Development of Sputtering System ULDiS-1500PHL for Optical Film Deposition

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Optical films can select transmittance and reflectance at certain wavelengths by a combination of thin films with different refractive indices. Such films have long been used as anti-reflection (AR) films, specific wavelength transmission filters, and so on. In the past, optical films were deposited on certain substrates and assembled with electronic devices. However, with the miniaturization of electronic devices, it has recently become more common to assemble optical films on wafers and electronic devices before dicing. As a result, a deposition system for optical films is required to allow wafer processing and particle control at the semiconductor level. We developed a sputtering system, ULDiS-1500PHL, for wafers, and present a system and process especially for infrared band pass filters.

1. Introduction

An optical multilayer film is a thin film that has the ability to transmit and reflect light at a specific wavelength by alternately forming several types of materials with different refractive indices on a substrate such as glass, resin, or metal (Fig. 1). Such films have been used for a long time as anti-reflection coatings for lenses and on reflectance enhanced mirrors, and have a wide range of applications such as in optical filters and half mirrors.

In recent years, optical thin films have also been used in devices such as 3D facial recognition sensors, LiDAR (Light Detection and Ranging) for distance measurement, and biometrics. In these devices, as illustrated in Fig. 2, a band pass filter (BPF) is used to illuminate the object with light of a specific wavelength from a light source and to detect only light of a specific wavelength reflected from the object. In particular, in order to reduce signal loss over a wide viewing angle, near-infrared BPFs for facial recognition applications are required to have a high transmittance and a small offset in the central wavelength of the BPF transmission band even when the reflected light from the object is incident at a large angle.

For this reason, attention has recently focused on BPFs that use hydrogenated amorphous silicon (a-Si:H), since it

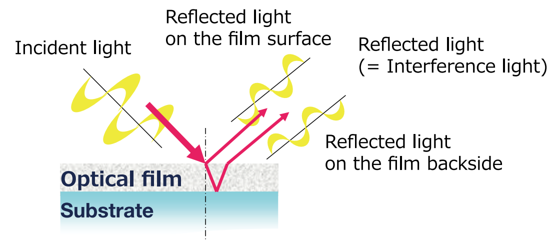

Fig. 1 Basic principle of optical thin films

has a high refractive index in the near infrared wavelength region while absorbing the visible light wavelength region, giving it advantages over Ta_2O_5, Nb_2O_5 and TiO_2, which are the high refractive index deposition materials that are traditionally used[1]. By using a-Si:H, it is possible to reduce the number of film layers and the thickness of the BPF, which can be expected to improve productivity.

In the case of optical devices such as camera modules for smartphones, optical components such as lenses and optical filters and semiconductor components such as CMOS were traditionally manufactured separately and then assembled as modules, as shown in Fig. 3. In the future, however, the dominant manufacturing method is likely to be WLO (Wafer Level Optics), in which each component is manufactured at the wafer level, and the pasted-together wafers are subsequently diced to form the individual products. Therefore, support for ∅200 mm and ∅300 mm wafers is required. In terms of quality, support is also required for equipment and handling management

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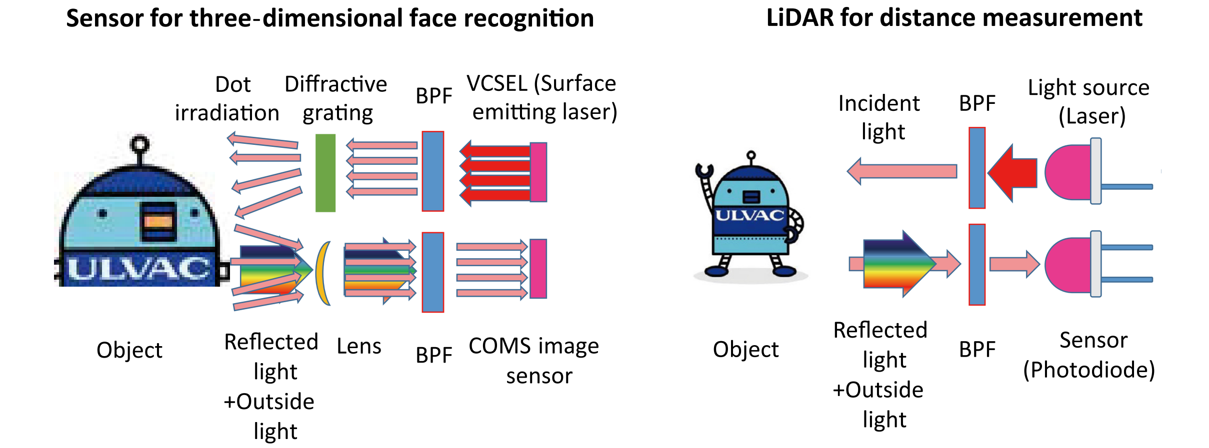


