Evaluation System for Thin-Film Oxide Semiconductor Using μ-PCD - Effectivity of Measuring Technique -

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A novel system has been developed for evaluating thin-film oxide semiconductors using a μ-PCD (Microwave Photo Conductivity Decay) method. Variations of the mobility and V_{th} *shift are issues in the manufacturing process of oxide semiconductors. To resolve these issues, an evaluation technique has been established. In addition, the mura (unevenness) of film quality on substrate has become another issue as the substrate size increases. It has been demonstrated that mapping measurement is effective in resolving this issue.*

Introduction

With the prevalence of smartphones and tablets, flat panel displays (FPD) are required to have higher definition, increased display frequency and lower power consumption. Thin-film transistors (TFTs) using oxide semiconductors, as typified by In-Ga-Zn-O (IGZO)1), have mobilities higher than those of conventionally used amorphous Si (a-Si), making higher definition possible. Additionally, the FPD manufacturing lines for IGZO also allow lines for a-Si to be used with almost no alteration. Therefore, there are an increasing number of compact panels using oxide semiconductors. Their demand for such panels for large-sized television sets is also expected to increase in the future.

However, there still are issues: i.e., ununiformity of the field-effect mobility (mobility) of TFTs in a whole substrate caused by film quality, and threshold voltage (V_{th}) shift after stress test including light negative bias and temperature stress (LNBTS). For these issues, an in-line evaluation is more important.2) In recent years, the substrate sizes have been increasing rapidly to improve the yield. This has raised the issue of *mura* in the film quality within each substrate.

Kobelco Research Institute, Inc. has established a technique using the microwave photo conductivity decay (μ-PCD) method for evaluating the defect states of Si wafers and the film quality of low-temperature poly silicon (LTPS).3) This technique was adapted in developing a new system for evaluating the film quality of oxide semiconductor thin films. This system has enabled the evaluation of the deterioration of mobility and V_{th} shift of oxide semiconductors. In addition, it was found that mapping measurement allows the evaluation of *mura* in the film quality within substrates.

This paper reports the results of evaluation of the mobility and V_{th} shift of an oxide semiconductor TFT using the μ-PCD method.

1. Outline of systems for evaluating oxide semiconductor thin film

Fig. 1 shows an example of the systems developed: the μ-PCD measurement system (LTA-2850SPHIIB) for generation-8.5 LCD (G8.5: substrate size, 2,200×2,500mm). This system has a depth of 5,880mm, width of 2,860mm and height of 2,550mm. The current lineup covers the range from research and development application (substrate size : 200×200mm) to the G8.5 substrate size.

With the substrate size increased, if the conventional system is used, the measurement time will increase. Therefore, the systems for G5.5 or larger sizes use a dual-head method involving two measurement heads. **Fig. 2** shows the configurations of a conventional single head and newly designed dual head. In each configuration, the stage moves in the X-axis direction, while the head is/heads are moving in the Y-axis direction. The dual-head configuration halves the amount of movement in the Y-axis direction, shortening the measurement time for a G8.5 substrate, from the approximate 40 minutes it used to take, to 20 minutes or less.

Fig. 1 Evaluation system for oxide semiconductor thin films (LTA-2850SPHIIB: substrate size G8.5)

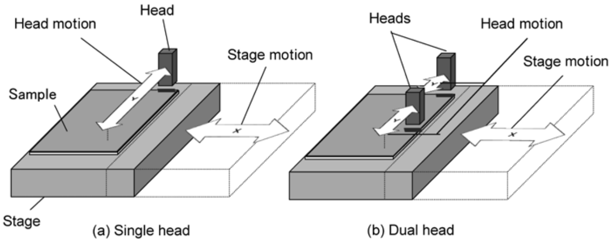


Fig. 2 Configurations of conventional single head and new dual head

2. Measurement principle of μ-PCD

When an oxide semiconductor thin film is irradiated with laser energy exceeding the energy bandgap, electron-hole pairs are generated and excess carriers are produced. These excess carriers are annihilated by recombination, and the time it takes to annihilate them (lifetime) depends on the physical properties of the samples. The excess carriers generated by laser irradiation increase the conductivity of the sample, changing the microwave reflectivity (**Fig. 3**). The μ-PCD is a method of measuring lifetime from the temporal change in the microwave reflectivity.

