論文の内容の要旨

Development of time- and angle-resolved photoemission spectroscopy system and study of light-induced phenomena on semiconductor surfaces

（時間及び角度分解光電子分光装置の開発と半導体表面の光誘起現象の研究）

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Abstract

Nowadays, dynamics of photo-induced phenomena in semiconductors have been intensively investigated. In contrast to treatments by thermal heating, excitation by light has advantages to regulate systems with high spatial resolution, down to nanometeters, and in ultrafast time-scale. Moreover, generations of the transient states, especially by high-intense lasers, often lead to unusual properties of matters. Despite the scientific interests, the proper understandings of such dynamical phenomena have been difficult since they are intrinsically fast and complicated. Development of the *real-time* measurement system has, thus, been required to trace the non-equilibrium electronic states with appropriate time and energy resolutions.

In this work, the relaxation of the surface photo-voltage (SPV) effect was investigated. The SPV effect iw the well-known photo-induced phenomenon at a semiconductor surface. It is induced by spatial separation of photo-excited electrons and holes by electric field near a surface (the surface band bending). The relaxation has been understood as recombination of

these two-types of carriers but the detailed mechanism has not been understood yet. Carrier drift in the space-charge region has been pointed out as the main limitation of the decay process of SPV. However, in the previous researches, the decay processes were explained by only thermionic process nevertheless the decay process is not composed of single component.

Using a model surface of Si(111)7×7, the relaxation after the SPV effect was traced by measuring time-evolution of the core-level (Si 2p) spectra. The decay time constant is limited by the carrier transfer process from bulk to the surface excessing the surface potential. As a result, the decay process is composed of two components, fast decay (<100 ns) and slow decay (>100 ns). The power dependence and surface phase dependence of these decay processes were investigated well. Then I concluded that the fast decay process was dominated by the tunneling process and the slow decay was dominated by the thermionic emission process. The fast decay (<100 ns) was controlled by the surface phase, especially the surface disorder. On the other hand, the slow decay (>100 ns) can be regulated by changing the surface potential of initial state.

To investigate these time evolutions with high energy and time resolution, the time-resolved photoemission spectroscopy system at the SPring-8 BL07LSU was developed. To perform the real-time measurement of the dynamical processes of the electronic system, two dimensional (2D) angle resolved and several tens picosecond time resolved soft X-ray photoemission system has been a desirable. The design concept and the performance were explained. To get good transmission with high energy resolution and 2D angle resolved data, a time-of-flight type electron energy analyzer was installed. For demonstration, the two-dimensional band mapping of Si(111) clean surface was performed. Moreover, ~50 ps time resolution can be achieved for time-resolved measurement.

In addition to the above results, in contrary to the expected monotonous decay, at a higher power density of the pumping laser, the oscillatory decay process were found. The origin of this unexpected oscillatory dynamic behavior was analyzed with oscillator models, such as the Lotka-Voltera scheme, possibly realized at the semiconductor surface.