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UV Irradiation Effect on the Surface $KTaO_3$ Crystals

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Abstract. The perovskite oxides property are wider band-gap semiconductors and are sensitive to visible light but opaque In this paper, we are interested in the resistance change of insulating $KTaO_3$ crystals could decrease as much as 3-4 orders of magnitudes under exposure to focused sunlight. But, these resistances under ambient pressure would change back quickly after light was off. And the resistances change in a similar way under exposure to synchrotron light but the increase resistance rate was much slower under vacuum condition. However, the large increase resistance rate by increasing the oxygen pressure. From the ARPES study, we found that the change in resistance occurred due to the oxygen vacancy induced by the exposure to ultraviolet light. These oxygen vacancies induce two-dimensional electron gas at the surface $KTaO_3$. This indicates that the $KTaO_3$ could be used as a light sensing device.

Introduction

Perovskite oxides have a variety of phenomena at their interfaces [1], including multiferroicity [2], magnetoresistance [3], high-T_c superconductivity [4] and switching of the conductance between insulator and conductor behavior by the application of electric field. All these are the important properties which may be useful in all oxide electronic devices [5]. Recently, the angle-resolved photoemission spectroscopy (ARPES) study finds that when the ultraviolet synchrotron light shines at the surface of insulating $SrTiO_3$ [6] or $KTaO_3$ [7] samples can occurred two-dimensional electron gases (2DEGs) at the surface of these samples due to the decrease oxygen at surface. So 2DEGs induced by oxygen vacancies [8] and occur electron accumulation on layer of samples. The electronic structure could change by light expose and varies temperature. The valence band spectrum at oxygen 2p (O2p) states rapidly decrease in the spectral intensity and energy shift of the valence band [9] caused the downward bending of the conduction band and dispersions of the 2DEG states occur electron accumulation near the surface spreads into the bulk samples which has a high electron mobility [10]. Therefore, oxygen vacancy influence on electronic properties in vacuum. So, we are interested in perovskite oxide of $KTaO_3$ which are wide-gap semiconductor, transparent under visible light. We also showed that the dielectric constant of $CaCu_3Ti_4O_{12}$ [10] and $Ba_{0.7}Ca_{0.3}TiO_3$ [12] could be change conductivity under UV light.

In this work, we study the change of the resistance upon light exposure to sunlight and controlled synchrotron light on the surface $KTaO_3$ samples. When the light is off completely, we investigated the change of resistance under different pressure as a function of time after UV light exposed on the surface samples until the resistance saturates. Note that the pressure is set from $\sim10^{-7}$ to 10^{-4} mbar. Next, we study the change in electronic structure of $KTaO_3$ samples by using the angle-resolved photoemission spectroscopy (ARPES).

Materials and Methods

Sample preparation

Potassium tantalum oxide ($KTaO_3$) sample measured in this work (Crystal Base Co., Japan) is single crystal orientation and 5 x 5 x 0.5 mm^3 in dimension. We make the electrode pattern on the surface of sample by using lithography technique as shown in Figure 1 (a). Which use titanium metal is first evaporated on the samples and then silver metal is evaporated on top are the electrode pattern on the surface.

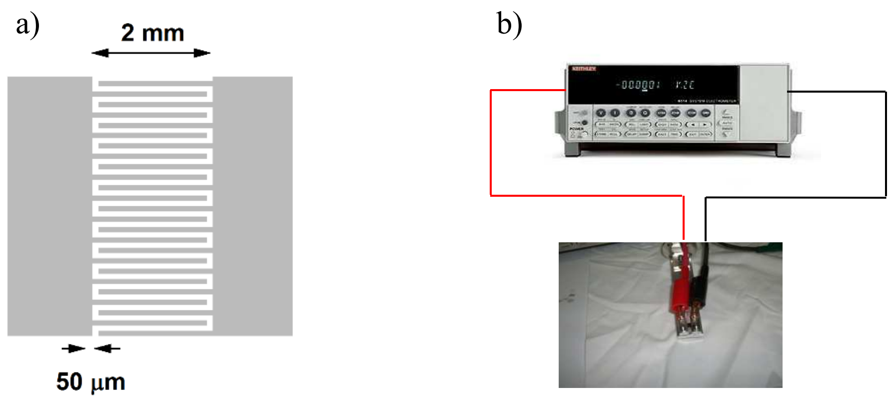

Fig. 1 a) Electrode pattern of silver and titanium metals on the surface of samples.
b) Instrument setup for measuring resistance of sample.

