# Realtime Densitometer for Glass Wool Using Solar Cells

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*ABSTRACT*

*An optical method to measure the weight density of raw glass wool has been developed for use in a manufacturing plant. The method is based on the light attenuation theory. The system consists of the usual white light as a light source, a solar cell as a light-sensitive receiver, an amplifier, a personal computer with an A/D converter for data acquisition and a monitor for display of the data. The accuracy of the system was found to be above 98% and the system can be effectively applied to practical use in the factory. The system may be further applied for quality control in manufacturing raw glass wool.*

## 1 INTRODUCTION

The glass has mainly been used heretofore in the solid state such as a windowpane, optical lens, heat-resistant glass and glassware. It is being used more and more due to advances in manufacturing techniques of high-purity glass fiber. An optical fiber in a communication service is the representative example.

The other examples are processed goods of glass wool such as a dust proof paper, separator to insulate plus and negative electrodes in a battery and heat-resistant, sound-resistant mat used mainly in cars and buildings. The efficiency of the finished goods, particularly homogeneity, depends on the manufacturing process, mainly on the weight density of raw glass wool.

We have previously reported a novel method to monitor the density of a semitransparent foam sheet in real time by laser light attenuation method.[1] The method is simple and can be effectively applied for industrial use when the foam sheet is rather thin. It, however, has a drawback in scaning the laser beam to examine all the area because intensity of the laser is rather low.

Furthermore, it requires a focusing lens to focus a transmitted laser light since it diverges while passing through the semitransparent materials and a light receiver (photodiode) is usually too small to receive all the transmitted light directly. The glass wool usually used is rather thick, hence the laser cannot be used because of these above mentioned reasons.

In this paper, we propose a practical method to overcome these two drawbacks, that is, high-intensity white light for the light source is used instead of laser light and a large-scale solar cell for the light receiver is used instead of photodiode.

## 2 PRINCIPLE AND METHOD

The principle of the method is similar to what has been reported previously[1] and is based on the light attenuation theory. It is, however, different in two points, as described in Section 1. One is to use the white light instead of laser light to obtain high-intensity light so that the method can be effectively applied for high attenuation object. The other is to use a solar cell as a light sensitive sensor instead of usual photodiode. The solar cell, in itself, is not a light sensitive sensor but a converter from the light power to an electric power. The noticeable feature of this method is to use the solar cell as a light sensitive sensor. It enables us to measure a diverging light through the thick semitransparent object directly without focusing lens since a large solar cell can easily be made and is cheap enough compared to the photodiode usually used as a light sensitive sensor. Furthermore, it makes an automatic spatial averaging over the cell dimension without scanning the area. The solar cell has, however, such disadvantages as a low sensitivity to light intensity and an incomplete characteristics in each cell. The low sensitivity can easily be solved by using a large scale cell since the output is directly proportional to the cell dimension. The second disadvantage can be solved by using some amplifiers to each solar cell independently as mentioned below.

Figure 1(a) shows a fundamental illustration of the optical arrangement and Fig. 1(b) the whole system used in a manufacturing plant. Five high intensity white lights each having an output of 500 W were used as light source. These were placed at a distance of about 800 mm from the glass wool to illuminate as uniformly in the direction pararell to wool width as possible. Eight solar cells of each dimension 90 mm × 230 mm were used for the light receiver. These were placed at about 30 mm from the glass wool to receive the transmitted light directly and at the same time to avoid an attachment of the glass wool to the cells.

The outputs of each solar cell are amplified independently of each other to correct the output characteristics of each solar cell as described above. That is,

