A PORTABLE MINIATURIZED X-RAY TUBE FOR IN-SITU GEOLOGICAL ANALYSES.
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Introduction: A miniaturized x-ray tube specialized for *in-situ* geological and petrological x-ray analyses of rocks and powder samples is being developed. The x-ray tube is a typical x-ray generator for analyses in laboratories, such as medical radioscopic, x-ray fluorescence and diffraction analysis, etc, and is generally used with large and heavy water or air cooling system. While attempts to downsize the x-ray tube have been done so far by some institutes in order mainly for micro medical practices, some of compact x-ray tubes including air-cooler, power unit, and electric circuit are small enough to be taken out of laboratories by hand. However their sizes still limit alignment of components in the equipment.

Our primary motivation for the miniaturization is to mount tubes on spacecraft for a future Japanese lunar lander/rover mission [1], which is the next Japanese lunar exploration program to the SELENE lunar orbiter, and perform remote controlled x-ray generators for *in-situ* geological x-ray analyses of lunar surface soil samples. Possible x-ray instruments for the mission would be: the x-ray fluorescence/diffraction analyzer on the lander [2], the x-ray fluorescence spectrometer mounted on the arm of the rover and in the "mole unit" for the investigations of underground materials. All above instruments requires a miniaturized x-ray tube fulfilling enough lightweight and downsized volume, low power consumption, and stable performance under the operations in the space environment while mission term. Of course this portable-sized x-ray tube will be applicable to the laboratory experiments and the field studies of x-ray analyses.

Cold Cathode X-Ray Tube: Breakthrough to the miniaturization and the better power consumption performance of the x-ray tube is use of the field emission (FE) electron gun instead of the conventional thermal emission (TE) gun. Recently the carbon nanotubes (CNT) or carbon nanofibers (CNF) were found to be quite suitable to the FE electron source for several purposes [3], and it is also for the x-ray tube [4][5]. We adopt the CNT-FE x-ray tube for the miniaturization and the future operations on the lunar surface. Due to FE gun's high electron current density and no need to heat itself up, Downsized x-ray tube is able to be achieved with simple cathode dimension.

Our goal for the miniaturized x-ray tube is: size of < 5 cm^3, weight < 500 g (including electronic circuit), power consumption < 10 W, electron acceleration voltage 3-10 kV (variable), electric current 0.05-0.5 mA (variable), stable x-ray output through long time operations in vacuum and variable temperature of space environment, robustness to shock and vibration. The applied voltage 10 kV maximum is for the analyses of principal elemental components of rocks: Mg, Al, Si, S, Ca, Ti, Fe, Ni, etc.

Miniaturized X-Ray Tube Test Model: A first test model of the CNT-FE miniaturized x-ray tube was made. Fig. 1 shows the photograph of the model. The cubic tube case is made of stainless steel for the robustness in the severe operation environments. This first model simply consists of the cathode CNT elec-

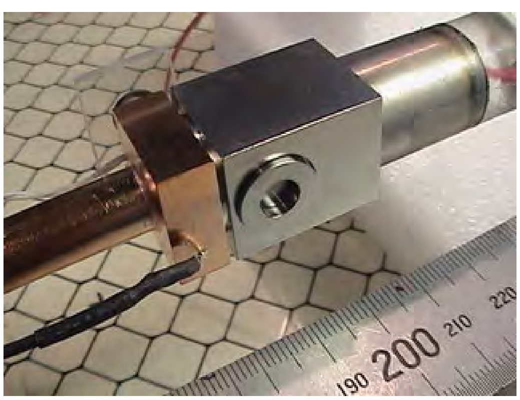

Figure 1: Photograph of the first test model. The CNT electron gun and the opposed Cu anode are placed in the stainless steel cube.

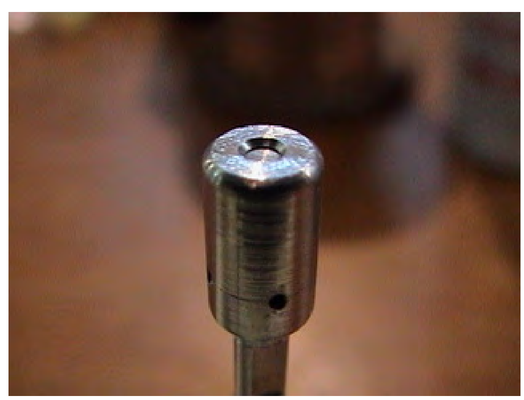

Figure 2: Photograph of the cathode CNT electron gun in the test model. The CNT is placed by conductive silver paste at the bottom of 1 mm ϕ hole.

