Mechanism of electromigration in metal nanocontacts in the diffusive transport regime

拡散的伝導領域における金属ナノ接合中のエレクトロマイグレーションの機構

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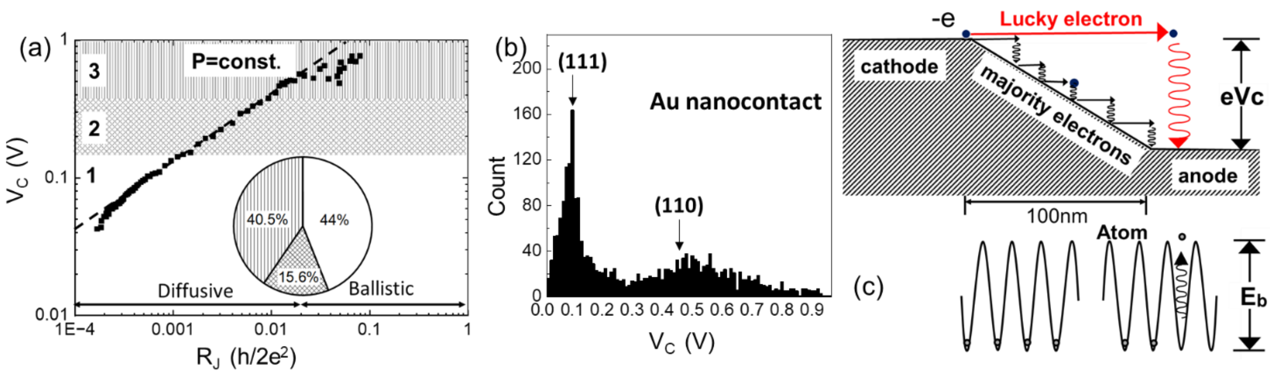
Electromigration (EM) is used to fabricate electrodes with atomic-scale gaps for capturing single molecules [1]. So far, it has been understood that Joule heating plays important roles in the EM when the electron transport in metal nanocontacts is diffusive [2], while kinetic energy transfer (KET) from one conduction electron to one metal atom becomes responsible when the metal nanocontacts enter the ballistic transport regime [3]. However, more recently, we observed that KET works even in the diffusive transport regime in the EM process of Ni and Pd. Since the junction length is longer than the electron mean free path in the diffusive transport regime, only a small fraction of conduction electrons contribute to KET [4]. In this work, we have investigated the EM process in metal nanocontacts and found that KET is more dominant than Joule heating even in the diffusive transport regime.

The EM process in gold nanocontacts is divided into two regions. When the junction conductance $G_J > \sim 50G_0$, ($G_0 \equiv 2e^2/h$), electron transport is diffusive, while it becomes ballistic when $G_J < \sim 50G_0$. We define the critical junction voltage V_c as the voltage at which atoms are removed by EM. Figure 1 plots V_c as a function of the junction resistance R_J for a gold nanocontact. For a wide range of R_J ($1/2{,}000G_0 < R_J < 1/50G_0$), a straight section is observed, which represents that the power consumption at the nanocontact is constant. This fact indicates that Joule heating works in the EM.

However, in the histogram of V_c shown in Fig.1(b), we find a very large peak at 0.1 V, which is close to the surface diffusion potential of Au (111) surface (0.12 eV). This peak strongly suggests that KET process shown in Fig. 1(c) works even in the diffusive regime. When we look more closely into the distribution of V_c in Fig. 1(a), we notice that very many data points distribute just before Joule heating section starts. In contrast, the data points for 0.15 V < V_c <0.35 V (region 2 in Fig. 1(a)), where only Joule heating is supposed to work for EM, are much fewer. This fact suggests that the KET process is



predominant and Joule heating plays a rather minor role in the EM process in metals.

Fig.1 (a) V_c is plotted as a function of R_J for a gold nanocontact. Inset: number of data points in regions 1,2 and 3 (b) histogram of V_C. The arrows indicate the surface diffusion potentials of gold. (c) Schematic illustration of the kinetic energy transfer process by “lucky electrons”.

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