When evaluating Si bulks and wafers, sufficiently strong signals can be obtained. For thin films, however, the signals are weak. Hence, a differential μ-PCD method is used for the microwave detection unit of the oxide semiconductor thin-film evaluation system. This enables an S/N ratio 500 times greater than that achieved by the conventional detection method.[3]

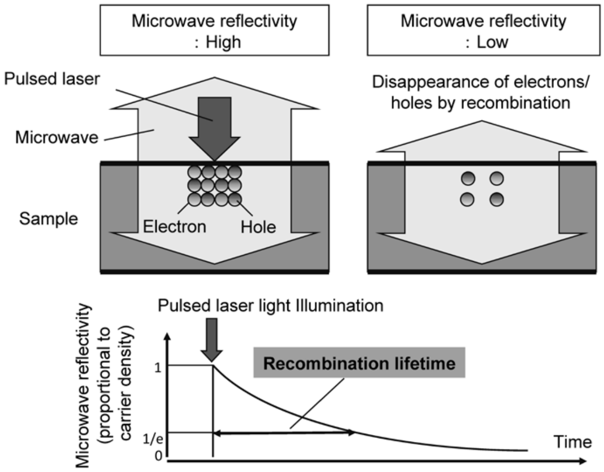


Fig. 3 Measurement principle of μ-PCD method

Fig. 4 depicts the measurement principle of a detection unit with the differential μ-PCD method. The oscillated microwave is split into a signal waveguide and a reference waveguide. The carriers in the sample area under the signal waveguide are excited by the laser. Then the detection unit measures the reflectance change caused by excess carriers. The signal from the signal waveguide ("A" in the figure) contains a noise component in addition to the signal of the reflectivity change caused by excess carriers. On the other hand, the signal from the reference waveguide ("B" in the figure) consists only of the noise component. The difference between these two signals ("A - B" in the figure) is calculated to cancel the noise component, which enables signals to be detected with a high degree of sensitivity.

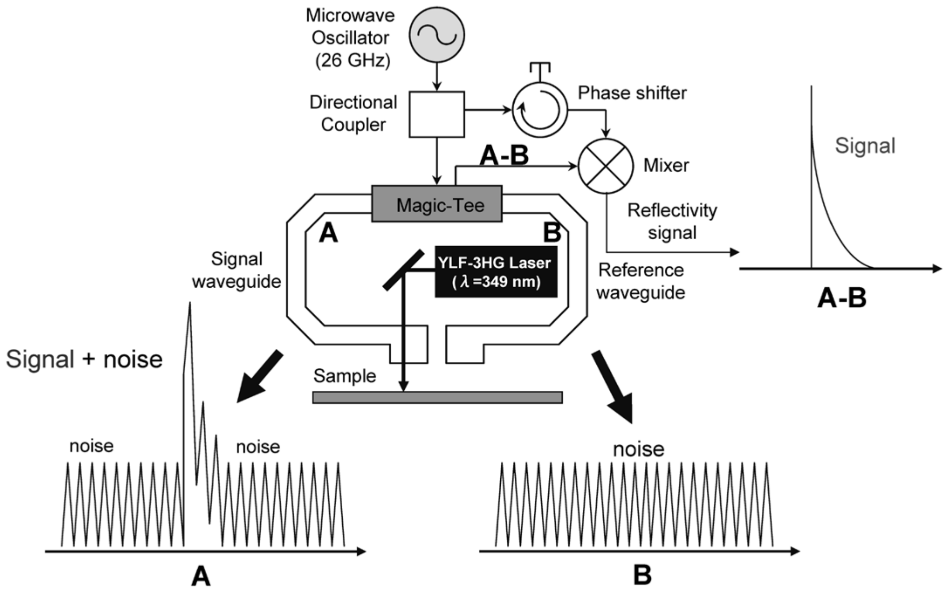


Fig. 4 Principle of differential μ-PCD for oxide semiconductor evaluation system (A: signal + noise wave, B: noise wave)

3. Method for evaluating oxide semiconductor thin film using μ-PCD

Fig. 5 illustrates a decay curve for the microwave reflectance of an oxide semiconductor. In an oxide