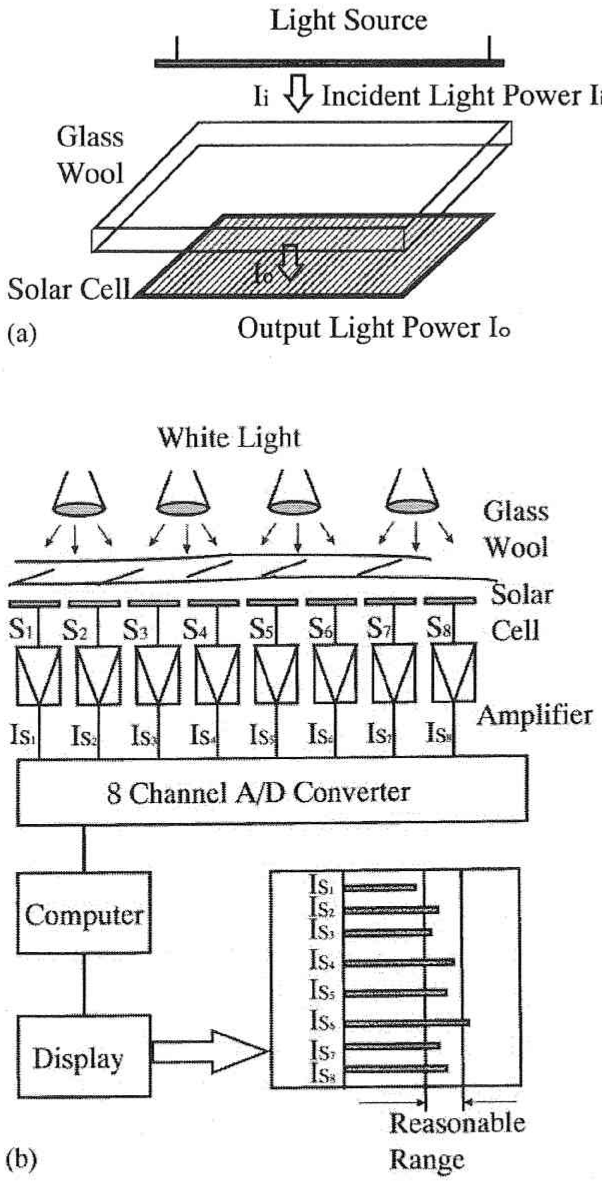


**Fig. 1.** System of the method. (a) Optical principle, and (b) system used in the manufacturing plant. In this case, the regions of channels 1 and 6 are out of reasonable density range.

all the outputs of each solar cell show the same value under the same light intensity. These amplified signals are then digitized by a A/D converter, averaged by a computer and displayed on the monitor as shown in Fig. 1(b). Each display can be done at an arbitrary time interval. The sampling time of data acquisition is about 5 ms. Then, each data on the monitor is a result of averaged value of about 200 sampling values. The production speed of glass wool is about 8 m/min and then each data on the monitor is the averaged value for an area of 230 mm × 270 mm.

Lambert's law,[2] which shows a relation between input and output light intensity, $I_o/I_i$, can be expressed as follows:

$$I_o/I_i = \exp(-kD) \quad \text{or} \quad \ln(I_o/I_i) = -kD \tag{1}$$

where $D$ is the glass wool density of the corresponding area and $k$ the absorption coefficient which depends on a property of the material. Thus, a natural logarithms of the light intensity ratio is in directly proportional to the density. The method is, in practical use, applied to a constant density $D_c$ and then to a constant light output intensity $I_{oc}$. Under these conditions, a fluctuation, for example, a small increment in light output intensity, $\Delta I_{oc}$ causes a small decrease in density $\Delta D_c$ as follows:

$$\Delta I_{oc}/I_i = -k(\Delta D_c) \tag{2}$$

This shows that a small increment in density from a constant density $D_c$ is directly proportional to a small decrease in light output $I_{oc}$.

## 3 EXPERIMENTAL RESULTS

First, preliminary experiment using a single solar cell was done to examine the possibility and the efficiency of the solar cell as a light sensitive sensor. Figure 2 shows the relation between light intensity by this optical method (solid line) and the density of glass wool by real measurement (dots).

The optical measurement was done at a manufacturing plant where the production speed of the raw glass wool was about 8 m/min as mentioned in Section 2. The light intensity in this figure shows the analog output from the amplifier and the density the measured weight of the dimension of about 230 mm × 270 mm. Thus, both the results are different. That is, the value of the measured density is the mean value of the analog light output over 270 mm length which corresponds to the mean value of about 3 solar cell receiver

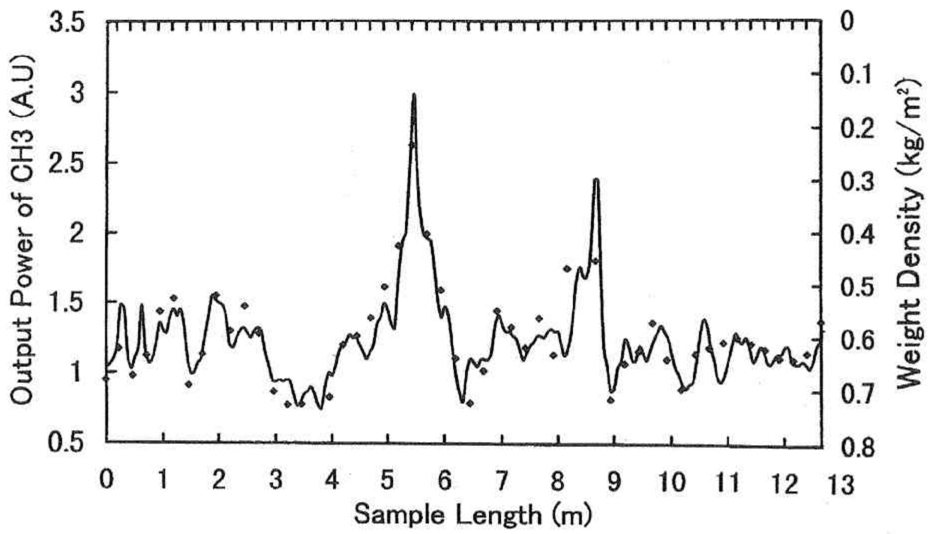


**Fig. 2.** Relation between an optical output power from the amplifier, i.e. analog output, and a measured raw density for time passage.

