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Equivalent Circuit Model of Electric Contact Phenomena with Elastic and Plastic Deformation
弾性・塑性変形で接触する電気接点現象の等価回路モデル

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1. Introduction

The physical phenomena of breaking electric contacts are softening, melting, arc ignition, and isolation as shown in Fig.1[1][2][3]. To analyze the transition process of the phenomena, a cluster model for electric equivalent circuits is proposed and experimentally examined. The mechanical contacting force breaks currents from energizing to isolation through melting and arc discharge. Due to tangency on a rough surface, the contacts consist of complicated contacting multi-points. The contacting points are classified simply as electric conductive cluster and electric field effect cluster according to electric function.

2. Electric cluster models of mechanical contacting points with elastic and plastic deformation

Mechanical contact force forms elastically and plastically contacting points between metal electrodes as shown Fig.2(a). They have mainly been studied in terms of electric conductive contacting points. The sequence of breaking phenomena ; metal softening, metal melting, metal bridge and arc discharge, has been considered to be serial phenomena. The authors paid attention to non-electric conductive contacting points, which exist from the first stage of a make/break operation. On the contacting metal surface, processed shape and undulation of surface (mm order), surface roughness (μm order), and crystal level disorder (nm order) exist together. The mechanism of making contact is elastic and plastic deformation. In addition, the surface is covered not only with pure metal but also with a thin insulating film. The combinations of contact points are very complex and change over time according to contact force as show in Fig.3. However, the breaking operation can be considered only as an elastic process as shown in Fig.2(b). Therefore, the contacting points are classified simply into electric conductive cluster and electric field effect cluster according to electric function. The contact points belonging to the electric field effect cluster mainly exist around large-scale undulations and surface roughness, and are based on crystal level and several nm disorders.

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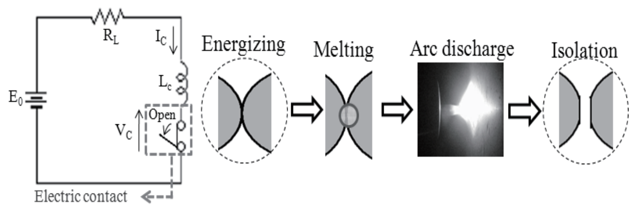
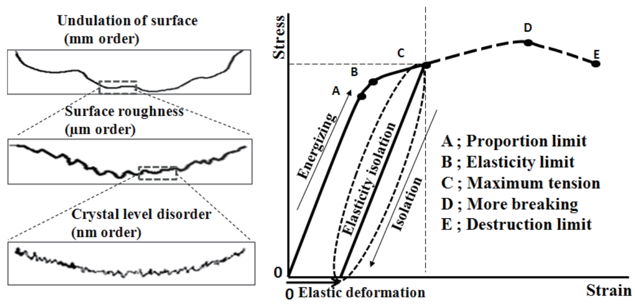
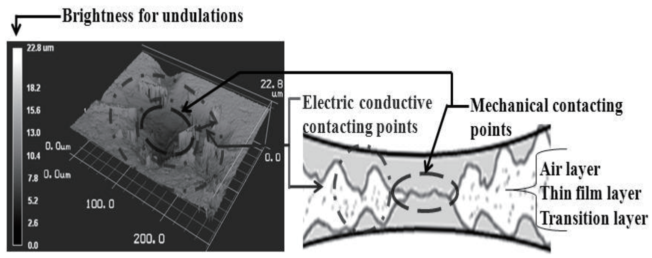


(a) Make/ break circuit (b) Physical process
Fig.1 Breaking contact operation.



(a) Irregularity of surface (b) Strain vs. stress
Fig.2 Elastic and plastic deformation of contact surface.



(a)Three-dimensional image of contacted surface (b) Appearance of a contacting point
Fig.3 Conductive and non-conductive contacting points.

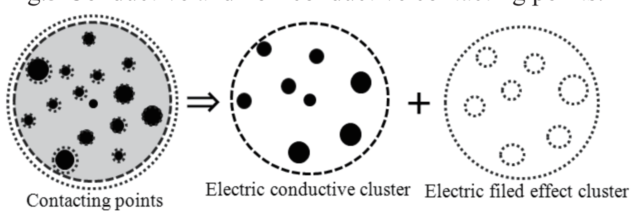


Fig.4 Classification of contacting points.

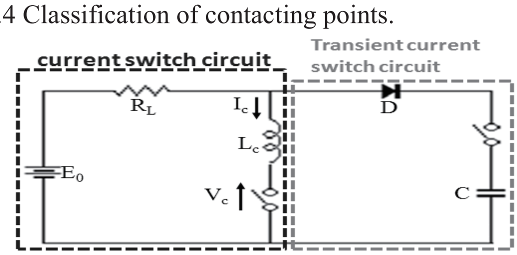


Fig.5 Make/break circuit with a transient current switch circuit and a residual inductance.

