Research toward the development of compact neutron interference imaging instrument with gratings

Yoshié OTAKE¹, Margie OLBINADO⁶, Yoshichika SEKI¹, Katsuya HIROTA¹, Yutaka YAMAGATA⁶, Jungmyoung JU⁴, Tomohiro ADACHI¹, Shinya MORITA¹, Yoshihisa IWASHITA² Masahiro HINO³, Masahiro ICHIKAWA², Masaaki KITAGUCHI², Toshio TAKAHASHI⁶, Hideki YOSHIZAWA⁴, Seung Wook LEE⁵, Wataru YASHIRO⁶, Atsushi MOMOSE⁶

¹RIKEN, Wako, Saitama, 351-0198, Japan
²UKUICR, Uji, Kyoto, 611-0011, Japan
³KURRI, Kumatori, Osaka, 590-0490, Japan
⁴ISSP U-Tokyo, Kashiwanoha, Kashiwa, Chiba, 277-8581, Japan
⁵KAERI, 1045 Daedeok-daero, Daejeon, Korea
⁶Advanced Material Science FS U-Tokyo Kashiwanoha, Kashiwa, Chiba, 277-8562, Japan

yotake@riken.jp

Abstract. The neutron interference imaging experiment with two absorption gratings has been done. We develop new way to fabricate absorption gratings for neutron with the pitch of 150 μm, 180 μm, and 200 μm. Compact imaging detector system is developed, whose weight is 2kg. Small break in an acrylic plate, the welded place of Nb plate were observed, it reveals that the neutron interference imaging method can become new method of a nondestructive inspection for reinforced plastics and composite material such as CFRP and so on.

1. Introduction
The composite material consisting of light elements becomes widely used such as a body of the airplane, cars, even space rockets. It is the serious problem that there is no established way for nondestructive inspection of the composite material until now. Here we show one potential method to observe the crack, internal delamination of them.
There are several methods of phase contrast imaging in the x-ray field, such as projection imaging method as phase contrast imaging with perfect crystal interferometer, with prism interferometer, with grating interferometer, by detecting refraction angle, and such technique of microscope as Zernike phase difference, differential phase, holography, and so on. The phase contrast imaging using Talbot-Lau interferometer for x-ray [1] [2] [3] [4] is now widely used. The neutron phase contrast imaging with grating [5] [6] [7] becoming more popular now a days. However, in neutron case, to fabricate absorption grating is much more difficult than in X-ray case, because Gd is unworkable material. We, here, show the result of neutron interference image with two absorbing gratings. We have fabricated neutron absorbing gratings whose pitches are as large as 150 μm, 180 μm, and 200 μm with gadolinium oxide powder, while neutron absorption gratings with wide pitch is normally made with Gd sputtering [8], or electroforming process. We also introduce a portable imaging detector system as an imaging detector. Three types of the images, absorption image, differential phase image, visibility contrast image, are obtained with them, as in the case of Talbot interferometer imaging method. A small crack in an acrylic plate, and a weld part of niobium plates were observed. We discuss future possibility in last chapter shortly.

2. Neutron Absorbing Grating
We have made new type of the neutron absorption gratings with large pitch. 100 μm width grooves with 200 μm depth are cut with the pitch of 150 μm, 180 μm, 200 μm on the surface of silicon substrate as is shown in Fig.1 (a). The silicon gum which contains Gd₂O₃ powder is filled in the channels, as is shown in Fig.1 (b).

(a)

(b)

Fig.1 (a) Channels of the width of 100 μm and the depth of 200 μm are cut on the surface of silicon substrates. (b) The silicon gum which contains gadolinium oxide powder is compacted there.

The aspect of this absorbing grating is shown in Fig.2. The diameter is 150mm.
The surface observation with ten times magnified is shown in Fig.3. The white lines are the silicon lines and the dark lines are the mixture of gadolinium oxide powder and silicon gum.

We made two of the same absorption grating by changing the weight ration of the Gd2O3 powder in Si-gum with 50%, and 60%. The neutron moiré fringes created by them are shown in Fig.4. It ensures their completeness as absorption gratings.

We can find the boundary line in the picture of the moiré fringes, the largest pitch of the moiré fringes is created by the superposition of the part of 150 μm pitch grating, and so on as shown in Fig.4.

We can find the boundary line in the picture of the moiré fringes, the largest pitch of the moiré fringes is created by the superposition of the part of 150 μm pitch grating, and so on as shown in Fig.4.

