Temperature Profiles of Glass Substrate According to Joule-Heating Induced Annealing

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Abstract—We conducted in-situ measurement of temperature of the glass substrate located on the top of quartz containing a conductive layer as a Joule-heat source. In-situ measured data of temperature were observed to agree well with the simulated data obtained from thermal simulation using Abaqus program.

Keywords—Glass, Joule-heating, Annealing

I. INTRODUCTION

Glass is a very common material widely used in display and other industries. Glass is a thermally susceptible material while silicon endures high temperature process for semiconductor manufacturing. [1-3] Thus it is essential to analyze mechanical behavior such as glass fracture and thermal deformation due to thermal distribution of the glass substrate during the heat treatment process.

Various methods of heat treatment processes are performed during the flat panel display manufacturing process. For example, tube furnace annealing, rapid thermal annealing using a lamp, and Excimer laser annealing which is used for crystallization of amorphous silicon thin films.[4-6] Heating and cooling rates according to various heat treatment processes affect thermal deformation of the glass substrates.

In this paper, thermal distribution of glass substrates was analyzed by using Joule-heating method. The Joule heating process is the only way to vary the heating rate by varying the magnitude of the applied voltage applied to the metal heating layer. A glass substrate was placed on a quartz substrate on which a Mo thin film was deposited. Then a voltage was applied to both ends of the quartz substrate resulting in heating layer located on the quartz substrate. Voltage and current was measured in real time using an oscilloscope during a period of Joule heating. In order to measure the temperature of a glass substrate thin film thermocouple was fabricated on the top of the glass substrate located on the quartz substrate having a Mo-layer as a Joule-heat source. The temperature of the glass substrate changed by applied voltage and current flow was measured in real time and the Abaqus simulation model was used to compare it with the actual experimental results.

II. EXPERIMENTAL

Figure 1 shows a process flow for manufacturing a substrate as a Joule heat source. 200 nm-thick Mo layer was sputter deposited on the quartz followed by depositing 100 nm-thick SiO₂ using PECVD. In order to form electrodes SiO₂ layers at both ends were patterned using photolithography and etching. Finally Cu was sputter deposited using a shadow mask. Then a wire was connected to an electrode using a silver paint. In order to measure temperature of the glass in the real time thin film thermocouples were fabricated on the top of the glass substrate as illustrated in Fig. 2. Figure 2(a) shows a plan view while Fig. 2(b) shows a cross-sectional view of a thermocouple used in this work. 200 nm-thick chromel and alumel were vacuum evaporated with a cross shape, respectively.

![Fig. 1 Process flow of fabricating Joule-heat source using quartz substrate](image)

![Fig. 2 Configuration of thin film thermocouple used in this work](image)

Figure 3 shows the cross-sectional view of the sample used in this work. Figure 4(a) and (b) show an experimental setup and a photograph used in this study. Joule heating system consists of charging circuit and output circuit. Nine supercapacitors (48 V -166 F) are connected to power supply in series for charging while the output voltage is controlled by the IGBT switch. Voltage charged in the battery is applied to a Mo-layer on the quartz substrate as indicated in Fig. 4(a).
Figure 4(b) shows a photograph of the experimental setup where the glass is placed in the middle of the quartz substrate. An electric pulse was applied to the Cu electrodes in order to raise the temperature of a Mo-layer (100 mm x 80 mm) by Joule heating. Voltage and current were monitored in the real time using voltage and current probes. Temperature was measured in the real time using a thin film thermocouple attached on the top of the glass substrate.

Fig. 3 Schematic of the sample used in this study. Glass is placed on the top of the quartz substrate.

(a) Circuit diagram for electric pulsing

(b) A photograph of the experimental system

Fig. 4 Schematic diagram of implantation conditions used in this study

Fig. 5 Experimental system for calibrating thin film thermocouple

Table 1. Actual temperature vs. TC temperature after calibration

<table>
<thead>
<tr>
<th>Actual</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>30</td>
<td>39.8</td>
<td>50</td>
<td>55.9</td>
<td>70</td>
<td>80</td>
<td>89.8</td>
</tr>
<tr>
<td>Error</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
</tr>
</tbody>
</table>

As shown in Fig. 3, Joule heat was assumed to be generated uniformly in the Mo thin film. Since the major process duration was within ten seconds in the process, the convective or radiation heat transfer was assumed to be negligible, compared to conduction heat transfer. Based on this approximation, the temperature of the glass could be estimated by the one-dimensional heat conduction model, given by

\[
\rho C \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( K \frac{\partial T}{\partial x} \right) + Q
\]  

(1)

Where \( \rho \), \( C \), and \( K \) are density, heat capacity, and thermal conductance, respectively for each layer, and \( Q \) denotes volumetric time-dependent Joule heating only in the Mo film.

We applied a pulse voltage with a magnitude of 120 V for 0.5 s. Figure 6 shows in-situ measurement data of voltage and current during electric pulsing. As shown in Fig. 6(a) the current of a Mo-layer was decreased from \(~ 60 \text{ A} \) to \(~ 40 \text{ A} \) indicating that the resistance of a Mo-layer was increased due to Joule heating. Figure 6(b) shows temperature on the top of the glass substrate.
The maximum temperature of ~130°C was reached at around 10 s. Temperatures obtained by thermal simulation using Abaqus program were fitted well with in-situ measured data. Figure 7(a) shows changes of resistance of a Mo-layer with a pulsing time under the input voltage of 120 V. As the pulsing time increases the resistance increases due to temperature rise by Joule heating. The resistance increases to ~3 Ω at a pulsing time of 0.5 s while it increases to ~2.5 Ω at a pulsing time of 0.1 s. Figure 7(b) shows temperature profiles as the pulsing time increases from 0.1 s to 0.5 s under the input voltage of 120 V. Even though the maximum temperature of a Mo-layer reaches at the end of pulsing time temperature on the top of the glass reaches to the maximum value at around 10 s far longer than the pulsing time. Time to reach the maximum temperature on the top of the glass is almost the same regardless of pulsing time as shown in Fig. 7(b) since heat conduction from a Mo-layer to the top of the glass determines temperature profiles along the depth of the glass.

When we increases a pulsing time to 10 s under the input voltage of 80 V the current decreases from ~40 A to ~10 A implying significant rise of the resistance of Mo-layer due to large amount of Joule heating as shown in Fig. 8(a). Temperature on the top of the glass reaches to ~500°C at ~10 s as indicated in Fig. 8(b).

Figure 9 shows temperature profiles according to changes of input voltages from 40 V to 80 V under a constant pulsing time of 10 s. The maximum temperature on the top of the glass reaches to ~500°C under the condition of 80 V ~10 s. It is interesting to note that time to reach the maximum temperature on the top of the glass is almost the same regardless of electric pulsing time.

We measured temperature of the glass located on the top of the quartz substrate containing a conductive layer. Using a thin film thermocouple we conducted in-situ measurement of temperature on the top of the glass. Results of thermal simulation using a numerical method with Abaqus program by the one-dimensional heat conduction model were in good agreement with the data measured in the real time.

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REFERENCES