3. Behavior of electric conductive cluster and electric field effect cluster

Conventional electro-magnetic relays were used for the experiment. Contact voltage Vc and contact current Ic during a breaking operation were measured in the make/break circuit with a transient current switch and a capacitor as shown in Fig.5[4][5]. The Vc rise during breaking contact was controlled. Vc and Ic responses before Vc=Um in Fig.6 show the behavior of the electric conductive cluster defined by mechanical contact force. Here, Um is melting voltage and 0.4 V corresponds to the melting temperature of Ag. On the contrary, Vc and Ic responses after Vc=Um in Fig.6 show a peculiar response [6][7]. We consider it to be "fusion". Melting shuts down Ic. It does not depend on a mechanical motion but on circuit condition. This means the electric conductive cluster is transformed into a melting cluster. Figure 7 is an explanatory drawing of the transformation from electric conducive cluster into melting cluster until disappearing through melting. Before Vc=Um, the sizes of electric conductive cluster and electric field effect cluster are reduced at the same time. On the contrary, during melting, only the electric conductive cluster or the melting cluster is reduced until it disappears, but the electric field cluster remains as it is. After fusion of the melting cluster, only the electric field cluster plays a role in Vc and Ic responses. Figure 8(a) shows impulsive noise due to electric field cluster. It shows the remaining time of the cluster. After contact current shut-down but within the remaining time, we increased Vc until arc ignition voltage using an adjusted capacitor in the transient current circuit. Figure 8(b) confirms arc ignition. We also increased Vc until the same arc ignition voltage outside the remaining time of the cluster using a larger capacitor. Figure 8(c) shows no arc ignition. This means arc ignition of Ag contacts is not a serial phenomena from metal evaporation through metal bridge.

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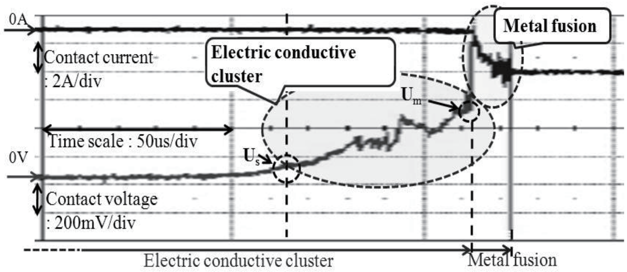


Fig.6 I_c and V_c of breaking contact of time responses at $V_c=U_m$.

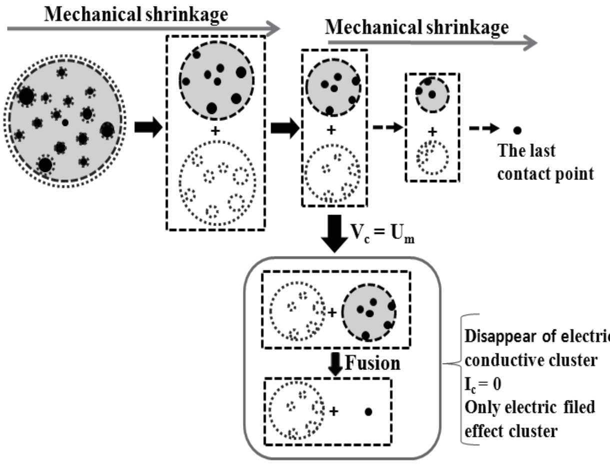
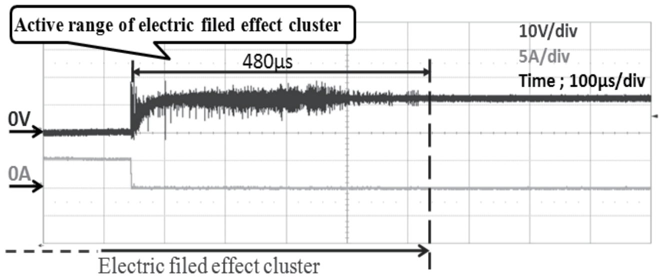
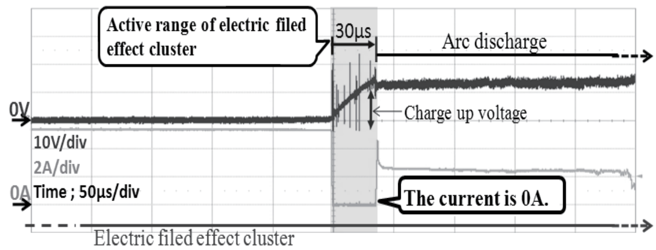


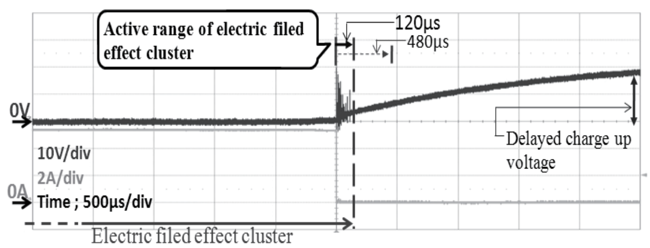
Fig.7 Transition process of electric conductive cluster until disappearing through melting.



(a) Impulsive noise due to electric field cluster (12.5V, 5A,1μF)



(b) Arc ignition after energizing current shut-down.: (25V,5A 10μF)



(c) No arc ignition due to delayed Vc increase. （25V, 5A, 400μF）

Fig.8 Arc ignition caused by electric field effect cluster