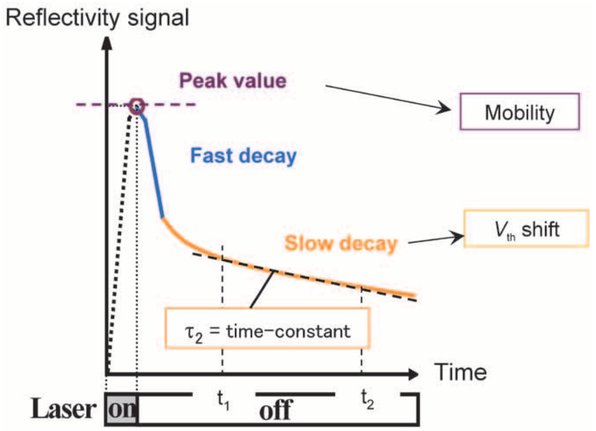


Fig. 5 Decay curve of microwave reflectance for oxide semiconductors

semiconductor thin film, the decay does not occur in accordance with a simple exponential behavior as predicted by Shockley-Read-Hall (SRH) theory [4] of recombination via trapping. Rather, a gradual decay occurs half way. In other words, the decay consists of two components: namely, a fast decay component and a slow decay component with tailing. The slow decay component can be formulated in several ways. In this paper, for ease of understanding, it is expressed by the linear combination of exponential functions as shown below:

$$n = n_1 \exp\left(-\frac{t}{\tau_1}\right) + n_2 \exp\left(-\frac{t}{\tau_2}\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots \text{(1)}$$

where n_1 and n_2 are the carrier densities for the fast decay and slow decay after laser irradiation, respectively, and τ_1 and τ_2 are the time constants for the fast decay and slow decay, respectively.

The fast decay is attributable to the deep localized states in an oxide semiconductor thin film, and these localized states affect the mobility of the TFT.[5] The slow decay, on the other hand, is attributable to the shallow localized states in an oxide semiconductor thin film, and these states are known to affect the V_{th} shift of TFTs.[6]

However, the lifetime of the fast decay is extremely short, as in the case of LTPS, making its direct observation difficult. When the pulse width of the pump laser is sufficient with respect to the lifetime, the peak value becomes proportional to the lifetime.[3] Therefore, for the evaluation of mobility, rather than using the lifetime value of the fast decay, the present system uses the peak value, which can be easily and accurately measured.

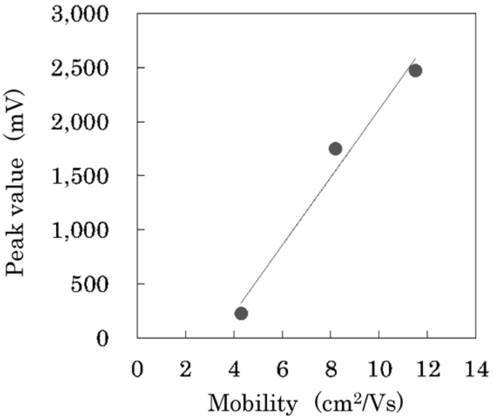


Fig. 6 Relationship between field-effect mobility of TFT and peak value measured by μ-PCD

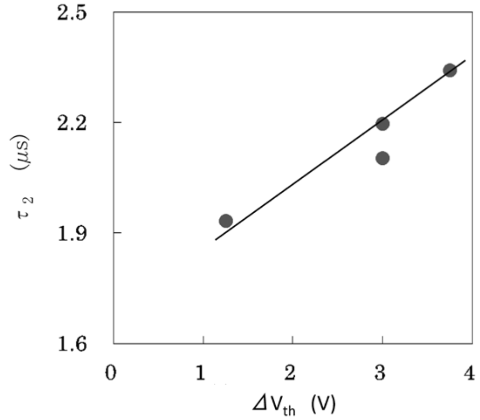


Fig. 7 Relationship between V_{th} shift of TFT under LNBTS and τ_2 measured by μ-PCD

Fig. 6 shows the relationship between the field-effect mobility of a TFT and the peak values measured by μ-PCD. The mobility represents the saturation mobility calculated from the values of switching characteristics (I_d-V_g characteristics) measured for the TFT. The measurement was performed for a gate voltage (V_g) of - 30 to 30V and a drain voltage (V_d) of 10V. There is a proportional relationship and correlation between the mobility and peak values.[7]

Fig. 7 shows the relationship between V_{th} shift of a TFT under the LNBTS and τ_2 measured by μ-PCD. The conditions of the LNBTS include V_g=-20V, V_d=10V, a substrate temperature of 60℃, light source of white LED (strength 25,000 Nit) and stress applied for 2 hours. Again, there is a proportional relationship and correlation between the V_{th} shift and τ_2.

