Fabrication of Annealing Furnace for Thin Film Characterizations.

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ABSTRACT

A simple, portable, and electromagnetically regulated annealing furnace was successfully fabricated for improving the microstructure and mechanical properties of materials by removal of crystal defects and internal stresses. The oven was fabricated using locally available materials in Nigeria such as fiberglass, nichrome element, and magnetic temperature controller. The oven is an adiabatic system with the dimensions of 35x28x30cm. It is powered by 240V, 1,100W nichrome heating element. The special feature of the furnace is an electromagnetic temperature controller which regulates the annealing temperatures. The furnace generates heat at the rate of 1,035.25Wm^{-2} with the high efficiency of 94%. Among other purposes, the furnace is found very useful in annealing materials (as-deposited crystals) at desired temperatures.

(Keywords: annealing, thin films, furnace, magnetic, temperature-controller)

INTRODUCTION

Annealing is a transformation process by which the microstructure of materials and their mechanical properties are improved. Annealing has been a very ancient art used by metallurgists in heating materials like metals in fire for a long period and cooling them by burying or covering the hot metal with clay or sand. It involves cycles of heating and cooling to change the properties of materials [2, 4, 8]. The aim was usually to obtain a good structure and quality metals.

This process has undergone a lot of advancements and can be achieved accurately and neatly using well controlled annealing furnace. This process has been used extensively in materials science and thin film physics research in the study of the behavior of materials with interesting results.

In this work we have successfully fabricated and characterized a portable and super-efficient electromagnetically controlled annealing furnace. The furnace is found to be very useful in improving the microstructure and mechanical properties of as-deposited crystals and thin films.

THEORETICAL CONSIDERATIONS

The furnace is simply a source of heat and there are three ways of heat transfer involved: 1) conduction, 2) convection, and 3) radiation [8, 9].

The rate of heat flow q_k from the furnace called the conduction rate is given as:

$$q_k = \frac{dQ}{dt} = kA\frac{d\theta}{dx} \qquad \textbf{(1)}$$

where Q is the quantity of heat of heat flowing in time t, A is the cross-sectional area, k is the thermal conductivity and $\frac{d\theta}{dx}$ is the temperature gradient.

$$\frac{d\theta}{dx} = \frac{T_H - T_C}{L} \qquad \textbf{(2)}$$

where T_H is the temperature of the furnace and Tc is the outside temperature and L is the thickness of the furnace.

The convective heat transfer is given as:

$$q_c = \frac{dQ}{dt} = hA\Delta T = hA(T_h - T_c) \qquad \textbf{(3)}$$

where h is the convective heat transfer coefficient and A is the cross-sectional area of the furnace.

The radiative heat transfer is given as:

$$q_r = \sigma e A T^4 \qquad \textbf{(4)}$$

where σ =5.67x10^{-8}Wm^{-2}K^{-4}, is the Stefan constant and e is the emissivity (radiant heat emitted per second per unit area at a given temperature).

The total heat transfer is given as:

$$q = q_k + q_c + q_r$$

$$q = kA\frac{\left(T_H - T_c\right)}{L} + hA(T_H - T_{C))}) + \sigma Ae(T_H{}^4 - T_C{}^4)$$

(5)

The rate of heat transfer per unit area is given as:

$$P = \frac{q}{A} = A\frac{\left(T_H - T_C\right)}{L} + h\left(T_H - T_C\right) = \sigma Ae\left(T_H{}^{\$} - T_C{}^4\right)$$

(6)

$$P = \frac{T_H - T_C}{\frac{1}{h_H} + \frac{\Delta x}{k} + \frac{1}{h_C}} + \varepsilon\sigma\left(T_H{}^4 - T_C{}^4\right) \qquad \textbf{(7)}$$

where h_H and h_C is the heat transfer coefficient for inside and outside, respectively.

