Invited Paper

Novel Electron Source using Wide Band Gap Semiconductor Photocathode with an NEA surface

Tomohiro Nishitani[a, b], Takashi Meguro[c], Masao Tabuchi[a], Hiroshi Amano[d]

[a] *Nagoya University Synchrotron radiation Research center, t.nishitani@nusr.nagoya-u.ac.jp, Japan*
[b] *Radiation Lab., RIKEN, Japan*
[c] *Tokyo University of Science, Japan*
[d] *Department of Electrical Engineering and Computer Science Graduate School of Engineering, Japan*

Photocathodes using III-V semiconductors with a negative electron affinity surface (NEA-semiconductor photocathodes) can emit spin-polarized electrons using a circular polarized laser [1]. The key technology of NEA-semiconductor photocathodes is that NEA surface enables excited electrons in the conduction band to escape to vacuum as shown in Fig. 1. NEA-semiconductor photocathodes have played very important roles as spin-polarized electron sources in several fields of fundamental science [2]- [4]. NEA-semiconductor photocathodes were also found to be useful high brightness electron source for a high energy accelerator based on linac [5], because the photocathodes has the advantages of short beam pulse width (several ps), large emission current (several mA [6]) and small momentum spread (~0.2eV [7], [8]) of extracted electrons. Recently, NEA-semiconductor-photocathodes are also expected to be a novel electron source for the next electron microscope such as the dynamic-TEM and the ultra-fast microscopy. The Spin-TEM using the NEA-GaAs photocathode is under development in Nagoya University [8].

However, the surface of NEA-semiconductor photocathodes is damaged by back bombardment of ionized residual gas by photoelectrons [9]. The decrease in quantum yield due to the damage to the surface results in a short lifetime during high-photocurrent operation. Therefore, the conventional NEA-semiconductor photocathode should be used under quality ultra-high vacuum for maintaining the NEA state.

We suggested that the material with smaller energy difference between the conduction band minimum and a vacuum level is more suitable photocathode material for improvement of the decrease in quantum yield. To confirm this hypothesis, we developed photocathodes using AlGaAs semiconductor and measured the lifetime during extraction of photocurrent. AlGaAs photocathodes achieved a 10-times longer life than the conventional NEA-semiconductor (GaAs) photocathode [10].

We also suggest that a wide-band gap semiconductor is more suitable photocathode material for a long NEA lifetime. We considered that the NEA-semiconductor photocathode with large $d\chi$ is essential for improvement of the decrease in quantum yield. In a p-type semiconductor, the vacuum level is pull down to lower energy level by the surface band-bending effect. The surface band-bending depth depends on the band-gap energy. Therefore, a p-type semiconductor with wide-band gap enables to have large $d\chi$ when the surface is activated to an NEA state.

We fabricated the p-GaN and the p-GaAs samples for an NEA-semiconductor photocathode and measured a change of quantum yield during the NEA activation of samples as shown in Fig. 2. The quantum yield of the p-GaN sample after the NEA activation was the same as that of the p-GaAs sample. However, in first cesium deposition process, the quantum yield of the p-GaN sample (4e-2) was higher more than 3 figure than that of p-GaAs sample (1e-5). These results suggest that the surface of the p-GaAs sample dose not reach an NEA state in first cesium deposition process, but the surface of the p-GaN sample reaches an NEA state in first cesium deposition process.

We concluded that a p-GaN semiconductor is expected to be more suitable the photocathode with a long NEA lifetime because the surface can reach an NEA state by small Cs effect. We will measure lifetime of samples under large current (100uA) using the 50keV photocathode electron gun of Nagoya University.

