N= numbers of turns
Ravg =average coil radius in mm
l= coil length in mm
B=coil thickness in mm

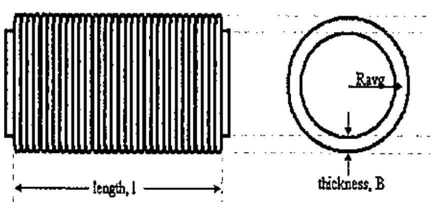

Figure 5: Dimensions of Cylindrical Air Cored Coil

VIII. RESULTS AND DISCUSSIONS

The results for this project will be divided into two parts. Part 1 is results from the simulation of the circuit by using PSim software. Part 2 is the experimental current waveform and coil design.

1) Coil design.

a) Theoretical:

Turn, N	Radius, Ravg	Length, l	Thickness, B	Inductance, L(uH)
192	30.50	16.6	3.10	2972.54
160	30.25	16.6	2.58	2068.70
128	30.00	16.6	2.06	1327.11
96	29.76	16.6	1.55	748.59
64	29.52	16.6	1.03	333.81
32	29.25	16.6	0.52	83.60

Table 4: Inductance value by calculation

b) Experimental

Turn, N	Radius, Ravg	Length, l	Thickness, B	Inductance, L(uH)
192	30.50	16.6	3.10	3112
160	30.25	16.6	2.58	2254
128	30.00	16.6	2.06	1465
96	29.76	16.6	1.55	850
64	29.52	16.6	1.03	382
32	29.25	16.6	0.52	112

Table 5: Inductance value by experiment

c) Result of graft Turn (N) Vs Inductance (mH)

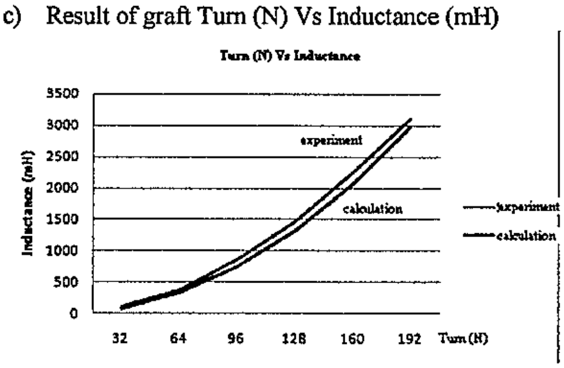

Figure 6: Changes an inductance value due to the changes in number of turns.

By using the Wheeler's Formula, the result in calculation is stated in Table 4 and the result by experiment is stated in Table 5. The length of the cylindrical coil is fixed at 16.6mm as in design. Then, the turns are reduced from 192, 160, 128, 96, 64 and 32 respectively. By doing that, the average radius and the thickness are also reduced due to reduction of turns.

By referring to both results; the experiment result is slightly different from the calculation. It can be represented by doing some computation in comparing its difference in percentage and can be shown in table below;

Inductance, L(uH) (Calculation)	Inductance, L(uH) (Experiment)	Difference in Percentage, (%)
2972.54	3112	4.48
2068.70	2254	8.22
1327.11	1465	9.42
748.59	850	11.93
333.81	382	12.60
83.60	112	25.36

Table 6: Difference value of inductance between calculation and experiment in percentage.

From the Table 6, the average of the difference between calculation and experiment value of inductance could be obtained. The average is 12.00%. By selected the high value of inductance, this can be applied in the circuit to ripple less the current waveform.

From the graph in Figure 6, the theoretical and the experiment result has the same relationship that the inductance will be varied according to the square of number of turns such as in Wheeler's Formula.

2) Simulation and Experimental Waveform of output current.

a) Simulation by using R(heater)=27Ω

L(inductor)=1.1mH

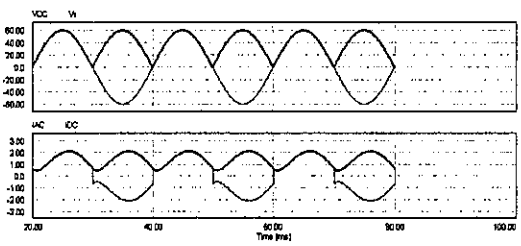

Figure 7: Waveform of output DC voltage and current.