The efficiency of the furnace is given as:

$$Efficiency, \eta = \frac{PowerOutput}{PowerInput} x100\% = \frac{P_{out}}{P_{in}} x100\%$$

(8)

MATERIALS AND METHODS

The materials available locally were used for the fabrication of the furnace and include metal pan (mp 1530^{o}C), fibre-glass [1] (k= -0.04Wm-1K-1, softens up to 2000^{o}C), heating element (nichromedoes not oxidize at 1000^{o}C) [7] and connecting wires. Others include constantan thermocouple wires, electromagnetic temperature controller [5, 6], hinges, and screws, insulating handle, and aluminum paint.

CONSTRUCTION OF THE FURNACE

Figure 1: The Constructed Furnace for Thin Film Annealing.

The annealing furnace has the metal outer covering of dimensions of 35x28x30cm and inner dimensions of 28x20x22cm [3]. The fiberglass was used in-between the outer and inner metal pans as an insulating material to prevent heat loses by conduction and convection. The door was perfectly sealed and with an insulating handle. The magnetic temperature controller was attached to the top of the furnace and is detachable. The temperature controller allows for the furnace temperature to be controlled to any desired point between 0-400^{o}C. The furnace provides only for annealing of materials in air. It can be modified for other gas environment and vacuum annealing.

RESULTS AND DISCUSSION

The characterization results for the furnace are shown in the Table 1 below. The temperature range of the furnace is 0-400^{o}C. The temperature of the furnace increases at the rate 5760K/min. The materials can be annealed within a relatively short interval of time, which is a very good advantage. The characterization curve, Figure 2, shows almost a linear curve. That is, the temperature increases linearly with time.

It is powered by 240V, 1,100W nichrome heating element. The special feature of the furnace is a magnetic temperature controller which regulates the annealing temperatures. The temperature controller is adjusted in such a way that when the desired annealing temperature is attained, the heater trips off and pointer returns gradually to zero. If a material, say a thin film, is to be annealed at 473K, the controller is preset at this temperature. On reaching this temperature, the furnace cools back to the initial temperatures, thus performing the desired task. The furnace generates heat at the rate of 1,035.25Wm^{-2} with the high efficiency of 94%. Among other purposes, the furnace is found very useful in annealing materials (as-deposited crystals) at desired temperatures.

Table 1: Furnace Temperature Variation with Time.

Temperature (^{o}C	**Time (minutes)**
0	0
50	2
80	4
120	6
160	8
200	12
230	14
290	16
320	18

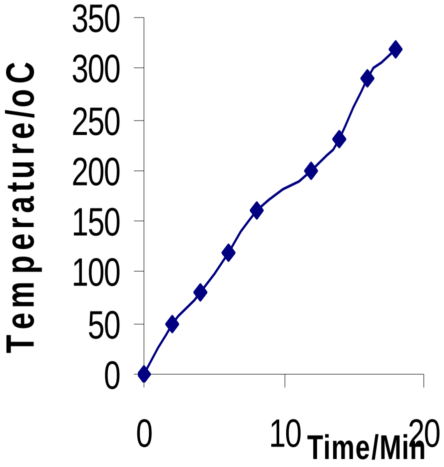

Figure 2: Characterization Curve.

CONCLUSIONS

We successfully fabricated a simple, portable and powerful electrically regulated annealing furnace for improving the microstructure and mechanical properties of materials by removal of crystal defects and internal stresses. The oven was fabricated using locally available materials in Nigeria such as fiberglass, nichrome element, and magnetic temperature controller. The oven is an adiabatic system with the dimensions of 35x28x30cm. It is powered by 240V, 1,100W nichrome heating element. The special feature of the furnace is a magnetic temperature controller which regulates the annealing temperatures.

The furnace generates heat at the rate of 1,035.25Wm^{-2} with the high efficiency of 94%.The furnace is found very useful in annealing materials (as-deposited crystals) at desired temperatures. It could also be very useful in other laboratory heating of materials and elevation of reaction temperatures.

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SUGGESTED CITATION

Offor, P.O. and B.A. Ezekoye. 2009. “Fabrication of Annealing Furnace for Thin Film Characterization”. *Pacific Journal of Science and Technology.* 10(2):126-129.

Pacific Journal of Science and Technology