A high-speed, high-sensitivity, large aperture avalanche image intensifier panel

Yasunobu Arikawa, Ryosuke Mizutani, Yuki Abe, Shohei Sakata, Jo Nishibata, Akifumi Yogo, Mitsuo Nakai, Hiroyuki Shiraga, Hiroaki Nishimura, Shinsuke Fujioka, Ryosuke Kodama,
Institute of Laser Engineering, Osaka University,
2-6 Yamadaoka, Suita, Osaka, 565-0871 Japan

Abstract Fast neutron radiography has been a powerful tool for diagnosing of the large size low-Z objects such as water or oil in stainless pipes, water in the concrete bridge or wall with sizes of a meter. Short pulse laser driven neutron source has been expected as an ideal neutron source because it has very small point source (~100 µm) and short pulse duration (~10 ps). We can discriminate the subjected radiography neutrons and back ground scattered neutron from unwanted places by using time of flight difference, because the pulse duration of neutron source is sufficiently short. In this technique, a fast response (~100 ns) and high sensitivity (single neutron detectable) scintillation imaging device is needed. Especially, an image intensifier to amplify a weak light from the scintillator to sufficiently bright light for the camera is key device. A large-aperture high-sensitivity image intensifier panel that consists of an avalanche photodiode (MPPC) array and a light-emitting diode (LED) array is developed. The device has 40% quantum efficiency, over 10^5 optical-optical gain, and 80-ns time resolution. The aperture size of the device is ~15 cm, and it can be scaled to arbitrarily larger sizes. The image resolution of the current device is 2 mm, although it can be scaled to smaller sizes in the near future.

Keywords: neutron radiograph, avalanche photodiode

1. Introduction

Neutron radiography has been expected as a next generation non-distractive investigation [1]. Conventionally thermal neutrons (~meV) were widely used for the radiograph because the detection of thermal neutron is relatively easy [2, 3]. Recently, fast neutron (~MeV) generated by ultra-intense-lasers has been getting popular because of its short pulse duration [4, 5]. Fast neutron can be used as an new generation radiograph source to insight the large size, low-Z materials in high-Z material, such as water or oil in the stainless steel pipes or water in concrete walls which are meter sizes.

Fast neutron radiograph imaging uses organic scintillator pixel array and an image intensifier CCD cameras [6]. However conventional image intensifier especially large aperture image intensifier using micro channel plate (MCP) was extremely expensive and it is almost impossible to create more than 15-cm diameter size. We developed a large aperture (15 cm x 11 cm) image intensifier using avalanche photodiode array and LEDs [7] with less than 1/10 of the cost.

2. Avalanche image intensifier panel

A MPPC (Multi-Pixel Photon Counter) array is a photon counting device produced by Hamamatsu, co ltd, having ~1 mm pixel size with containing more than 1000 geiger avalanche elements. MPPC is a semiconductor device that can be mass-produced, so the cost can be greatly reduced in the near future. MPPC has a higher quantum efficiency (~40% as shown in Fig. 2) than that of MCP (~14%), here the quantum efficiency of MPPC is defined as a product of the APD's quantum efficiency, fill factor, and Geiger avalanche probability, and that of MCP is defined as a product of 20% quantum efficiency of the cathode and 70% effective MCP hole area. The electron–electron gain is also large, ~10^6. The electric current output from MPPC generates photons by LEDs. MPPC requires only a small

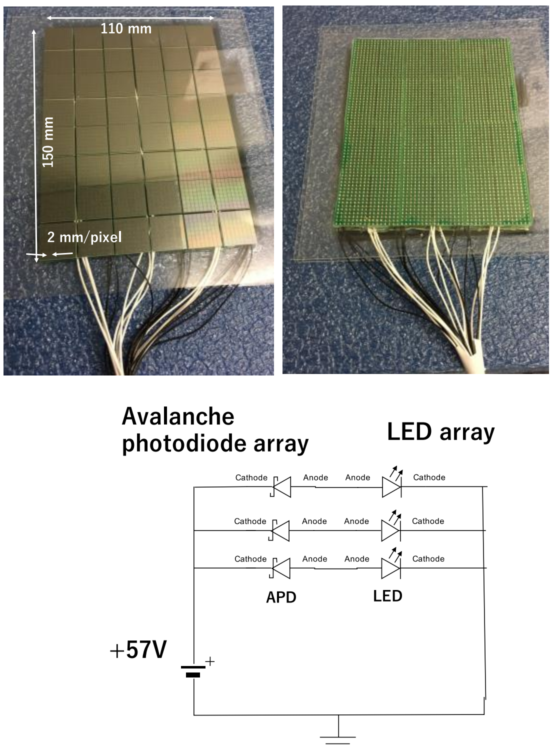

Figure 1 The photo of the avalanche image intensifier panel and circuit of the system.

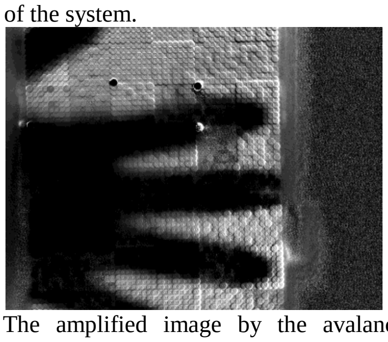

Figure 2 The amplified image by the avalanche image intensifier panel with a weak light (~1 µW).

voltage power supply (+57V) unlike MCP (~5000 V). Figure 1 shows the photo of the avalanche panel and the schematics of the circuit.