Resistance measurement

To setup instrument to measure in the resistance before and after light exposure on the $KTaO_3$ surface as shown in Figure 1 (b).. Firstly, we setup the sample holder with the sample and we measure the change in resistance of the $KTaO_3$ surface before and after exposure with unfocused sunlight and record the resistance before and after exposed as a function time. Next, we measure with focus sunlight by using a magnifying lens on the surface samples. Secondly, we measure in the resistance before and after exposed to synchrotron light with a) the ultraviolet at 60 eV and b) zeroth-order type (all the frequencies light) at Beamline 3.2a, Synchrotron Light Research Institute, Thailand; Note that the measurement under synchrotron light is performed at base pressure ~10^{-8} mbar. Next, the samples are exposed zeroth-order until minimum in the resistance then light is off to measure increase resistance under the difference pressure using by oxygen pressure. And we study electronic structure by ARPES technique, and we study the change in resistance under the different oxygen pressure, effect of oxygen vacancies, induce two-dimensional electron gas at the surface by the exposure to ultraviolet light.

Results and Discussion

$KTaO_3$ could change the conductivity rapidly when light exposure with focused sunlight. The resistance of $KTaO_3$, while there were no light in order of ~9 GΩ. When the sample were exposed to unfocused sunlight, the resistance of samples changed to ~0.2 GΩ. But the sample were exposed to focused sunlight by using magnifying lens, the resistance could change to in order of ~3 MΩ. Note that the sample were the changed in the resistance upon light exposure are very fast in time. When the light is off, the resistance changed to back very fast.

We study the change of conductivity on the surface samples by using the controlled synchrotron light. We found that the resistance of $KTaO_3$ could change in slower manner upon UV light at 60 eV. As shown Fig. 2 (a), when we exposed UV light at photo energy of 60 eV on the $KTaO_3$ by repeatedly on 30 sec and off another 30 sec during the measurement until the resistance became saturated at ~0.5 GΩ.

The resistance of $KTaO_3$ changed dramatically when exposed to zero order light (synchrotron light at all frequency) as shown Fig. 2(b) when we exposed zero order light on the $KTaO_3$ by repeatedly on and off 15 sec. The resistance was first changed quickly from 14 GΩ to ~3 MΩ and saturated at ~1 MΩ.

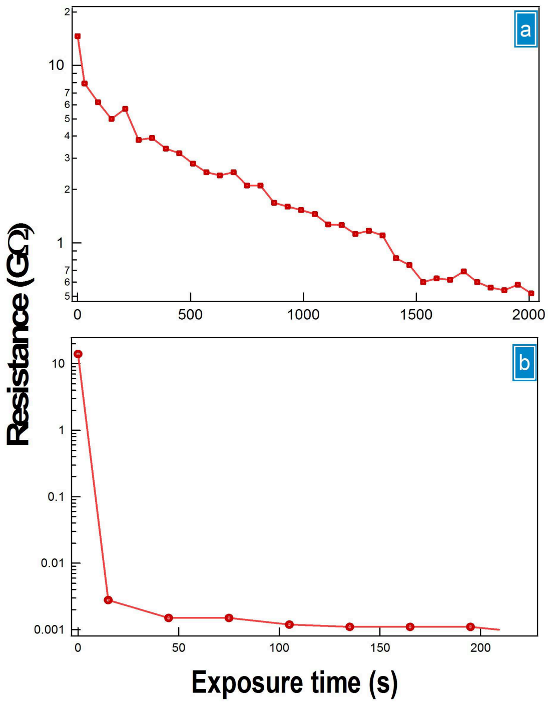

Fig. 2 The resistance after exposed to a) UV synchrotron light at 60 eV and b) zeroth-order light of $KTaO_3$.

