Measurement of Photoelectron Emission by Vacuum Ultraviolet Ray Irradiation

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Abstract

Recently, the satellite plays many roles depending on the purpose, including communication, weather observation, astronomy observation and space development. The satellite is requisitioned long life and high reliability in such situation. However, around an altitude of several 100 km, there is Atomic Oxygen (AO) which is a main ingredient agents. AO has high reactivity and its density is about 10^{15} atoms/m^3. Because the satellite collides with AO, surface materials of the satellite are deteriorated. As a result, it leads unevenness and oxidation. Accordingly, it is necessary to monitor the surface condition.

In this study, photoemission characteristics of several materials, such as metals, glasses and polymers are measured by use of the deuterium lamp and the band path filters. From the measurement the threshold energy for photoemission and the quantum efficiency was evaluated. As a result, the thresholds of samples are 4.9 to 5.7 eV. The quantum efficiency of metals is about 100 times higher than other samples. The quantum efficiency of PS which includes benzene ring is several times higher compared with PP and PTFE. From these results, it is deduced that deteriorated materials may emit large amount of photoelectron.

Key words : photoelectron emission, vacuum ultraviolet ray, polymer, threshold energy for photoemission, quantum efficiency

1. Introduction

Recently, the satellite is requisitioned the long life and high reliability. By the way, there is Atomic Oxygen (AO) which is a main ingredient agents in LEO (low-earth orbit). An altitude of several 100 km (about 10^{-3} Pa) AO is the main constituent of the atmosphere in LEO. It is formed by dissociation of O_2 by ultraviolet irradiation from the sun. AO has high reactivity and its density is about 10^{15} atoms/m^3. Because the satellite collides with AO, surface materials of the satellite are deteriorated [(1)]. Therefore it is necessary to monitor the surface materials of the satellite. The authors thought that the change of the deteriorated situation of surface materials might be detected by the measurement of the photoemission characteristic by the sun. Therefore, it is necessary to summarize the fundamental data concerned with photoemission characteristics related to the surface condition of materials. On the other hand, analysis of the surface condition by AO irradiation is important. Compared with these results, it might be effective for the monitoring of the deteriorated situation. In this report, results of preliminary experiment are summarized.

2. Experimental setup

The experimental setup is shown in Fig.1. The deuterium lamp of 200 W and band pass filters (BPF) are used for a source of VUV (vacuum ultraviolet) ray. The VUV ray is reflected by an aluminum vapor deposition mirror made by the vacuum evaporation method on the optical flat glass and is irradiated on the sample. Photoelectrons are collected by the semi-spherical electrode and are measured at the electrode placed the sample. Here, the radiation wavelength range of the deuterium lamp is 115-400 nm. The transmittance of BPF has 15-20 % at the peak wavelength and the half bandwidth is about 20 nm with each filters. Negative bias voltage around 7 V is applied to the sample side, to prevent the pull back electrons that were emitted from the sample and the electrons emitted at the surface of chamber. Additionally, irradiated flux of VUV ray is measured by using a photomultiplier for each wavelength to evaluate the quantum efficiency for the photoemission. The measurement is performed by pressure less than 10^{-2} Pa. The measured samples are metals, glasses, films, paints and polymers.

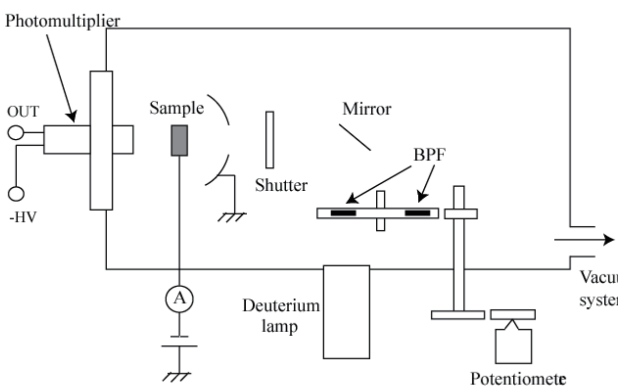

Fig.1 Experimental setup.