tron gun and 2.75 mm distant opposed anode Cu target metal. 8.04 keV Kα emission line of Cu is most suitable for rock analyses. Side face of the target is exposed to outside for efficient cooling. Close-up of the cathode is shown in Fig. 2. Double wall carbon nanotubes (Honjo Chemical Co., Japan) is used for the electron emitter, pasting on the 1 mmϕ top plane of the stainless steel cathode by conductive silver paste. This flat large FE area makes more redundant electron emissions, therefore stable driving and long lifetime are expected. The wehnelt shape cover on the CNT focuses the electron beam on the anode. X-rays generated on the anode by electron collisions pass through the beryllium film. Whole tube size is 3 cm $\times$ 2 cm^2. Note that this model has some margins in its size for the investigations of basic specifications and future modifications. Substantial size would be less than 2 cm $\times$ 1 cm^2. The sputter ion pump currently connected to the tube case keeps residual gas pressure in $< 10^{-8}$ Torr for none operation time.

Fig. 3 and Fig. 4 shows the results of the first operation test of the model. Fig. 3 shows voltage-current characteristic of the test model. The plot is every 0.5 sec data by increasing voltage at 0.5 kV/min to 100 μA current. Stable electron current was found in the whole operation. We also got linearity feature in Fowler-Nordheim plot. Fig. 4 shows x-ray fluorescence analyses by the model for a powder sample in Mid-Ocean-Ridge-Basalt like composition. Distance from the sample to the x-ray tube and to the x-ray detector were approximately 10 cm. The Si-PIN photodiode (AMPTEK) is used as the x-ray detector. We clearly obtained line spectra of Ca, Ti and Fe for 300 sec integration at 8 kV, 80 μA. Photons of $<$ 3 keV including lines of Mg, Al, and Si were absorbed by the air, therefore it is needed to measure in vacuum or light weight gas for such elements. However it is no problem because the lunar surface is almost vacuum fortunately. Enough photon counts were found for the elemental composition analyses by the close range quick operation.

Future Works: We are currently investigating properties of the test model. Especially it is strongly needed to investigate vacuum quality in the tube. It was reported that stability and lifetime of the CNT emitter critically depends on residual gas pressure [6]. The first test result shows stable current behavior under 10^{-7} by the ion pump. The pump is cut off and place getters in the case after the investigations to carry out complete stand alone x-ray tube. Stability and lifetime tests will be done again after that. On the other hand, a second test model is being manufactured, which has an aperture grid electrode in front of the CNT surface to adjust electron current arbitrarily at a certain voltage.

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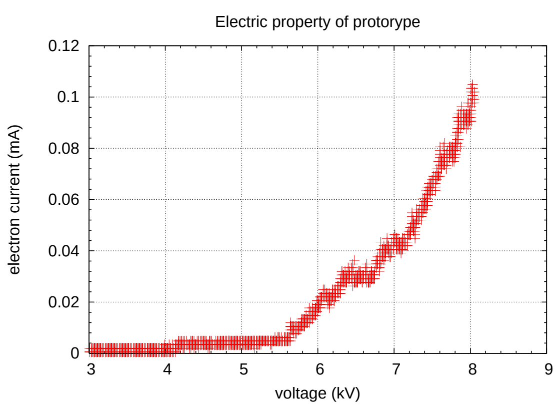

Figure 3: Voltage vs current plot of the first operation of the test model. The electron current from CNT increases to 100 μA with applied voltage increasing at 0.5 kV/min. Every 0.5 sec data was plotted.

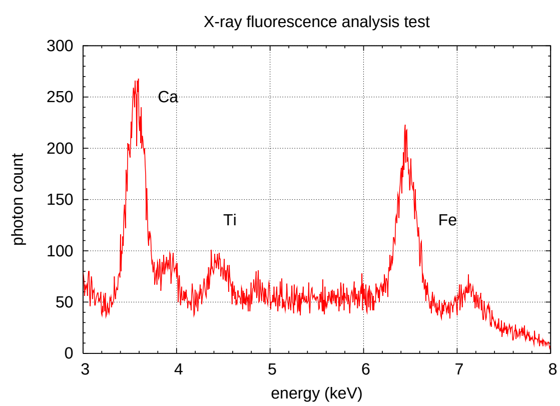

Figure 4: Fluorescent x-ray spectrum from MORB like sample excited by the test model. Enough photon counts was found for the elemental composision analyses by the close range quick operation.