Fig. 2 Example of BPF use

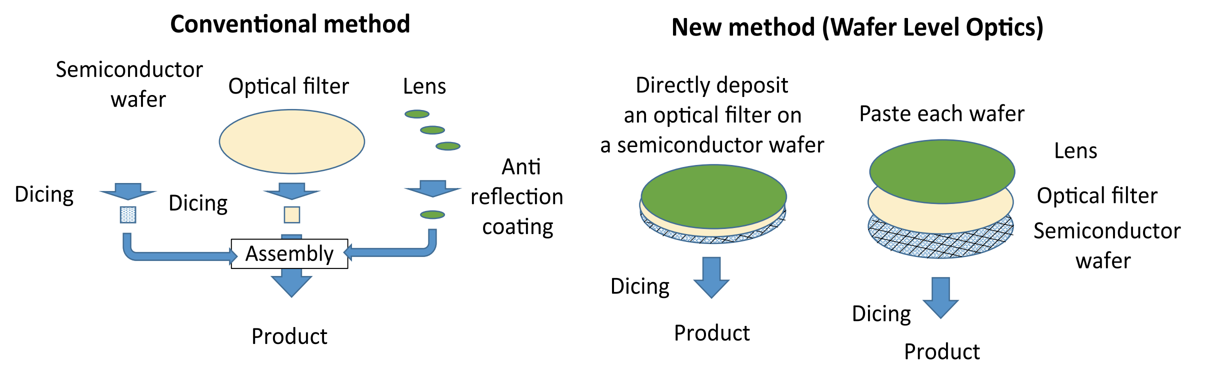


Fig. 3 Manufacturing methods of optical devices

for lower particle counts than before. Vapor deposition is a common deposition method for optical films. However, as the applications of optical films have expanded, the requirements for thickness controllability and in-plane distribution have become more sophisticated, and attention has shifted to the sputtering method for the deposition of optical films.

In this paper, we introduce the hardware of our digital sputtering system, ULDiS -1500PHL, for ∅200 mm and ∅300 mm wafers and describe the a-Si:H-based near-infrared BPF deposition process technology we developed using this system.

2. PVD (Physical Vapor Deposition) Method for Optical Film Deposition

Reactive sputtering and digital sputtering

Optical thin films are generally made up of multiple layers of metal oxide films. There are two methods for depositing these metal oxide films using the PVD method: to use RF sputtering with oxide targets, and to use metal targets that are oxidized by flowing a reactive gas into the chamber. When the target is pure metal, two sputtering methods are available: reactive sputtering, in which Ar and the reactive gas are simultaneously fed into the chamber to oxidize and form sputtered particles on the target surface; and a post-oxidation method, commonly known as digital sputtering, in which a few atomic layers of metal film are deposited and then oxidized in a different location, and then the process is repeated[2]. Fig. 4 shows a schematic diagram of the deposition methods using metal targets.

Reactive sputtering is generally unsuitable in terms of productivity because the deposition rate can be several times or even several orders of magnitude lower than that of digital sputtering. Digital sputtering, in contrast, can be quite productive if an oxidation source with sufficient oxidation capacity is provided. In addition, digital sputtering results in excellent surface smoothness and makes it easier to obtain a dense film. Fig. 5 shows SEM images of the cross section and surface of TiO_2 films deposited by reactive sputtering and digital sputtering. The TiO_2 film deposited by reactive sputtering has a columnar structure and a rough surface, while the TiO_2 film deposited by digital sputtering is amorphous and smooth.

The following is an introduction to our optical film deposition system and process using the digital sputtering method.