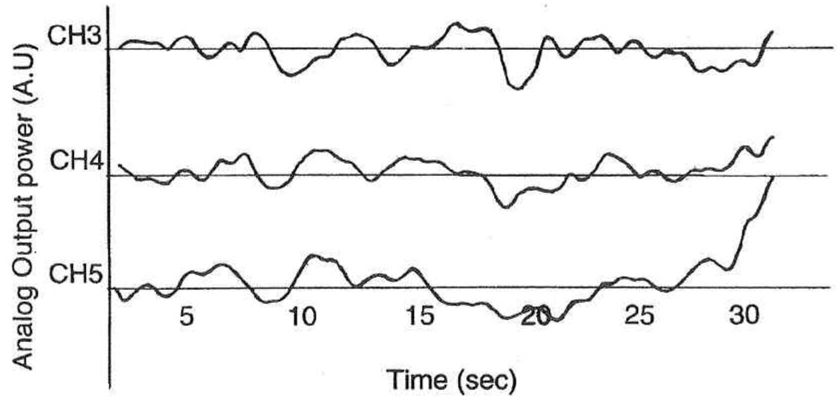


**Fig. 3.** Time chart of analog outputs (channels 3, 4 and 5) from the amplifier.

**TABLE 1**
Relation Between an Optical Output Power Processed by Digital Computer and a Measured Density for 8 Channels

| *Channel* / *Method* | *CH1* | *CH2* | *CH3* | *CH4* | *CH5* | *CH6* | *CH7* | *CH8* |
|---|---|---|---|---|---|---|---|---|
| Optical method (A.U.) | 0·530 | 0·528 | 0·495 | 0·501 | 0·536 | 0·540 | 0·533 | 0·540 |
| Measured density (kg/m$^2$) | 0·535 | 0·525 | 0·500 | 0·498 | 0·542 | 0·545 | 0·527 | 0·535 |

output in series. It is, however, found that the tendencies between both results agree well and can be effectively used in a manufacturing plant. Next, the analog outputs of all channels have been examined. Figure 3 shows only three channel outputs (channels 3, 4 and 5) of the eight channels, as an example.

Finally, digital outputs of all channels have been examined. Table 1 shows an example obtained by optical method at time $t$ ($= t_1$) in a practical manufacturing plant and a measured density. The result by optical method was the one digitized by 12 bit A/D converter, averaged over 2 s and normalized in accordance with the practical density. A preset density was 500 g/m$^2$. The error rate to the present value (in this case, 500 g/m$^2$) between both results was less than 2% in this case. The same result on the error rate was obtained for all results of 20 samples ($t = t_i$, $i =$ 1–20) examined. Furthermore, the error did not depend on the densities between 400–1000 g/m$^2$ which are usually produced. The maximum width of the raw glass wool was about 1·8 m in the practical plant and the production speed was about 8 m/s.

The optical method has been used in the manufacturing plant at Japan Inorganic Chemistry Co. Ltd. during about two months. It was found that the weight density of the produced raw glass wool was about 7% higher than that of the preset value 500 g/m$^2$ and about 5% higher for 800 g/m$^2$. It was necessary to do so to avoid partial lack of density. The data by this method can be used for a quality control. In practice, an alarm signal was generated when the fluctuation beyond a preset value, for example, over 540 g/m$^2$ and below 490 g/m$^2$. The signal is now applied for the production process of the raw glass wool to produce a constant weight density.

## 4 CONCLUSIONS

The optical method using a solar cell as a light receiver has been developed for the density measurement of raw glass wool. The accuracy of the method is above 98% by using individual amplifiers for each solar cell to correct the output characteristics of the cell. The method was used in manufacturing plant and was found to be effectively applied for quality control. It can further be used for the production process.

## ACKNOWLEDGEMENTS

All the experiments have been done with Japan Inorganic Chemistry Co. Ltd. at Yuki Factory, Ibaragi, Japan and technical support throughout the present study was provided by Mr T. Inaki of Fukui University.

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