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Dual dispersive interferometric probe system for measuring double-sided film structures

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In this investigation, we design a dual optical probe system to measure double-sided film structure similar to a pouch-type secondary battery cell. By adopting the dispersive interferometric principles, the optical path difference between the reference and measurement arms can be determined by the phase slope of the spectral interferogram without any mechanical movement. Therefore, the measurement probe can measure the surface positions on each side of the specimen, and the geometrical relationship between two probes enables to determine the whole thickness of the specimen, substrate thickness and film thicknesses at once. As the experimental results, the physical thickness of the cover glass was measured to evaluate the system performance, and a pouch-type secondary battery cell was measured as a double-sided film structure with sub-micrometer precision.

NOMENCLATURE

T = whole thickness of a specimen
ΔL_T = optical path difference measure by *Ch1* probe
ΔL_B = optical path difference measure by *Ch2* probe
δ= gap between two probe focal positions

1. Introduction

Film structures has been widely used invarious industrial fields to be compact, multi-functional and reliable [1]. In integrated circuit, especially flexible devices, the products should be manufactured to avoid defects for the purpose of ensuring their desirable performance. However, these film structures are typically various and complex corresponding to their functionalities, and it is not possible to characterize all kinds of film structures with a single general measurement system. Instead, a specific measurement probe should be specifically designed and instrumented for measuringdimensional parameters. In case of a pouch-type secondary battery [2], which consists of a flexible metal substrate and inner and outer coating layers, for example, both sides of the battery cell should be safely sealed, and the thickness of the metal layer and the coating film thicknesses on both sides need to be measured. In this case, most of the measurement systems have the limitation to be applied because they are designed as a one-way structure [3] because they only measure the film structure on a single side of the specimen.

Traditionally, film thickness measurements have been achieved by reflectometry [4] and ellipsometry [5]. Both techniques are based on the film theory, and the experimental parameters such as spectroscopic reflectance and polarization change are compared with the counterparts of the theoretical model by the optimization procedures. Although their measurement results show high accuracy and sensitivity, they should be fundamentally incorporated with the theoretical model by the indirect approach, which needs the complicated post-processing to obtain the results.

In this investigation, we design a dual optical probe system to measure double-sided film structure similar to a pouch-type secondary battery cell [6]. By adopting the dispersive interferometric principles, the optical path difference between the reference and measurement arms can be determined by the phase slope of the spectral interferogram without any mechanical movement at each side.

2. Dual dispersive interferometric probe system

2.1 Optical configuration

Figure 1 shows the optical layout of the dual optical measurement probe system proposed in this investigation. As an optical source, a broadband light is used, and the light is delivered to an optical circulator (OC) and goes to an optical switch (OS) for choosing the measurement probe channels at the top (*Ch1*) and bottom (*Ch2*). At each channel, a Michelson-type interferometer is configured, and the light which goes back from the interferometer can be detected by a spectrometer. For analyzing the interference signal, dispersive interferometry (DI) is used for measuring the dimensions of the specimen by the acquisition of the spectral interferogram from the spectrometer.

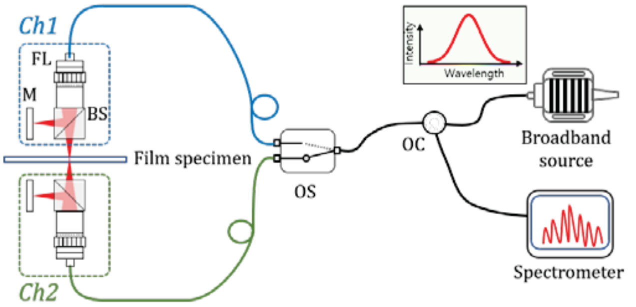

Fig. 1 Optical configuration of the dual optical measurement system; FL, focusing lens; M, mirror; BS, beam splitter; OS, optical switch; OC, optical circulator.

Meanwhile, two measurement probes at *Ch1* and *Ch2* are consecutively operated at the same axial position of the specimen by the OS to detect the interference signals from both sides of the specimen. In each channel, the lights split by a beam splitter (BS) are focused on a reference mirror (M) and a specimen, and the focal points of two measurement probes toward to the specimen are ideally coincide. However, two focal points cannot be practically matched, and deviated from each other. In case that the focal point of the probe at *Ch1* is located far from that at *Ch2*, the gap (´) between two focal points needs to be measured and used for the calibration of their geometrical relationship.