3. Interference imaging with two absorbing gratings

The neutron interference imaging experiment has been done at ULS, C1-3 beam port of JRR3 in JAEA (Japan Atomic Energy Agency), Tokai, Japan. Neutron wave length is 0.44nm.

The interference imaging experiment has been done with two absorption gratings, and portable 2D detector system. Two neutron absorbing gratings are set behind the sample; the distance between two gratings is 14.5mm as shown in Fig. 5(a). Portable compact neutron camera system is developed with Zn/S6LiF scintillator of 0.25mm thickness and CCD (IMB-7012G) together with camera box. The total weight of this system is less than 2kg. The effective area of imaging is 53×40mm², and the pixel number is 656×484.

The experiment has performed by scanning one of two absorption gratings. We use two 180 μm pitch gratings.
The distance between two absorption gratings which is 14.5mm is determined by the estimated source size. To take the interference imaging, five shots are taken with and without sample by scanning the second gratings. The samples are acrylic plate with small crack as shown in Fig. 6 (c) and the weld part of Nb plate as shown in Fig. 6 (g).

![Experimental setting and measured moiré fringes without sample](image)

(a) Two absorption gratings are set behind the sample.
(b) The moiré fringes observed behind the second gratings with camera system.
(c) The intensity measured with 3He detector.

The distance between two absorption gratings which is 14.5mm is determined by the estimated source size. To take the interference imaging, five shots are taken with and without sample by scanning the second gratings. The samples are acrylic plate with small crack as shown in Fig. 6 (c) and the weld part of Nb plate as shown in Fig. 6 (g).

![Images of a small crack in an acrylic plate](image)

(a) absorption image (b) differential image (c) visibility contrast image with neutron, and (d) its photo, small crack part is surrounded by red dotted line.

Images of welded part of Nb plate, (e) absorption image (f) differential image with neutrons, (g) its photo.
Small break and crack of an acrylic plate which is in the area of red square in the picture, Fig.6 (d), is observed in absorption image and differential phase image clearly with two absorption gratings. The weld part of niobium plates shown in Fig.6 (g) is observed with absorption image, Fig.6 (e), small spots are observed in differential phase image, Fig.6 (f).

As is shown in Fig. 6 (a)-(c) and (e)-(g), with two absorption gratings, we could get phase contrast imaging. It means that we use the deformation of the shadow of the first absorption grating which is created by phase shift through the sample, in other words, the deformation of the wave front, caused by the sample, and draw out the phase information of the sample by scanning the second absorption grating. In Fig.6 (c) shows the deformation of the shadow of the first grating schematically. The deformed shadow is scanned by the second absorption grating show as in Fig. 6(d). Actually the special coherence length at the second grating is 50.1 μm. With this method, we don’t need the longer special coherence length than the pitch of the second grating.

One of our important aims of the useful neutron interference imaging system is following. We like to develop non-destructive inspection system for such composite materials as resin material, CFRP, FRP, reinforced plastic and so on. These materials become widely used as a body of car, airplane or important parts in aeronautical field because the light weight and strength although until now there is no way to detect their internal deletion, internal water penetration and so on. The main elements of CFRP or reinforced plastic are H, C, and O. The neutron scattering cross section of C and O are more than thousands times larger than absorption cross section. So, we evaluate neutron phase imaging method be one of the best way to detect their internal small deletion. The crack in the acrylic plate is clearly shown in absorption imaging as shown in Fig. 6(a), and differential phase imaging as shown in Fig.6 (b). This method is different from the experiment of two absorption gratings in [9].

4. Conclusion
The small break in an acrylic plate was successfully observed using two neutron absorption gratings. This result ensures us that the interference neutron imaging method using gratings can be one method of nondestructive test for the deletion or small crack or internal delamination inside reinforced plastics, composite material such as CFRP, and so on.

References
[1] A.Momose et al. Jpn.J.Appl. Phys. 42 (2003) L866
[2] T.Weitkamp et al. Appl.Phys.Lett. 86 (2005) 054101
[3] F.Pfeiffer et al. Nature letters 2 (2006) 258
[4] A. Momose et al. Jpn. J. Appl. Phys. 45 (2006) 5254
[5] Pfeiffer, et al. Phys. Rev. Lett. 96 (2006) 215505
[6] C. Grunzweig, et al. Phys. Rev. Lett. 101 (2008) 025504
[7] S.W. Lee et al. Nucl. Instr. and Meth. A605 (2009) 16
[8] C. Grunzweng, et al. Rev. of Sci. Instr. 79 (2008) 053703
[9] Zhi-Feg Huan, et al. Phys. Rev. A 79 (2009) 013815