3. Results and discussion

3・1 Threshold energy

The square root of the magnitude of photoemission current value corrected by the irradiated VUV ray intensity is shown at the axis of ordinates and energy of the irradiated VUV ray is the axis of abscissas, which is so called Fowler plots is shown in Fig.2. From the graph, the threshold energy for photoemission is evaluated. The results are summarized in Table 1. The metals have the same magnitude as the reported one [(2)]. Now, the dispersion of evaluated value was about ±0.2 eV. The other samples have 5.4-5.7 eV. In the case of polymer, it is reported that the bandgap of polymer has about 9 eV [(3)]. On the other hand, it is reported that the surface level exists around 4-5 eV in the case of polymer [(4)]. Therefore, the reason why the threshold of about 5 eV was obtained is existing a lot of the surface level around 5 eV. The surface depth to emit photoelectrons are extremely shallow, accordingly the results obtained by the measurement may be influenced by these surface level.

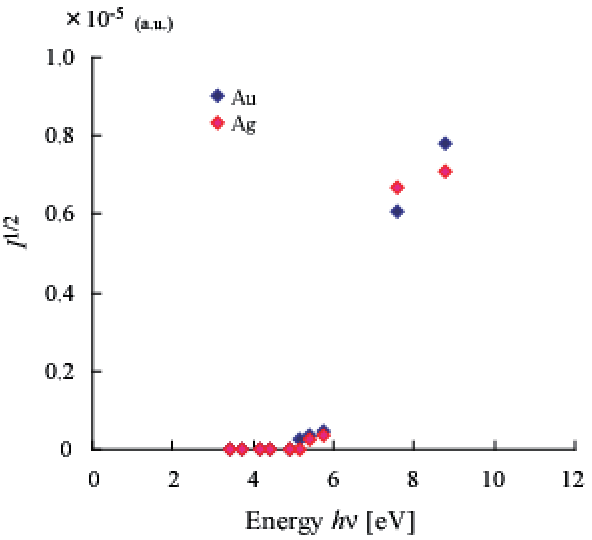

Fig. 2 Fowler plots.

3・2 Quantum efficiency

Quantum efficiency for photoemission was calculated by using the flux of VUV ray irradiated on the sample for each BPF and magnitude of the photoemission current. The flux of VUV ray irradiated on the sample was corrected by the transmittance of each BPF by using the sensitivity of the photomultiplier and was converted into the intensity at the central wavelength of each one. The results are shown in Figs.3-7. The samples with relatively high conductivity tend to emit electrons easily from the figures. For example, It is clear that volume resistively of metals have about 10^{-8} Ω・m and that of polymers have about 10^{15} Ω・m. In the case of paint, samples of conductivity have 10^{5}～10^{6} Ω・m. As well the samples that conductivity is small were not seen in the tendency that photoemission currents decreased with time.

Table 1 Threshold energy for photoelectron emission of each samples.

Materials		Characteristics	Threshold energy (eV)
Au		Metal	4.9
Ag			5.1
Glass A		Glass	5.4
Glass A(deteriorated)			5.7
Glass B			5.7
Glass B(ITO-coated)			5.7
Film A		Film	5.7
Film B			5.4
Film C			5.7
Paint A	Conductive	Paint	5.4
Paint B			5.4
Paint C	Non-Conductive		5.7
Paint D			5.7
Paint E			5.7
PP		Polymer	5.7
PTFE			5.7
PS			5.4

For example, the quantum efficiency of film A from Fig.4 is about 10^{-5} at the photon energy of 7 eV. It is necessary to irradiate photons about 10^{5} with energy of about 7 eV for one electron. The exposure dose of the photon of about 7 eV by the sun in space is measured with about 10^{11}/ m^{2} per second. Accordingly, many electrons might be emitted.

