NANOSCALE DISTRIBUTION OF SURFACE POTENTIAL AT CLEAVED DIELECTRIC SURFACE

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SUMMARY
Tribocharging generate triboelectromagnetic phenomena, which causes serious tribological problems such as
decomposition of lubricants. However, the mechanism of tribocharging phenomena has not yet been fully clarified. To
have an knowledge on the mechanism of tribocharging at the worn fresh solid surface, the charge distribution in cleaved
dielectric single crystal surface was investigated. MgO single crystal was cleaved under an ultrahigh vacuum of 10^{-8} Pa
and the surface potential and topography distributions were measured simultaneously in nanometer scale using a
scanning Kelvin probe microscopy (SKPM) and non-contact atomic force microscopy (NC-AFM). It is observed that
both negatively and positively charged regions were produced on the cleaved surface as charged islands of charged
regions with the size of tens nanometer scale. These nanometer scale charged regions were combined and formed
broader charged regions having the size of several hundreds nanometers.

Keywords: tribocharging, surface potential, tribo-electrification, dielectric, SKPM, NC-AFM, cleavage, MgO

1 INTRODUCTION
When a dielectric solid slides against another, micro-plasma generation and emission of electrons, ions and
photons occur [1]. These phenomena are caused by discharging the surrounding gas molecules due to
intense electric field generated by tribocharging [2]. These phenomena are generally termed as
triboelectromagnetic phenomena [3]. The triboelectromagnetic phenomena give rise to various tribological
problems in microtribosystems, such as a head sliding on a magnetic recording disk in development of high
density magnetic recording system. This is serious since the triboelectromagnetic phenomena results in the
decomposition of a thin perfluoropolyether (PFPE) lubricating oil film to shorten the life of the system [4].
To develop the technology for protecting the decomposition of the lubricant film, it is necessary to
develop a protective film to suppress the intensity of the triboelectromagnetic phenomena, i.e. to decrease tribo-
charging. However, the knowledge on the origin of the tribocharging has not yet been fully clarified. As the
electric field to cause discharging is resulted from the charge density on the worn fresh surface, it is important
to know the charge distribution on the surface in detail. However, charge distribution in the surface has only
been measured so far in the resolution of the order of several tens of micrometers say 65 µm [5].

The purpose of the present study is to investigate the charge distribution of the surface by measuring the
potential distribution generated at the fresh cleaved surface of MgO single crystal of dielectric solid in
nanometer scale to get basic knowledge of tribo-charging.

2 EXPERIMENTS
MgO (100) single crystal was cleaved under an ultrahigh vacuum (UHV) of less than 1.1×10^{-8} Pa. Then,
the surface potential and topography distributions of the cleaved MgO surface were measured simultaneously
under the UHV using the SKPM with the NC-AFM (JAFM-4500XT, JEOL co. ltd.).

Figure 1 shows the principle of the NC-AFM and SKPM. An conductive Si cantilever with the spring
constant of 50 N/m was oscillated at its resonance frequency of 350 kHz and the frequency shift by the
atomic force interaction between the cleaved surface and the cantilever tip was measured by NC-AFM. An
AC modulation voltage of 1 kHz with 3 Vp-p was applied to the cantilever and the surface potential distribution
between the cantilever and cleaved surface was measured detecting the electrostatic force interaction
between them using the SKPM. The experimental apparatus and the method was described in detail
elsewhere [6]. In the Kelvin method, the specimen surface potential was measured relative to the cantilever
tip surface. During measurement, the amplitude of the oscillating cantilever was 8 nm and the distance
between the specimen surface and the cantilever tip was 1 nm and the scan speed of cantilever was 0.6 s/line.

3 RESULTS AND DISCUSSION

Before measuring surface potential distribution, surface morphology of the cleaved MgO single crystal surface was investigated in an area of micrometer scale. Figure 2 shows an image of scanning electron microscopy (SEM) of the cleaved MgO single crystal surface produced in an ambient air atmosphere. It is seen that parallel steps with the height of micrometers were produced. The smaller second steps were also seen on the terrace of the first steps in the direction perpendicular to that of the first steps.

Then the MgO single crystal was cleaved under the ultrahigh vacuum less than $1.1 \times 10^{-8}$ Pa and surface topography and potential distributions on the cleaved surface were measured simultaneously in nanometer scale using the NC-AFM and SKPM. Figures 3 and 4 show the topography and the corresponding potential images measured.