The impulse response of the avalanche image intensifier system was measured by using an input light of 70-ps pulse

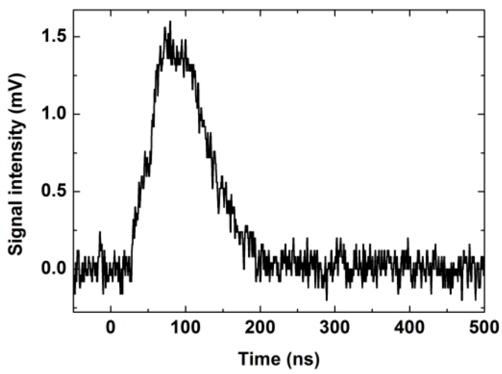

Figure 3 The impulse response of the avalanche image intensifier panel.

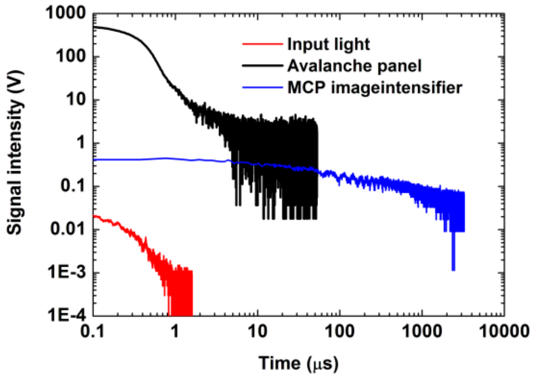

Figure 4 The comparisons of the response function of the amplified light output. Red line is input light from a scintillation of NaI:Tl scintillator with Am-241 alpha source, black line is the light output of avalanche image intensifier panel, blue line is light output MCP image intensifier.

duration (Hamamatsu PLP-10). The light output was measured by using a 300-ps time response Si photodiode (Hamamatsu S5973) and a 1 GHz oscilloscope. The pulse duration of the output pulse was measured to be 80 ns in FWHM as shown in Fig. 2. Figure 3 shows the comparisons of the impulse response of the amplified light output between MCP image intensifier and the avalanche image intensifier panel. the red curve indicates input light (NaI; Tl scintillator), black curve indicates the avalanche panel output (with +57 V voltage supplying), and blue curve indicates the MCP-I.I. output with linear time scale (a) and log time scale (b). The output signal from a typical MCP I.I. (Hamamatsu C9546-02) was also compared. The gain was set to its maximum with the voltage of +6000 V and the luminous gain was $5x10^6$. The peak brightness of the avalanche panel was 1000 times higher and the response time was 1000 time faster than the conventional MCP I.I. This system can also switch On/Off by applying gate pulse with the response time of ~100 ns. This allow us to utilize this device as a high speed imaging sensors with the combination of the standard CCD camera.

3. Future prospects

Currently, the pixel size is limited to 2 mm due to the limitation of the manufacturing process of the circuit using printed board. In the future we will design a smaller pixel size down to 0.1 mm using micro-patterning technique like LED panel. MPPC is basically made by silicon thus avalanche diode coupled LED element can be also manufactured. The 80 ns of the total system response time, which is much slower than response times of the MPPCs (~2 ns) and LEDs (~3 ns), is also considered to be limited by the imperfection of the circuit design. There are no resistor in the circuit for stabilize the current flow in current design, and we are designing new proto type circuit. We expect to open a new collaborations between the image sensing developing group and us and by doing this we can break through the these limitations.

Reference

[1]Von der Hardt Heinz Rottger, "Neutron Radiography Handbook: Nuclear Science and Technology", Springer Science & Business Media, (2012)

[2] Hawkesworth, M.R. (1977). Neutron radiography Equipment and methods. Atomic Energy Review, 15(2), 169-220.

[3] M Strobl, I Manke, N Kardjilov, A Hilger, M Dawson, J Banhart, JOURNAL OF PHYSICS D: APPLIED PHYSICS, 42 (2009) 243001,

[4] M. Roth, D. Jung, K. Falk, N. Guler, O. Deppert, M. Devlin, A. Favalli, J. Fernandez, D. Gautier, M. Geissel, R. Haight, C. E. Hamilton, B. M. Hegelich, R. P. Johnson, F. Merrill, G. Schaumann, K. Schoenberg, M. Schollmeier, T. Shimada, T. Taddeucci, J. L. Tybo, F. Wagner, S. A. Wender, C. H. Wilde, and G. A. Wurden, Physical Review. Letters. 110, 044802, (2013)

[5] A. Kleinschmidt, V. Bagnoud, O. Deppert, A. Favalli, S. Frydrych, J. Hornung, D. Jahn, G. Schaumann, A. Tebartz, F. Wagner, G. Wurden, B. Zielbauer, M. Roth, Physics of Plasmas 25, 053101 (2018)

[6] Y.Arikawa, S. Matsubara, Y. Abe, Y. Kato, H. Kishimoto, A. Yogo, H. Nishimura, M. Nakai, H. Shiraga, S. Fujioka, H. Azechi, Y. Otake, K. Mima, Y. Honda, Proc. SPIE 10328, Selected Papers from the 31st International Congress on High-Speed Imaging and Photonics, 103280T, (2017)

[7] Y. Arikawa, S. Matsubara, H. Kishimoto, Y. Abe, S. Sakata, A. Morace, R. Mizutani, J. Nishibata, A. Yogo, M. Nakai, H. Shiraga, H. Nishimura, S. Fujioka, and R. Kodama, Review of Scientific Instruments 89, 10I128 (2018)