b) Simulation by using R(boat) = 7.1mΩ

L(inductance) = 1.1mH

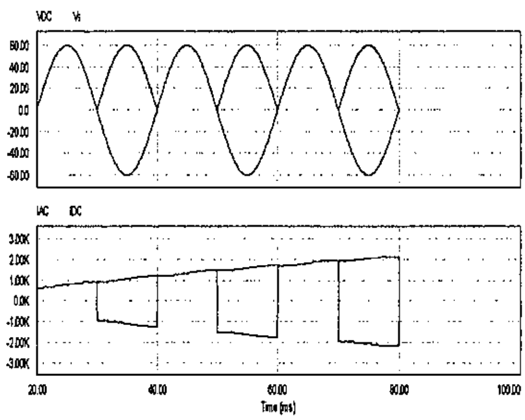

Figure 8: Waveform of output DC voltage and current.

c) Experimental result of output DC voltage

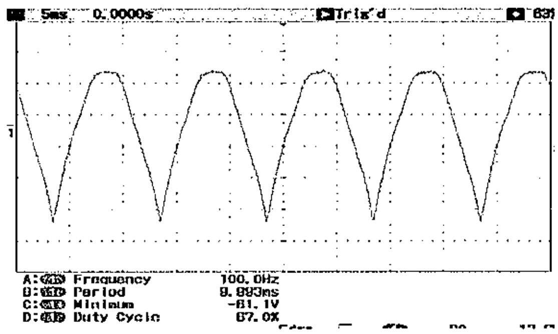

Figure 9: Waveform of output voltage.

From the simulation and experimental output voltage, the waveform of both site are approximately same. The current from the simulation are enough to evaporate the material like water in 1 hour or 3600s.

3) Experiment of vary voltage to get the value of temperature.

The related of voltage and time are importance to get the result of temperature to boil the water.

Time	voltage	Temperature	Current
T(s)	V	□C	A
0	0	29	0
60	10	29	0.4
120	20	29.5	0.8
180	30	31	1.2
240	40	34	1.5
300	50	38	1.9
360	60	44	2.3
420	70	51	2.5
480	80	60	2.9
540	90	72	3.3
600	100	84	3.7
660	110	95	4
720	120	96	4.4
780	130	97	4.8

Table 7: Result temperature by vary the voltage.

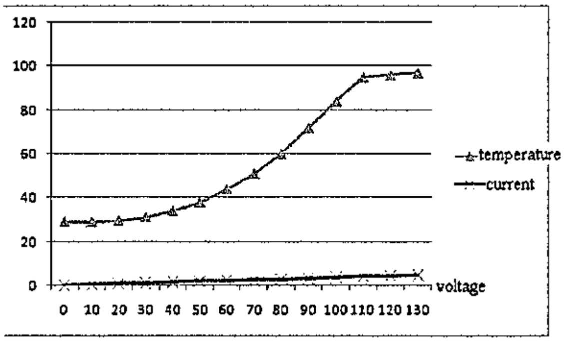

Figure 10: Graf of temperature and current by vary the voltage.

a) Result by experiment

		Temperature	
Time	V=130	V=100	V=70
T(s)	□C	□C	□C
60	48	45	35
120	70	61	44
180	87	72	50
240	96	82	57
300	97	92	63
360	98	96	68
420	100	97	73
480	100	97.5	77
540	100	98	81
600	100	98	84
660	100	99	87
720	100	100	89

Table 8: Result of temperature by increase time and constant voltage.

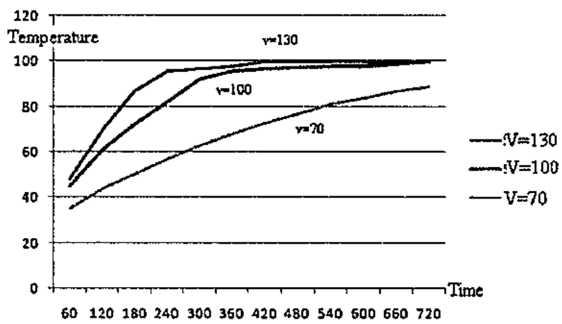

Figure 11: Graph of temperature by increase time and constant voltage.

From the result of experiment above, the temperature will increase faster by using high voltage and current. This is because the resistance of coil heater is 27Ω and it used high voltage and current to evaporate the water. The water was evaporate on 100 □C.