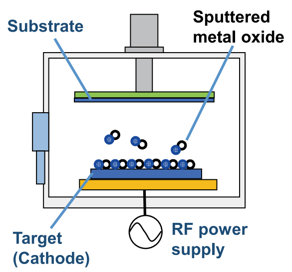
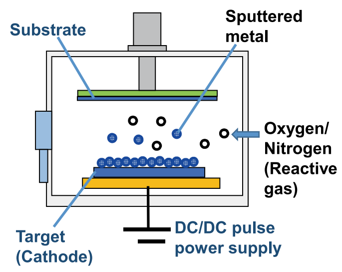
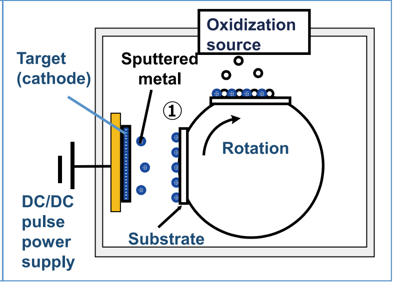
Sputtering method	RF sputter	Reactive sputter	Digital sputter
Sputtering target	Oxide metal	Pure metal	Pure metal
Chamber structure			

Fig. 4 PVD method of optical thin films

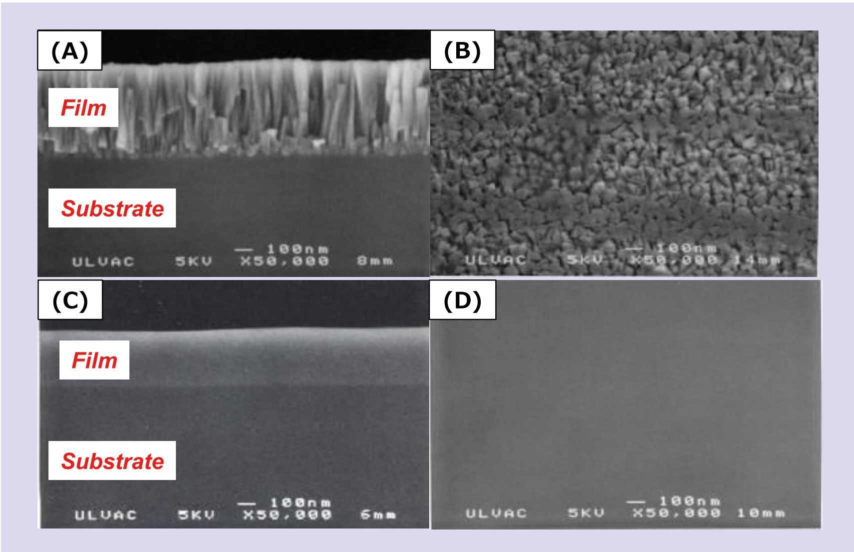


Fig. 5 (A), (B) Cross section and surface SEM image of TiO_2 film deposited by reactive sputtering
(C), (D) Cross section and surface SEM image of TiO_2 film deposited by digital sputtering

3. ULDiS-1500PHL Optical Film Deposition System for Wafers

Fig. 6 shows a schematic diagram of the ULDiS-1500PHL optical film deposition system for ∅200 mm and ∅300 mm wafers. The system consists of a cassette chamber where the substrates are loaded, a transfer chamber for conveying the substrates, and a process chamber for deposition processing. Two cassette chambers are provided to allow the loading of the next batch of substrates during the deposition process, thus improving productivity. In the process chamber, a turntable on which the deposition substrate spins at high speed is arranged in parallel with a cathode unit, Inductivity Coupled Plasma (ICP) oxidation source, and heater for heating the substrate. The PVD method uses digital sputtering, where a thin metal film is deposited as the

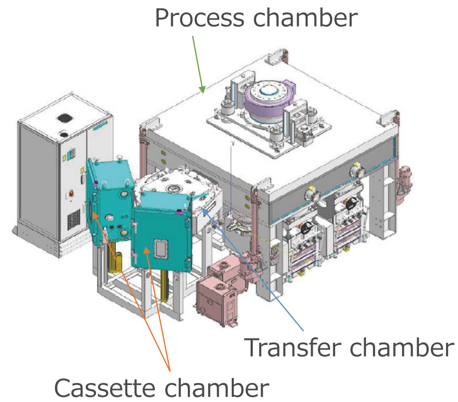


Fig. 6 ULDiS-1500PHL

substrate passes over the cathode unit, and then the metal film is oxidized as it passes over the ICP oxidation source. The cathode unit has two cathodes per unit, and a maximum of three units can be installed.