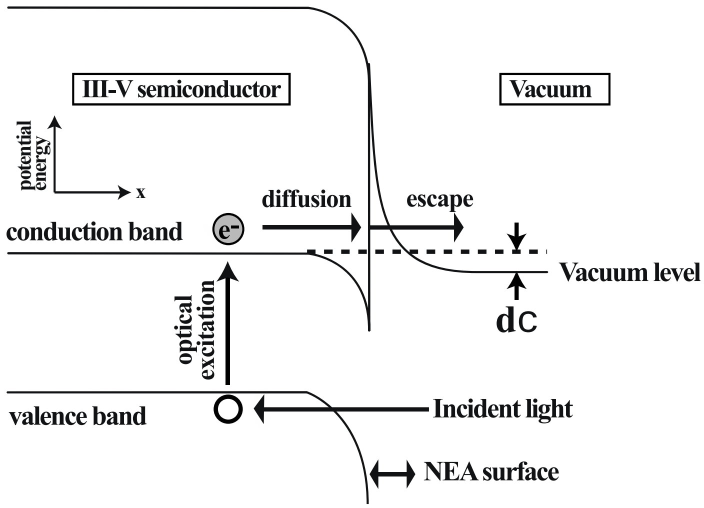

Fig. 1 Emission model from NEA-semiconductor photocathode: optically excited electrons drifting toward the surface can escape to the vacuum through NEA surface.

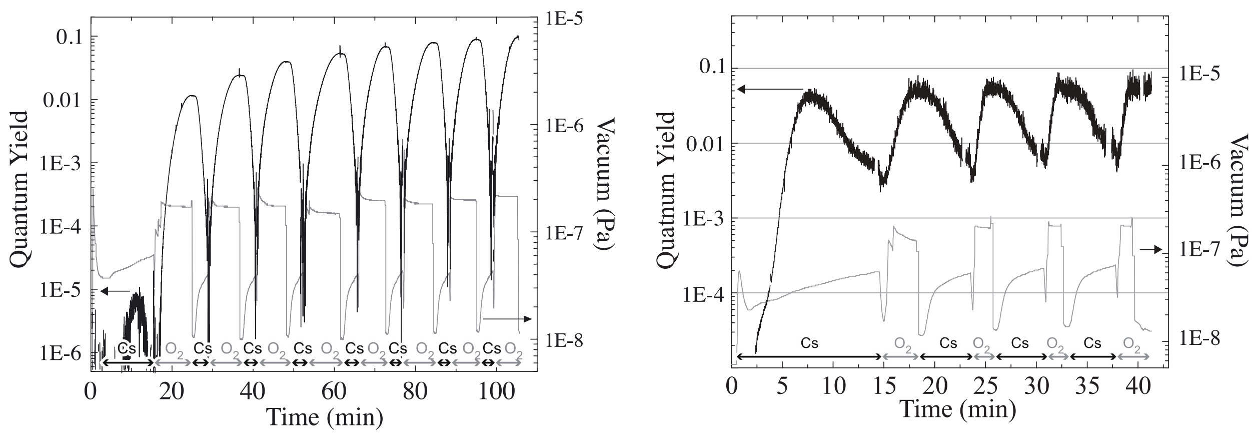

Fig. 2 NEA activation processes of the p-GaAs sample (left) and the p-GaN sample (right). The quantum yield reaches a maximum while repeating the increase and decrease by alternate introduction of cesium and oxygen.

References

[1] T. Nishitani et al. *J. Appl. Phys.* 97 (2005) 094907
[2] SLD Collaboration *Phys. Rev. Lett.* 70 17, pp.23-31 (1993)
[3] J. Kirschner, D. Rebenstorff, and H. Ibach, *Phys. Rev. Lett.* 53, 698- 701 (1984)
[4] J. Unguris, A. Seiler, R. J. Celotta, D. T. Pierce, P. D. Johnson, and N. V. Smith, *Phys. Rev. Lett.* 49, 1047- 1050 (1982).
[5] Sol M. Gruner, et al., *Review of Scientific Instruments*, Vol. 73 Issue3 pp.1402-1406 (2002)
[6] G. R. Neil, et al., *Phys. Rev. Lett.* 84, pp.662-665 (2000)
[7] D.A. Orlov, et al., *Nucl. Instrum. Methods* A 532, 418 (2004)
[8] M. Kuwahara , S. Kusunoki , X. G. Jin , T. Nakanishi , Y. Takeda et al., "30-kV spin-polarized transmission electron microscope with GaAs–GaAsP strained superlattice photocathode", *Appl. Phys. Lett.* 101, 033102 (2012)
[9] J. Grames et al., *Proceedings of Particle Accelerator Conference*, pp. 2875-2877 (2005)
[10] Tomohiro Nishitani, Masao Tabuchi, Yoshikazu Takeda, Yuji Suzuki, Kazuya Motoki, Takashi Meguro, *Japanese Journal of Applied Physics* 48 (2009) 06FF02