4) Supply Current for Evaporation Process

Supply Current Requirement for evaporation of evaporant (t = 3600 s) by using Fenske equation.

$$E_m = mL_f \quad (1)$$

$$E_v = mL_v \quad (2)$$

$$E_r = mC\Delta T \quad (3)$$

$$E_t = E_m + E_r \quad (4)$$

$$E_t = E_m + E_v \quad (5)$$

$$P_o = \frac{E_t}{t} \quad (6)$$

$$P_o = IV\cos\theta \quad (7)$$

Where

E_m	=	Energy for melting in Joule (J)
E_v	=	Energy to raised the temperature from melting temperature to evaporation temperature in Joule
E_r	=	Energy to raised the temperature from initial temperature to melting temperature in Joule
E_t	=	Total of energy in Joule (J)
P_o	=	Input power in Watt
L_f	=	Latent heat of fusion in J/kg
L_v	=	Latent heat of evaporation in J/kg
C	=	Specific heat in J/Kg/C°
ΔT	=	Change in temperature in °C
cos θ	=	Power factor
t	=	Time in seconds (s)
m	=	Mass in tonnes

5) Current Requirement for Evaporation by calculation.

(a) Current required for melting of Silicon

Equations (1) to equation (7) were applied except equation (2) and (5).

E_m	=	963 J
E_r	=	123453 J
E_t	=	124416 J
P_o	=	34.56 Watt
I	=	0.144 A

(b) Current required for evaporation of Silicon

The procedures at (a) was followed whereby Equations (1) to equation (7) were applied except equation (3) and equation (4) were unused.

From the above calculations, the current for evaporation was 0.151 A. Thus, total current, It = 0.295 A.

- **Graphical and Numerical Representation of Current Requirement at Fixed Time and Variable Voltage**

Figure 12 shows the current required if there is vary in voltage. The time was fixed at one hour or 3600 s, and the supplied voltage was gradually increased from 1V to 415V.

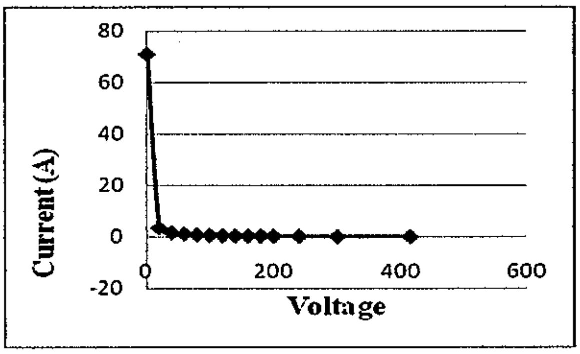

Figure 12: Graph of Current Requirement with Changing Voltage

- **Graphical and Numerical Representation of Current Requirement at Fixed Voltage and Variable Time**

Figure 13 was the graphical representation that shows the current required if there is varying in time from 60s to 3600s at fixed voltage of 240V.

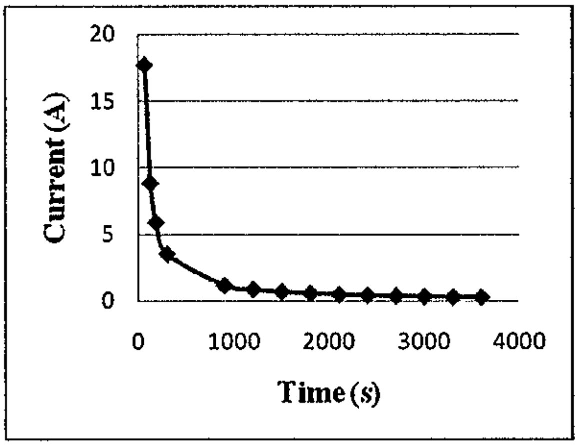

Figure 13: Graph of Current Requirement with Changing Time

From both representation, it can be concluded that, at fixed voltage of 240V, current was inversely proportional to the time of evaporation.

IX. CONCLUSIONS

In this project, an electrode is used as a heater which was designed according to the current generator to heat a heater. By using full wave bridge rectifier to convert AC to DC voltage, the current can be control by varying the voltage input using variac transformer.

Different type of material has been used in this experiment in order to get the result. The actual material is silicon but since silicon is not available, water has been used. Each material has different time to evaporate. A sufficient current is required in the process to evaporate the material. For the actual material which is Silicon, the current supply required to evaporate the Silicon for the pressure of 10^{-5} torr in the period of 3600 seconds or one hour is 0.295 A.

10. FUTURE DEVELOPMENT

For future development, this controller can be change to the automatic controller by using the PIC controller to measure the current and temperature requirements. It is easier to set the melting point using controller to evaporant or depositional material of silicon to substrate when the processes of evaporation occur. By using the real Boat as a heater in this project, the process of evaporant the silicon to the substrate is more suitable to get the actual result. This process is related to the pressure of 10^{-5} torr to achieve the objective.

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