OBSERVATION OF NUCLEAR EXCITATION BY ELECTRON TRANSITION IN $^{197}$Au WITH A SILICON APD ELECTRON DETECTOR

We have succeeded in observing nuclear excitation by electron transition (NEET) in $^{197}$Au using a silicon avalanche photodiode (APD) detector [1]. NEET is a rare phenomenon that occurs only when nuclear excitation and electronic transition have nearly the same energy and a common multipolarity during atomic inner-shell ionization. For $^{197}$Au, the NEET condition is satisfied in the K$^{-1}(1s_{1/2}) \rightarrow M_{1}^{-1}(3s_{1/2})$ electronic transition and the $3/2^+ \rightarrow 1/2^+$ nuclear transition (Fig. 1). The common multipolarity is $M_1$.

By using monochromatic X-rays, the nuclear resonance and the NEET were independently observed using the same experimental setup. The solid circles in Fig. 2(a) show the time spectrum of internal-conversion electrons observed for the nuclear resonance at $E_R$. Figure 2(b) is the corresponding background measured at 77.455 keV. The tail caused by the prompt radiation, and the peaks at 2 ns intervals caused by the sub-bunches between the main bunches in the storage ring, are seen. In Fig. 3(a), the solid circles show the time spectrum observed at 80.989 keV, which is higher than $E_K$, and a corresponding spectrum obtained at 80.415 keV which is lower than $E_K$ (Fig. 3(b)). In both Fig. 2 and Fig. 3, the open circles in (a) are background-subtracted intensities, which are fitted by experimental curves. A lifetime of 2.80±0.29 ns, was observed, which is in good agreement with the expected lifetime of 2.76 ns from the resonance level. The decay curve caused by the NEET is clearly distinguished from the background.

The experiment was carried out at the undulator beamline BL09XU. A 116-bunch mode was used to detect the delayed radiation emitted from excited nuclei by the time-gate method. Third order X-rays from a Si(111) monochromator were used to obtain high incident energies which cover the nuclear resonance energy ($E_R$: 77.351 keV) and are higher than the K-shell ionization energy ($E_K$: 80.725 keV). A 3 μm thick gold foil set at the center of a vacuum chamber was irradiated by the X-ray beam. A silicon APD detector (φ3 mm, 30 μm thick) located 2.5 mm above the center of the foil was used to distinguish weak L internal-conversion electrons from the intense radiation promptly emitted by atomic processes. The number of incident photons was estimated from the current through a PIN photodiode detector located on the back side of the gold foil.
The NEET probability, $P_{NEET}$, could be precisely determined by comparing the two observed event numbers per photon since the cross section and the level width of the resonance were well known in Mössbauer experiments. The cross section of the NEET, $\sigma_{NEET}$, is defined as $\sigma_{NEET} = P_{NEET} \sigma_K$, where $\sigma_K$ is the photoelectric cross section of the K shell. Using the measured X-ray width ($W$); the Mössbauer cross section ($\sigma_0$), the level width at $E_R$ ($\Gamma$) and a factor depending on the spectral function of X-rays ($f_p$), the effective cross section of the nuclear resonance is given by $\sigma_R = \frac{\Gamma}{W} f_p \sigma_0$.

The ratio of $\sigma_{NEET}$ and $\sigma_R$ is expressed by $\frac{\sigma_{NEET}}{\sigma_R} = \frac{R_{NEET}}{R_R}$, where $R_{NEET}$ and $R_R$ are the numbers per photon events for the NEET and the nuclear resonance, respectively. From the observed event numbers between 5 and 15 ns after the prompt peak, $P_{NEET} = (\sigma_0/\sigma_K) (\Gamma/W) f_p (R_{NEET}/R_R) = (5.0 \pm 0.6) \times 10^{-8}$.

This value is smaller by three orders of magnitude than the previous experimental value of $(5.1 \pm 3.6) \times 10^{-5}$ [2], but is much closer to the calculated value of $1.3 \times 10^{-7}$ by Tkalya [3]. Due to the simplicity of our experiment, our present value for $P_{NEET}$ is more reliable than the previous experimental value.

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References