K-8-05 Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp743-744

Development of large size crystal growth technology of oxide eutectic scintillator and a proto-type Talbot-Lau imaging system

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Abstract

The 25 x 25 mm^2 wafers of Tb doped GAP/α-Al_2O_3 eutectic were fabricated by μ-PD method using the Ir crucible with a 25 x 25 mm^2 die. The proto-type of X-ray phase imaging detector was developed using the CMOS sensor with the FOP and eutectic wafer. X –ray spots with 8.24μm period was observed using the detector. X-ray phase imaging of the nylon ball was carried out in this study. It could be confirmed that a phase change of about 2 μm as the phase change occurs in the air and the nylon spherical interface.

1. Introduction

In X-ray Talbot-Lau interferometry, single or mulch absorption gratings between a sample and X-ray generate detector differential-phase, and visibility-contrast images. The absorption gratings generate Moire fringes and differential-phase, and visibility-contrast images are obtained from analysis of the spatial frequency of the Moire fringes. However absorption gratings absorbed the transmitted X-ray and sensitivity is degraded. Recently submicron-diameter phase-separated scintillator fibers (PSSFs) were reported and they possessed both the properties of an optical fiber and a radiation-to-light conversion. The PSSFs were fabricated using a directionally solidified eutectic (DSE) system. The DSE systems have been discovered in various materials for many applications [1,2]. In PSSFs, the light emitted from the scintillator fibers is confined and transported along the fiber direction by a total reflection mode, so that high-resolution radiation imaging can be achieved. Up to now, $GdAlO_3$(GAP)/ α-Al_2O_3 [3], have been reported as PSSFs. Tb:GAP/α-Al_2O_3 showed well aligned PSSFs eutectic with optical transparency structure. The high-resolution X-ray imaging was reported by combining with both the properties of an optical fiber and an X-ray-to-light conversion. The 65% of contrast transfer function (CTF) a gold grating phantom with a 4 μm aperture, corresponding to a bundle of 10 fibers, was achieved using a 2 x 2 mm square plate with 350 μm-thick Tb 8mol%:GAP/ α-Al_2O_3 scintillator[3]. In this study, large area growth technique of Tb doped GAP/α-Al_2O_3 eutectic scintillator using the micro pulling down (μ-PD) method was developed for designing direct X-ray phase imaging. Furthermore, proto-type of X-ray Talbot-Lau imaging system was developed.

2. RESULTS

A stoichiometric mixture of 3N Tb_4O_7, 4N Gd_2O_3 and 5N α-Al_2O_3 powders were used as starting material. Tb and Eu doped GAP/ α-Al2O3 eutectic crystal was grown at the eutectic composition (Gd_2O_3-Al_2O_3 (23:77 mol. %). Crystal growth was performed by using a micro-pulling down (μ-PD) furnace with the vacuum-tight chamber. Ir crucible with a 25 x 25 mm^2 die and a 0.5 mmΦ hole for supplying the melt was used. At the beginning of the fabrication, solid-liquid interface on the die was not stable. When the temperature is too high, the melt overflows from the die and seed, and when the temperature is too low, the melt does not sufficiently cover on the die (Figure 1-a). After optimizing growth condition such seed size, pulling rate, atmosphere, insulator set-up and temperature gradient along the growth direction, prismatic shaped eutectic could be fabricated (Figure 1-b). Figure 1-c showed a cut and polished wafer of the 3-b eutectic at the cross section. Optically transparent parts can be confirmed in a over 80% area on the 25 x 25 mm^2 wafer. Figure 1-d showed a cut and polished sample with 3 x 3 x 0.3 mm^3 size.

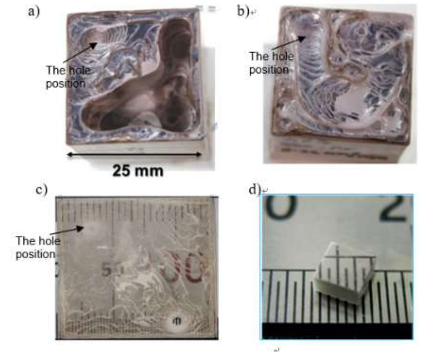

Fig. 1 Photographs of the grown eutectic (a) at the beginning stage, (b) after optimization of the growth conditions, (c) cut and polished wafer of the 3-b eutectic and (d) sample with 3 x 3 x 0.3 mm^3 size.