Here in polymers, PS which includes the benzene ring in its chemical structure emits more electrons in each wavelength than PP and PTFE which does not include the benzene ring. Therefore, it is thought that having benzene ring may contribute to photoemission. When polymers are irradiated by AO, it is expected that many polar bonds including oxygen are formed at the surface. It is expected in particular that a lot of double bonds such as a carbonyl group, the carboxyl group and so on are generated. In other words, quantum efficiency of the materials which is deteriorated by AO irradiation might increase, because photoemission quantity of PS having a benzene ring including a lot of double bond increased. On the other hand, unevenness of surface is generated by AO irradiation [(5)]. In figure, quantum efficiency of the deteriorated glass decreased. It is necessary to clarify effect which is dominant for photoemission, one is the introduction of double bonds and the other is the formation of unevenness at the surface. Samples introduced double bonds and formed unevenness will be prepared and its quantum efficiency will be measured in future. In addition, data between 170-210 nm will be measured in future, because quantum efficiency is looked like discontinuity.

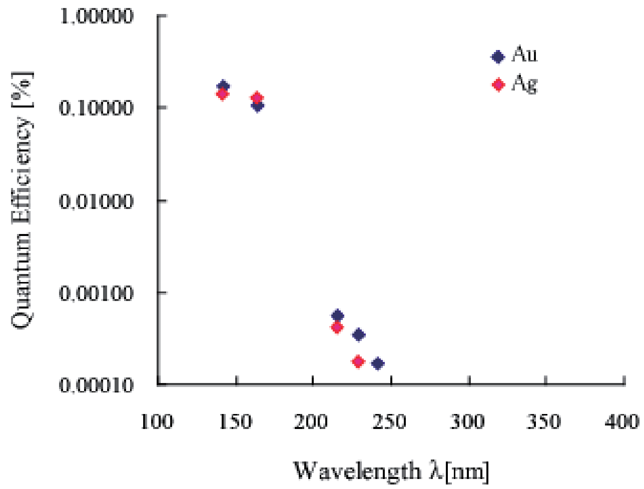

Fig. 3　Quantum efficiency of metals.

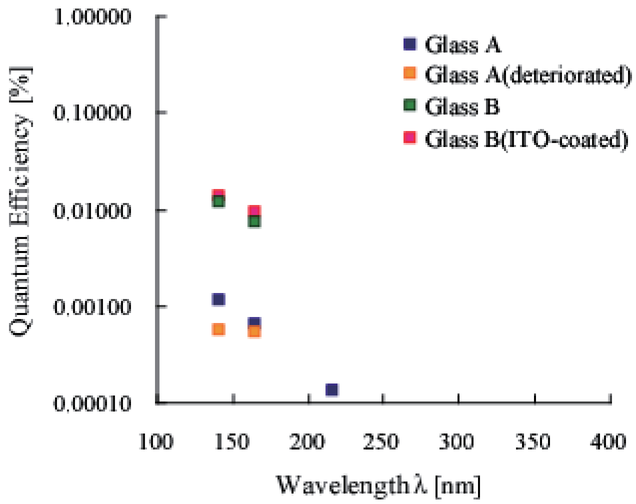

Fig. 4　Quantum efficiency of glasses.

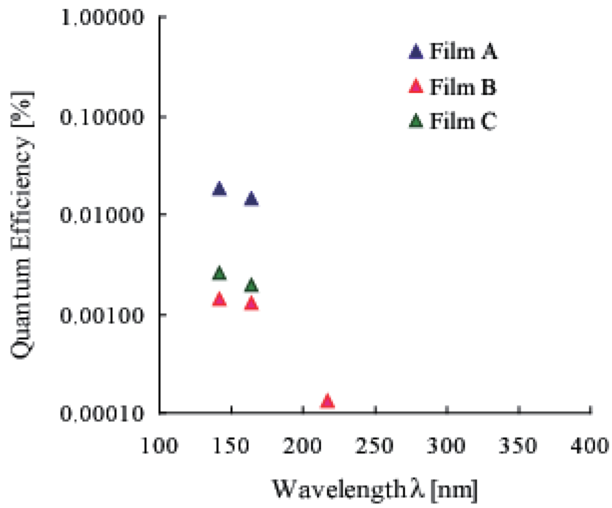

Fig. 5　Quantum efficiency of films.