4. Near-Infrared BPF Deposition Process Using a-Si:H

4.1 Optical properties of a-Si:H

One of the optical properties required for a-Si:H is a high refractive index *n*. A high refractive index is preferable in order to reduce the offset amount of the center wavelength of the transmission band of the BPF, to reduce the total film thickness, and to reduce the total number of film layers. In addition, the extinction coefficient *k* should be as close to zero as possible in order to obtain high transmittance.

Fig. 7 shows the H_2 flow rate dependence of a-Si:H. The refractive index *n* and extinction coefficient *k* are the values at a wavelength of 940 nm calculated by optical film design software based on the transmittance and reflectance of a-Si:H films deposited on glass substrates measured by a spectrophotometer. The results show that the refractive index *n* and extinction coefficient *k* decrease as the H_2 flow rate increases.

Next, Fig. 8 shows the optical properties of a-Si:H as related to the substrate temperature during deposition. As the substrate temperature increased, the refractive index *n* increased and the extinction coefficient *k* decreased.

4.2 Film thickness distribution of a-Si:H and SiO_2

The uniformity of film thickness distribution is very important in optical thin films because it affects the optical property of wavelength shift.

In this system, in order to improve the film thickness distribution caused by the difference in peripheral speed between the inner and outer circumference of the turntable system, two cathodes were installed in each cathode unit, and the thickness distribution was controlled by adjusting the input power to each cathode. Fig. 9 shows the film thickness distribution after input power optimization. Good results were obtained with a film thickness distribution of ±0.15% or less at ∅300 mm (edge exclusion 10 mm) for both a-Si:H and SiO_2.

4.3 Near-infrared BPF using a-Si:H and SiO_2

We designed a near-infrared BPF using SiO_2 as a low refractive index material and a-Si:H as a high-refractive index material, performed deposition with the materials, and then evaluated the optical properties of the resulting films. The near-infrared BPF we designed was composed of a 33-layer film (5.4 µm) with BP characteristics centered on the 940 nm wavelength on one side of the glass substrate, and a 22-layer film (1.8 µm) with BL (blocking layer: increases transmittance in the BP wavelength range and blocks light outside the BP wavelength range) characteristics on the other side. Based on the results of the optical properties described above, the a-Si:H was optimized to *n* = 3.68 and *k* = 1E-4.

Fig. 10 shows the transmittance characteristics and in-plane distribution for the ∅200 mm wafer. Good