Figure 2-a shows a schematic drawing of the typical X-ray Talbot-Lau imaging set up. G0 is a source grating with a 12.75 μm pitch. G1 is a Phase grating with a 10.01 μm pitch. X-ray was eradiated using a W target with 0.3mm of effective focal spot size at 40kV and 120mA. Generally, absorption gratings at the G2 position used in X-ray phase imaging generate periodic patterns by transmission and absorption of X-rays. In the case of our developed eutectic scintillator based detector, the G2 absorption grating was not used.
Figure 2-b shows a detector using a CMOS sensor (SONY, 2.5μm pitch, 2080x1552pizels, 5.2 x 3.9mm sensitive area) with a fiber optic plate (FOP, Hamamatsu J5734, 3μm fiber diameter) and the eutectic wafer. An Al deposited layer was formed on the surface of the eutectic plate as a reflective layer. This detector was installed at the position of G2 in figure 1 to construct an X-ray phase imaging apparatus without any absorption gratings.At the beginning of the X-ray phase imaging, the image of the detector itself as a back ground (BG) image was acquired. After the fast Fourier transforming (FFT) of the BG image, the spots corresponding to the periodic image of the eutectic and FOP image were confirmed.
A nylon ball with 4mm diameter was set at the sample position in figure 1 and was imaged using the developed X-ray phase imaging detector. In general, in this X-ray phase imaging method, it is possible to obtain an absorption image and a scatter image in addition to the differential phase image from the change of the X-ray image pattern itself. Line profiles at edge position of the nylon ball before and after inserting the ball was shown in figure 3. The shift of the spot position of the X-ray image becomes a differential phase image, the difference of the average value of the image pattern forms an absorption image, and the amplitude change of the image spot forms a scatter image.
The above three kinds of changes before and after inserting the ball were imaged at the same time in figure 4. Here, imaging time was 180 sec. Since the differential phase image and the scattered image can be displayed in the x direction and the y direction, a total of five outputs are obtained by one imaging. It was also observed that this nylon sphere has a hollow region at the centre.
It could be confirmed that a phase change of about 2 μm as the phase change occurs in the air and the nylon spherical interface. A technique of X-ray phase imaging could be realized in the absence of absorption grating.

a) b)

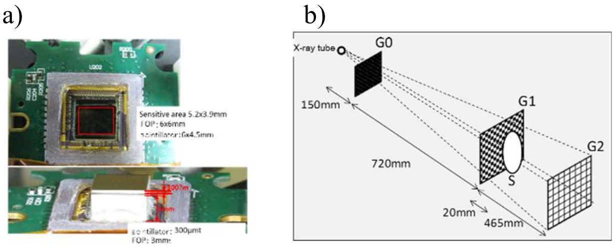

Fig.2 a) schematic drawing of the X-ray Talbot-Lau imaging set up and b) Photograph of the CMOS sensor with the eutectic scintillator wafer and FOP.

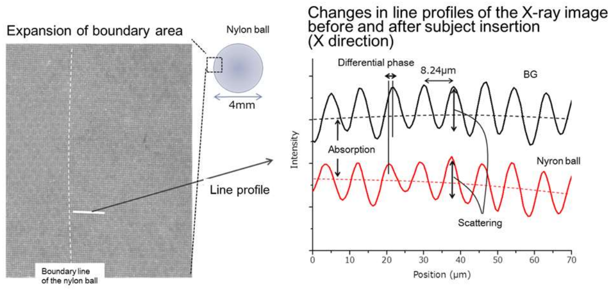

Fig. 3 X-ray image of nylon ball (left) and Line profiles at edge position of the nylon ball before and after inserting the ball (right)

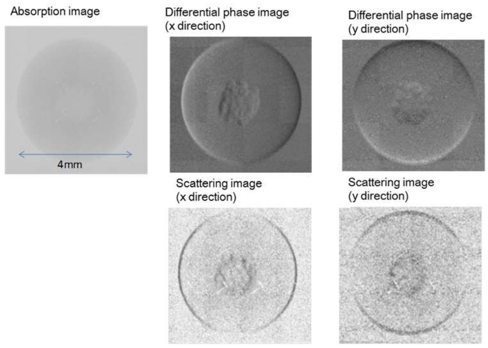

Fig. 4 Absorption, differential-phase, and scattering images of the nylon ball

3. Conclusions

The 25 x 25 mm^2 wafers of Tb doped GAP/α-Al_2O_3 eutectic were fabricated by μ-PD method using the Ir crucible with a 25 x 25 mm^2 die. The proto-type of X-ray phase imaging detector was developed using the CMOS sensor with the FOP and eutectic wafer. X –ray spots with 8.24μm period was observed using the detector. X-ray phase imaging of the nylon ball was carried out in this study. It could be confirmed that a phase change of about 2 μm as the phase change occurs in the air and the nylon spherical interface. A technique of X-ray phase imaging could be realized in the absence of absorption grating.
In this study, X-ray phase imaging without absorption lattice using eutectic structure have demonstrated for the first time in the world.It is possible to fundamentally solve the reduction in sensitivity and the accompanying increase in the amount of X-ray irradiation to the subject, which is a problem in conventional X-ray phase imaging using absorption gratings. Future tasks include further expansion of eutectic wafer with well aligned eutectic structure. In the near future, comparison of the signal difference to noise ratio (SDNR) and resolution with conventional X-ray phase imaging and bio-imaging using our detector are planned.

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