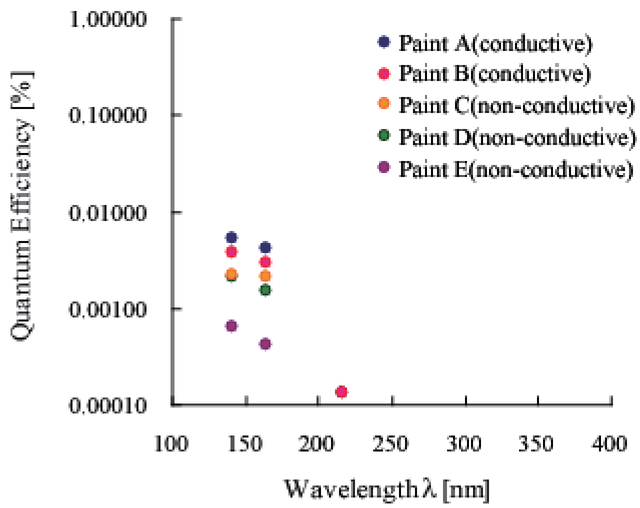

Fig. 6　Quantum efficiency of paints.

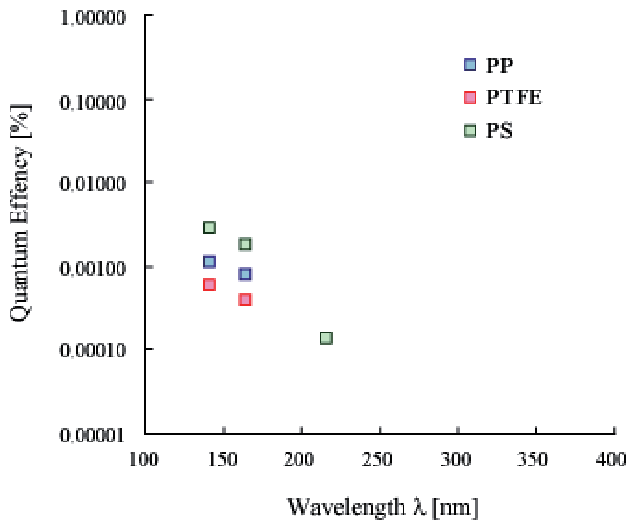

Fig. 7　Quantum efficiency of polymers.

3・2 Magnitude of photoelectron current irradiated by the sun

Comparing with the intensity irradiated by the test and the intensity of the sun, magnitude of photoelectron current from the sample irradiated by the sun was calculated. The results are shown in table 2. More than 10^{-6} A/m^2 is estimated for each sample including the insulator, and more than 10^{-4} A/m^2 is obtained in case of conduction one.

Table 2 Estimated photoelectron current by the sun irradiation of each samples.

Materials		Photoelectron current (A/m^2)
Au		3.6×10^{-3}
Ag		3.2×10^{-3}
Glass A		2.8×10^{-4}
Glass A(deteriorated)		9.7×10^{-6}
Glass B		1.3×10^{-4}
Glass B(ITO-coated)		1.6×10^{-4}
Film A		2.5×10^{-4}
Film B		2.9×10^{-4}
Film C		3.4×10^{-4}
Paint A	Conductive	3.4×10^{-4}
Paint B		3.2×10^{-4}
Paint C	Non-Conductive	3.6×10^{-5}
Paint D		2.6×10^{-5}
Paint E		9.3×10^{-6}
PP		1.4×10^{-5}
PTFE		6.9×10^{-6}
PS		3.0×10^{-4}

4. Conclusion

The photoemission characteristics from many materials were measured. The result is as follows;

- The threshold energy of metals were similar magnitude to the reported wok function.
- The threshold energy of other samples have 5.4-5.7 eV.
- The samples with small magnitude of volume specific resistance tend to be easy to emit electrons. As the results, the quantum efficiency is high.
- It is deduced that samples with double bonds emit photoelectron easily.

We are planning to clarify the relation between the photoemission characteristics and the deterioration by formation of unevenness by introduction of double bonds.

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