In figure 3, when the zeroth-order light was off completely, the resistance of $KTaO_3$ sample increased slowly in the vacuum under pressure around 10^{-8} mbar. But the resistance increased faster at higher oxygen pressure as shown in figure 3. This result indicates that the higher pressure of oxygen makes surface of the sample recover faster.

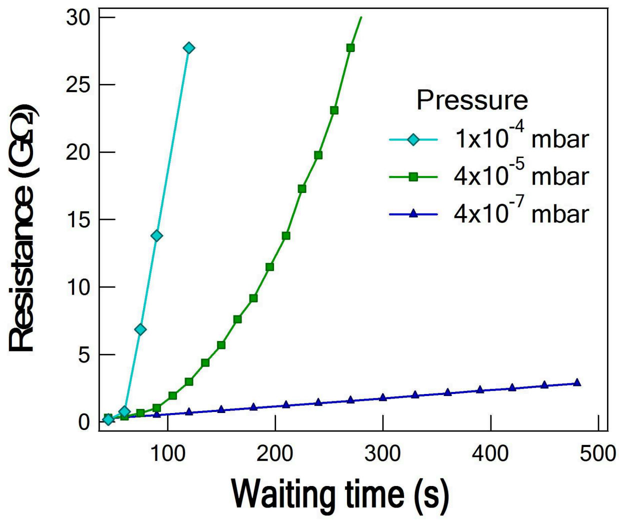

Fig. 3 The recovery of surface resistance for $KTaO_3$ after exposed to zeroth order light at different oxygen pressures.

From the angle-resolved photoemission spectroscopy (ARPES) study, we found that the ultraviolet synchrotron light exposure at the surface of insulating $KTaO_3$ sample could cause the increase electron accumulation and 2DEG states can occur on the surfaces. In figure 4, we found that the sample spectrum shows oxygen vacancy state (V_0) at binding energy between 3 to 9 eV and 2DEG states occur on the surface of $KTaO_3$.

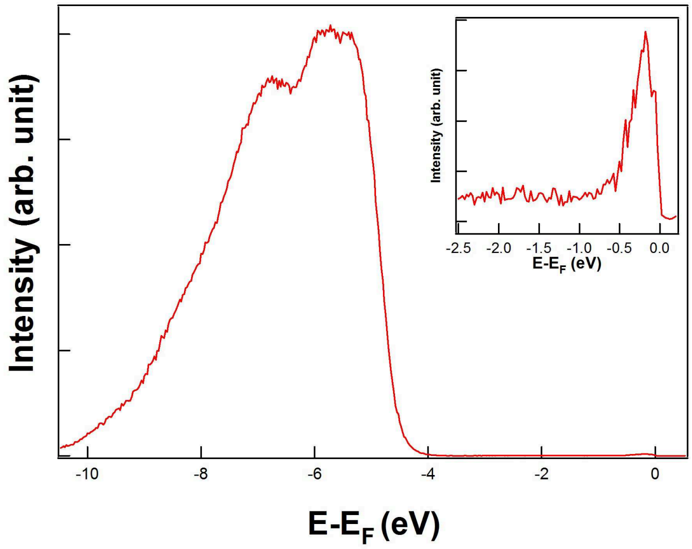

Fig. 4 The binding energy of valence band maxima when UV synchrotron light exposure on the surface of $KTaO_3$.

Summary

The $KTaO_3$ could change conductivity ultrafast upon focused sunlight expose. The resistivity of $KTaO_3$ could change from GΩ to MΩ. For UV synchrotron light at 60 eV, the resistance of $KTaO_3$ changed around 2 order of magnitude lower. For zero order light, the resistance of $KTaO_3$ change from 14 GΩ to 3 MΩ or around 4 orders of magnitude lower. For the resistance of $KTaO_3$ sample after exposed UV synchrotron light under higher oxygen pressure, we found that the resistance increase faster. For ARPES study, we found that the ultraviolet synchrotron light exposure at the surface of $KTaO_3$ can occur the increase in electron accumulation and 2DEG states can occur on the surface of sample. When irradiated with UV light, the sample spectrum shows oxygen vacancy state (V_0) and 2DEG states occur on the surfaces. This indicates that the $KTaO_3$ could be used as a light sensing device.

Acknowledgments

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