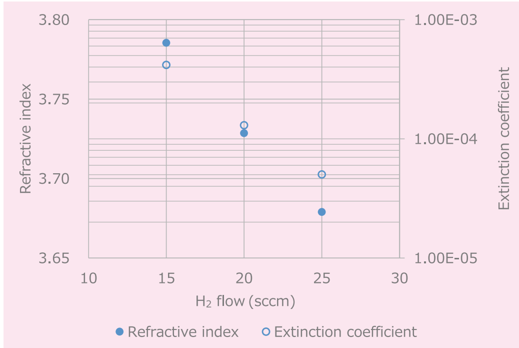


Fig. 7 a-Si:H optical characteristics as a function of H_2 flow rate

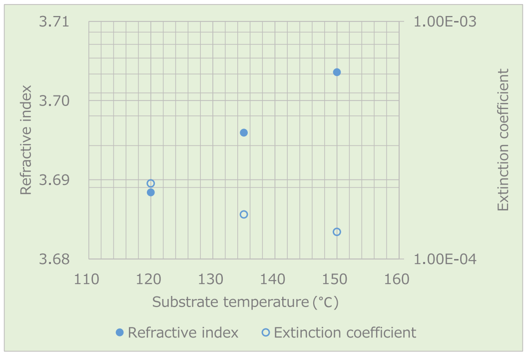


Fig. 8 a-Si:H optical characteristics as a function of substrate temperature

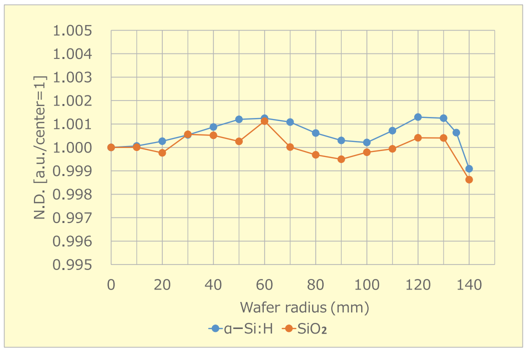


Fig. 9 Film thickness uniformity of a-Si:H and SiO_2

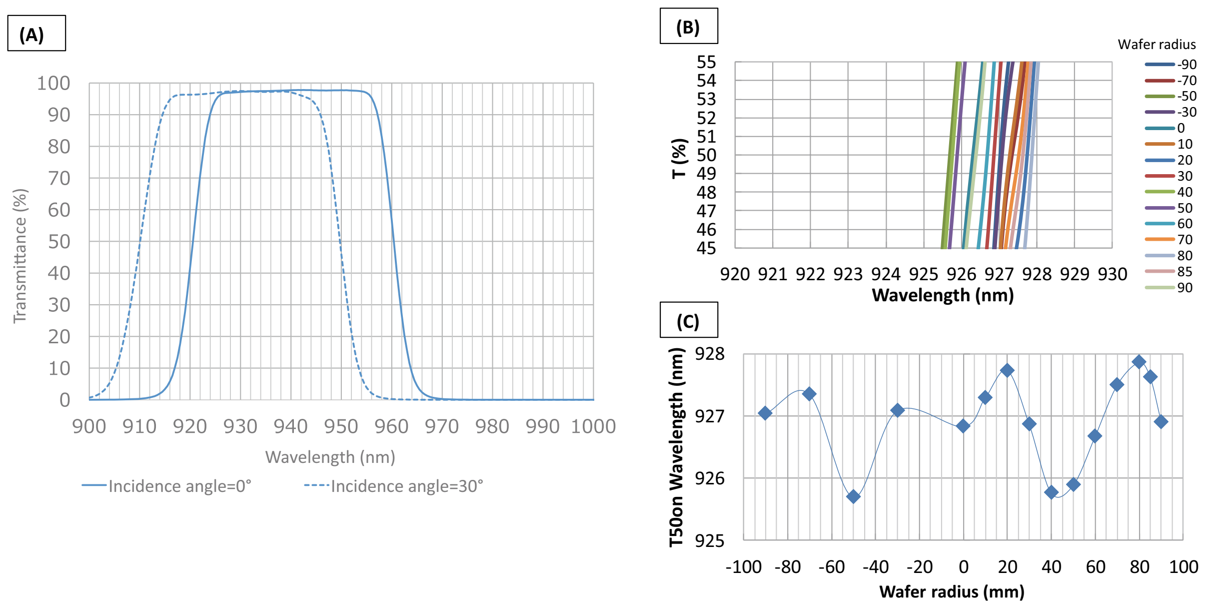


Fig. 10 (A) Transmittance characteristics of 940 nm BPF (Incidence angle 0° and incidence angle 30°)
(B) Transmittance characteristics in ⌀200 mm wafer
(C) Wavelength uniformity at 50% transmittance in ⌀200 mm wafer

Table 1 Transmittance at target end of life

	Target life (kWh)	Tave@930-950 nm (%)
TEST1	466	97.3
TEST2	515	97.3
TEST3	565	97.5
TEST4	615	97.2
TEST5	747	97.5

transmittance characteristics were obtained, with an average transmittance of 97.6% from 930 to 950 nm at incident angle 0° and an average transmittance of 97.1% from 920 to 940 nm at incident angle 30° (Fig. 10A). Good results were also obtained in terms of angle dependence, with a center wavelength shift amount of 10.5 nm in the BP characteristics from 0° to 30° (Fig. 10B). The in-plane distribution showed a wavelength variation of about ±1 nm (±0.12%) at a transmittance of 50% (Fig. 10C).

In addition, the results of continuous deposition tests from the middle to the end of the target life (Table 1) showed that an average transmittance (Tave) above 97% at 930 to 950 nm could be stably maintained.

5. Summary

In this paper, we introduced the ULDiS-1500PHL, our optical film deposition system for wafers, and reported on an a-Si:H-based near-infrared BPF we developed using the system. The a-Si:H exhibited good optical properties in the verification results, and therefore can be expected to be applicable to not only 940 nm BPFs but also to BPFs near 1320-1480 nm, where there is high biological permeability, and to the thinning of IR-pass filters. Finally, since this device can also be used with various metal materials such as Nb, Ta, and Ti rather than Si, it can be expected to contribute to a wide range of production technologies in the optical thin film field, such as IR-cut filters and anti-reflective film applications.

References

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