As described above, the use of the two parameters (peak value and τ_2) is found to enable the evaluation of the mobility and V_{th} shift of LNBTS in oxide semiconductor thin films before the fabrication of TFTs.

4. Effectivity of mapping measurement

With increasing substrate size, one of the problems encountered in mass production lines is the *mura* of film quality in a whole substrate. Mapping measurement is effective because the *mura* can be easily evaluated in a whole substrate.

As shown in **Fig. 8**, a glass substrate was placed right above a target material. After the film deposition, the peak value was measured in a whole substrate. Here, two types of target materials were used to confirm the difference: namely, a divided target and a non-divided target without seam. The results are shown in **Fig. 9**. Both the maps show a tendency for the circumferential portions to be lower. The divided target, (a) in the figure, shows lower peak values in the portions corresponding to the joints of the target. This tendency is particularly noticeable in the central portion, where the peak value is approximately 300mV lower than that of the same portion of the non-divided target, (b) in the figure. For this portion, the saturation mobility was calculated from the I_d-V_g characteristics of the TFT (**Fig.10**). The results indicate that the divided target with lower peak values also has a mobility lower than that of the non-divided target.

The sputtering targets of Ga_2O_3, In_2O_3 and ZnO were placed as shown in **Fig.11** to perform co-sputtering of multi-elements. Using this arrangement, an experiment was conducted to evaluate the difference in film quality due to the composition of the oxide semiconductor thin film. The peak values obtained by the mapping measurement and the mobilities measured for the TFT are shown in the figure. There are agreements between the high and low portions of the peak value and mobility, indicating strong correlations.[5] Thus, the peak value mapping permits convenient checking of the *mura* in transistor characteristics (mobility).

Fig.12 shows an example of the peak value mapping of an oxide semiconductor thin film (substrate size: 370×470mm) before and after annealing. The mean peak value changes before and after annealing. This indicates that film quality is changed by annealing. Regarding film quality distribution, both of the results show a tendency for

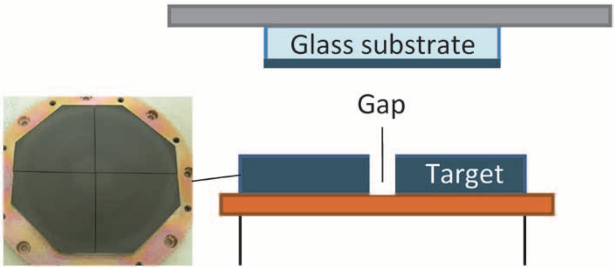


Fig. 8 Arrangement of target and glass substrate

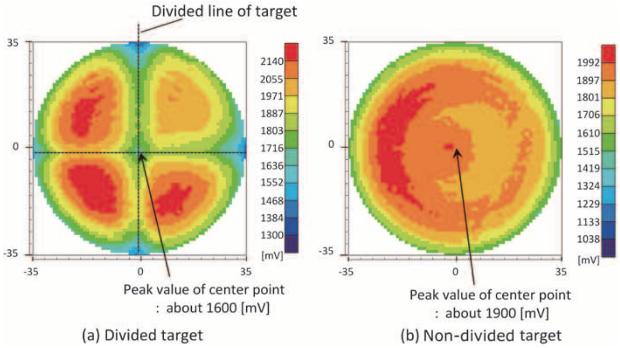


Fig. 9 Peak value mapping measured by μ-PCD (a) divided target, (b) non-divided target

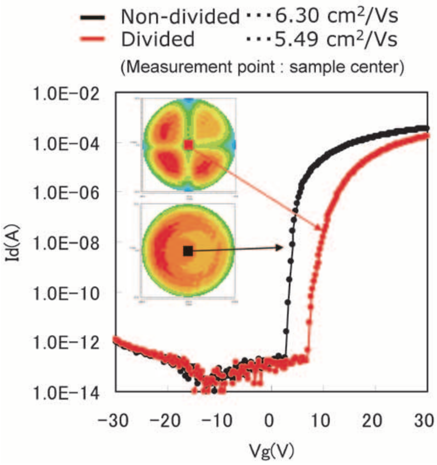


Fig.10 I_d-V_g characteristic of samples deposited using divided and non-divided target