2.2Dispersive interferometry

In typical reflective type of DI, the optical path difference (OPD) between the reference and measurement arms can be determined by the phase slope of the spectral interferogram without any mechanical movement [3]. Based on the Fourier and inverse Fourier transformations with bandpass filtering to choose one of the interference peak signals, the OPD can be obtained.In case of a film structure, the spectral interferograms between the reference and the measurement lights reflected off by all surfaces of the specimen are overlapped, and each spectral phase can be extracted by selecting the peak signal by using a bandpass filter in the Fourier domain, which leads to calculating the corresponding OPD.

When DI is used for measuring a single layered film specimen in the dual optical measurement probe system, three kinds of spectral interferograms can be observed at each channel, where the measurement lights are from the upper and lower surfaces of the film layer. In the Fourier domain, therefore, three peak signals are detected at each channel, and one of them indicates the optical thickness of the film layer, caused by the interference between the reflected lights from film layer itself. Then, the optical thickness of the film layer can be obtained. In addition, the optical thickness of the film layer can be also determined from the OPDs of the other peak signals. In case that the specimen is located above the focal position of the probe at *Ch1*, furthermore, the whole thickness of the specimen (*T*) can be calculated with the OPDs corresponding to the top and bottom surfaces of the specimen as

$$T = \Delta L_T - \Delta L_B + \delta \qquad (1)$$

where ”L_T and ”$L_B$are the measured OPDs corresponding to the top and bottom surfaces of the specimen at *Ch1* and *Ch2*, respectively. Under the conditions for prior knowledge of refractive indices, the physical thickness of the film layers and substrate can be also extracted.

3. Experimental results

After the system calibration and the performance evaluation with a transparent plate to determine ´, a pouch-type secondary battery cell specimen was measured as a double-sided film specimen in this investigation. The specimen consisted of an aluminum substrate with 40 μm thickness, polypropylene (PP) with 80 μm thickness as an inner layer and nylon (Ny) film with 30 μm thickness as an outer layer as shown in the inset of Fig. 2. Figure2(b) shows Fourier transformed results of DI at both channels. Because the reflected light from the film surface was relatively too weak, a small peak corresponding to the optical thickness of the film was not detected at each channel. However, the optical thickness of inner and outer layers and the whole thickness of the specimen were able to be calculated from the main peaks at both channels, and they were 110.41 μm, 50.58 μm and 148.98 μm, respectively.

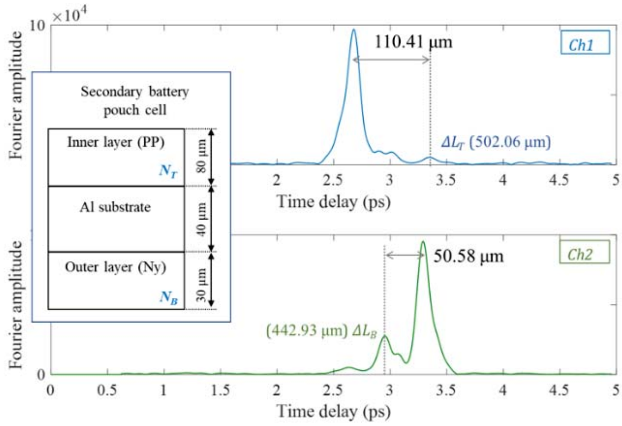

Fig. 2Fourier transformed results of spectral interferograms obtained with pouch-type secondary battery cell by DI, and the inset indicates the designed structure of a pouch-type secondary battery cell.

4. Conclusion

In this investigation, we described a dual optical probe system to measure double-sided film structure with an opaque substrate. By adopting the dispersive interferometric principles, the measurement probe was able to measure the surface positions on each side of the specimen, and the geometrical relationship between two probes enabled to determine the whole thickness of the specimen, and optical film thicknesses at once. As the experimental results, a pouch-type secondary battery cell was measured as a double-sided film structure.

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