![Figure 2 SEM image of cleaved MgO(100) surface](image)

Figure 2 SEM image of cleaved MgO(100) surface

![Figure 3 Topography image of the cleaved MgO(100) surface](image)

Figure 3: Topography image of the cleaved MgO(100) surface

The brighter and darker area in the topography image of Fig. 3 reveal to higher and lower height regions, respectively, while those in the potential image of Fig. 4 correspond to the higher and lower potential regions, respectively. Topography image shows the parallel steps with the height of tens nanometers. While potential image shows existence of the positively and negatively charged regions. In Fig. 4, the boundary between the bright and dark area was 5.84 volts, which is the middle of the maximum and minimum potentials measured in Fig. 4.

![Figure 4 Surface potential image of the cleaved MgO(100) surface](image)

In Figure 4, we define the bright and dark area as positively and negatively charged regions in this study, respectively. The size of the negatively and positively charged regions are seen to be hundreds nanometers. A lots of small charged regions with the size of tens nanometers are also produced on the charged regions. The smaller charged regions are produced along the step lines. This suggests that surface potential distribution correlates with the topography distribution.

Figure 5 and 6 show the topography and potential profiles measured along the scanning line of A-A’ in Fig. 3 and B-B’ lines in Fig. 4, respectively. It is seen that the heights of the steps are in the order of several tens of nanometers. It has been reported that large, thick cleavage steps appears in cleaved single crystal surfaces with heights varying from less than 5 to 200 nm and that the height varies along their steps [7].

![Figure 5 Topography profile along A-A line in Figure 3](image)

Figure 5: Topography profile along A-A line in Figure 3
Surface structure of cleaved MgO was extensively studied by electron microscopy using decoration replicas [8]. Recently, morphology of the cleaved MgO surface was studied by AFM and it was shown that various kinds of step exists, i.e., monolayer steps, bilayer steps, trilayer steps, multiplayer steps up to 2 nm, thick multiplayer steps of 20 to 50 nm and 55 to 590 nm [5, 6, 7].

The size of the steps in the present study was in the order of tens nanometers, corresponding to those of the report. However, good correlation between the topography and potential profiles was not always found from the comparison between the profiles in the Figs 5 and 6, though the charges are generated along the step lines.

Then the topography and potential profiles along the step lines were investigated. Figure 7 and 8 show the topography and potential profiles measured along the C-C and D-D’ lines in Figs. 3 and 4, respectively. Many circular protrude with the size of approximately 10 nm are seen in the topography image of Fig. 3. However, at present we do not know what they are. They are also exist on the step lines, so that the topography along the step lines are not smooth. The charged regions with the size of tens nm are seen in the potential image of Fig. 4. However, when we compare the topography and potential profiles along the step line, good correlation was also not always found.

Figure 9 and 10 shows the relationship between the frequency and the dimension of the negatively and positively charged regions measured perpendicular and parallel to the step lines, respectively. It is seen that the size of both negatively and positively charged regions distribute from several nm to 120 nm and 150 nm. The charged regions beyond 150 nanometers size also observed in both negatively and positively charges. The sizes of the charged regions beyond 150 nanometers are produced by the combination of the small elemental charged regions with tens nanometers scale. The frequency peak of the size of the elemental charged regions has a maximum at 10 to 50 nanometers. They also combine and may produce micrometer and further millimetre size charged regions. In the sliding experiment of diamond sliding on dielectric solid the negatively and positively charged regions of mm size are observed [8]. Present results suggest that the mm size charged regions in sliding contacts are composed of hundreds nanometers sized and further tens nanometers sized charged regions. In the present study, the charged regions are produced along the step lines. Every irregularity in an ionic crystal, such as edges, surface steps, and especially intersection points of dislocations are potentially charged [5, 9]. Further study is needed to clarify the origin of the charges in atomic scale.
4 CONCLUSIONS

To have the knowledge of the origin of tribocharging at the wearing fresh dielectric surface, surface potential distribution at cleaved MgO single crystal surface were measured simultaneously with topography using the SKPM and NC-AFM in an ultrahigh vacuum. The results showed that negative and positive surface charging occurs at the newly formed cleaved MgO surface. The charging occurs on the step of which height is several tens nanometers. The charging also distributes along the step lines. The sizes of the elemental charged regions are several tens of nanometers distributing from several to 150 nanometers having the maximum in frequency at 10 to 50 nm. The combination of the elemental charged regions produce larger charged regions of hundreds nanometers, which may further combines to give rise to micrometer and millimetre sized charged regions. These results suggest similar charge distribution are generated on the wearing di-electric surfaces.

5 REFERENCES