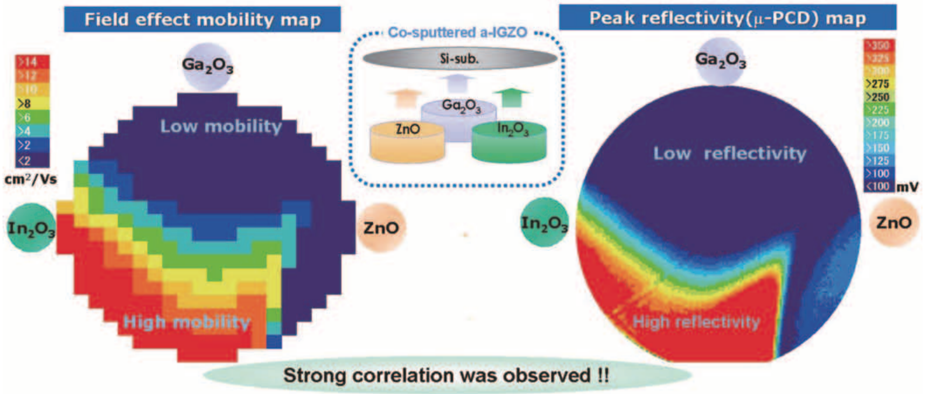
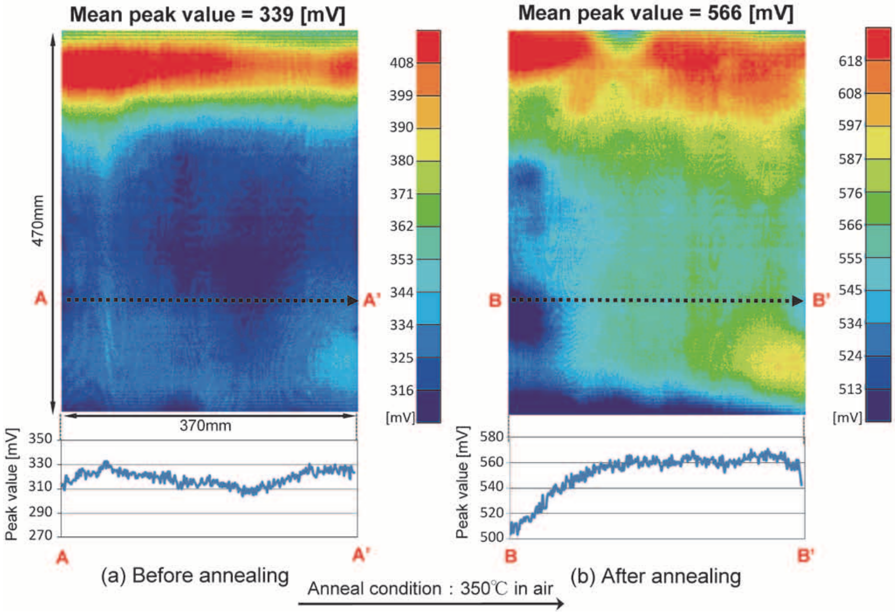


Fig.11 Relationship between field-effect mobility and peak value using μ-PCD



(a) Before annealing

(b) After annealing

Fig.12 Peak value mapping for IGZO film before and after annealing

the upper portion of the sample to exhibit higher values; however, they show different distributions as indicated in the left lower portion. The values along A-A' and B-B' are plotted in the corresponding graphs below the maps. For both of the graphs, one division represents 20mV. These graphs for before and after annealing are compared; the comparison shows an improvement of *mura* in film quality in the center-to-right region; however, there is a precipitous decrease in the peak value on the left side. As shown, peak value mapping allows a convenient evaluation of *mura* in film quality in a whole substrate of the sample; and mapping measurement is effective in process optimization and anomaly detection when adapted for in-line evaluation.

Conclusions

This paper has introduced a technique for evaluating oxide semiconductor thin films and described the effectivity of mapping. The use of the present system enables the evaluation of the mobility and V_{th} shift of oxide semiconductor thin films before the fabrication of TFTs. In addition, the system allows mapping measurement in a non-contact, non-destructive manner, permitting the evaluation of *mura* in film quality within each substrate. These advantages of the system can be exploited in optimizing the process conditions for manufacturing oxide-semiconductor TFTs and in improving the yield of mass production lines. The future plan includes obtaining the results for mapping measurements of peak values and τ_2, and acquiring the correlation data with TFT characteristics from films deposited under various conditions: for example, oxygen concentrations and annealing temperatures during the film deposition.

Finally Kobelco Research Institute, Inc. will strive to exploit these techniques for the present system so as to contribute to the development of the FPD market.

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