The annealing effect for the air-exposed surface on the GaN photocathode

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Semiconductor photocathode can easily create multi-electron beams with multi laser beams. Therefore, it is an attractive candidate for e-beam lithography to improve manufacturing throughput with multi e-beams.[1] In general, the pressure of an e-beam lithography system is over 10^{-6} Pa. On the other hand, ultra-high vacuum (UHV) environment (~10^{-8} Pa) is essential for a GaAs photocathode because of the fragility of a negative electron affinity (NEA) state created by Cs deposition. Meanwhile, GaN has longer NEA life time than GaAs in UHV.[2] Therefore, we can expect a better performance of GaN photocathode compared with GaAs photocathode in rough vacuum. Assuming a rough vacuum application such as e-beam lithography, we investigated behaviors of NEA GaN photocathode which is exposed in atmospheric pressure gas.
A p-type GaN is used in this study. The NEA activations were performed in the typical way using the NEA test system[3]. Firstly, the activated sample was exposed by pure N_2 and annealed in NEA test system to observe a recovery of the quantum efficiency (QE). Secondly, the NEA activated sample was transferred to the photoelectron spectroscopy measurement system at Aichi Synchrotron Radiation Center BL7U[4] to study the change of work functions and energy distribution curves (EDC) of photoelectrons at several temperatures. Figure 1 shows that QE increased with increase of anneal temperature. Figure 2 shows that EDC’s from GaN photocathode changed with anneal temperature: photoelectrons increased by 12 times, threshold decreased by 0.32 eV and FWHM of EDC increased from 0.19eV to 0.35 eV. The vacuum level of the surface shifted toward lower energy and electron affinity became negative with the anneal. In conclusion, although QE of GaN photocathode decreases by the atmosphere pressure gas, the functional surface survives and recovers with an anneal treatment in UHV.

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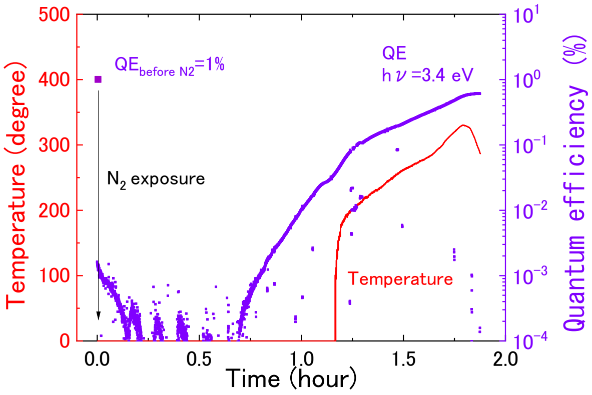

Figure 1: Quantum efficiency (QE) evolution while the anneal treatment: The sample is a p-type GaN with 250 nm thickness. To monitor photo current, a bias voltage of −100 V was applied to the sample with illuminating the light with energy of 3.4 eV. When the sample was exposed to N_2, QE dropped from 1 % to less than 10^{-4} %. After the exposure, when the annealing temperature increased gradually, the QE increased slowly to 0.28 %. The anneal stopped when the increase of QE saturated.

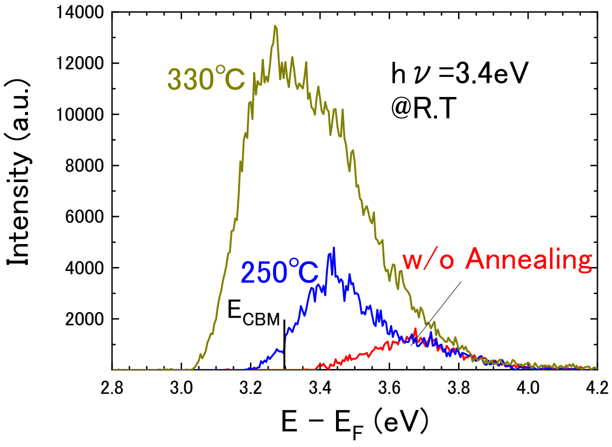

Figure 2: Comparison of energy distribution curves (EDC) from GaN photocathode between before and after annealing: The excitation energy was 3.4 eV and the applied voltage was -20 V to detect electros with lower energies.[5] The horizontal axis shows an electron energy above fermi energy of the sample, and the conduction band of the sample is labeled as E_{CBM}, which is estimated from the carrier density of the sample. Each curve was measured at room temperature after anneals. As anneal temperature increased from room temperature to 330°C, photoelectrons increased by 12 times, threshold decreased by 0.32 eV, and FWHM of EDC increased from 0.19eV to 0.35 eV.

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