Control of photoemission properties from NEA-GaAs surfaces by repetitive thermal pretreatments

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Negative electron affinity (NEA)-GaAs is an important candidate for next-generation electron sources[1] because of its superior electron-emission characteristics, such as high spin polarization, small energy spreading, short pulse availability, and high quantum efficiency (QE). Figure 1 shows an NEA sequence consisting of the thermal pretreatment and the NEA activation at room temperature. The NEA activation was carried out using the yo-yo method, which is the co-adsorption of Cs and oxygen on the GaAs surface after the thermal pretreatment. The NEA surface is extremely sensitive to environments and easily degraded, and the photoemission properties depend on the surface pretreatment condition.

In our works, we have found a higher QE through the specific combination of the NEA sequence[2], as shown in Fig. 2. It should be noted that the thermal pretreatment process at a lower temperature condition insufficient for removing residual species (480°C) resulted in a higher QE than that at 580°C by the following NEA activation. This is probably due to the formation of efficient electron emission sites by the reaction of residual species with newly supplied Cs and O_2. However, the simple repetition of the NEA sequence at a lower temperature condition led to the abrupt decrease of QE. Only the combination of NEA activation with the pretreatment at 580°C and the successive NEA activation sequence at 480°C realizes the approximately 30% increase of QE.

Figure 3 shows the QE evolution as a function of the NEA activation sequence. Samples A and B were scribed from the same kind of GaAs(100) substrate, but the stable QE values obtained were different. However, the behavior of both was almost similar and this tendency was independent of the absolute QE value. These results indicate that the formation and emission processes of electrons are independent and that the electron emission process is very sensitive to surface adsorbates. We have reported that several kinds of Cs-related adsorbates exist at NEA surfaces[3], and only some of them are expected to contribute to actual electron emission. It was also found that a huge number of nano-structures were formed at the NEA-GaAs surfaces[3]. Additionally, the relation of QE with surface nano-structures will be discussed in this study.

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[1] T. Nishitani, et al., Jpn. J. Appl. Phys., 48, 06FF02 (2009).[2] Y. Inagaki, et al., IEICE Trans. Electron., E99-C, 371 (2016).[3] K. Hayase, et al., Jpn. J. Appl. Phys., 52, 06GG05 (2013).

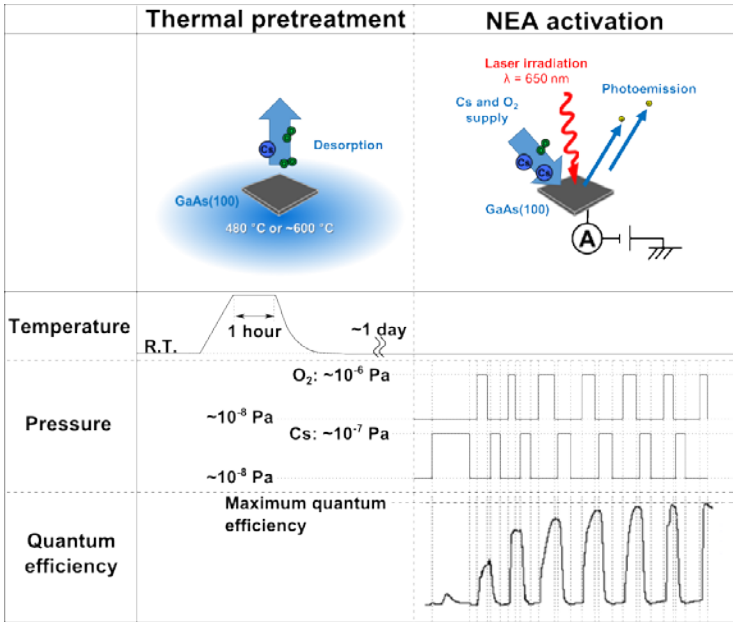

Figure 1: Schematic diagram of the NEA sequence: First, the sample was heated to ~600°C or 480°C for an hour and cooled to room temperature (RT). Subsequently, NEA activation was performed by the yo-yo method.

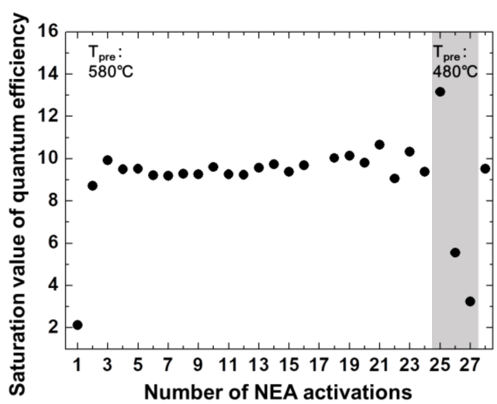

Figure 2: QE evolution as a function of the number of the NEA sequence: Repetition of the NEA sequence with the thermal pretreatment at a higher temperature condition induced a stable QE value (~10%), and the QE was increased by the following low-temperature NEA sequence.

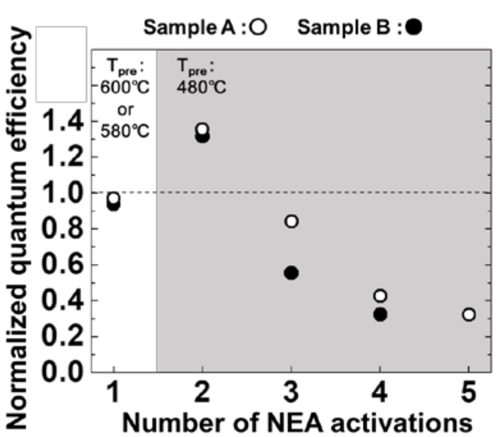

Figure 3: QE as a function of the number of the NEA sequence: Open and solid circles indicate QE of samples A and B, respectively. The QE values were normalized by each stable value of 4% (sample A) and 10% (sample B), respectively. In this figure, plots at "1" NEA activation show QEs with the thermal pretreatment at a higher temperature condition (600°C or 580°C), and other plots were taken with the pretreatment with a lower temperature condition (480°C).