SOME ELECTRICAL PROPERTIES OF URANIA—PART 1

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ABSTRACT

Australia is the world's largest producer of uranium. Uranium is used as fuel for nuclear power plants and for weapons. However, little effort has been devoted to establishing other uses. The United States Department of Energy has initiated the Depleted Uranium Uses Research and Development Project to evaluate potential beneficial uses of uranium. As part of the Project's effort to evaluate photovoltaic (solar cell) and thermophotovoltaic cell applications, samples of polycrystalline and single-crystal urania (UO_2) were characterized as to their electrical and photoelectric properties. Optical and infrared absorption and transmission data were obtained on samples that had been ion implanted from 10^{17} to 10^{21} atoms/cm^3 of aluminum, phosphorus, and boron. Dark and light currents were measured as a function of applied voltage for each dopant and for an intrinsic single crystal. Thermal currents were measured over a temperature range from -300 to 480 K.

For electrical measurements, samples were contacted either by pressing indium strips placed under spring-loaded probes onto them or by applying two lines (-4 mm long and 1 mm apart) of a fast-curing silver epoxy. It was verified that both methods of contacting resulted in the same current and current-voltage dependence. Results were obtained on dark and light currents measured under a dc bias of 20 V. The illumination intensity was 1 Sun, striking a surface area of . 1 cm^2. Dark current (I_d) is that current measured when a dc electrical voltage is placed across the contacts; light current (I_L) is the total current measured when the sample is illuminated and is still under the dc bias. For an undoped single crystal of UO_2, the peak I_d and the peak I_L observed were 0.039 and 0.067 mA, respectively. For aluminum doped polycrystalline UO_2 at 10^{17} atoms Al/cm^3, the values of I_d and I_L were 0.633 and 1.036 mA, respectively, more than an order of magnitude higher than those for an undoped single crystal. However, at a higher concentration (10^{21} atoms Al/cm^3), I_d and I_L were found to be lower, 0.153 and 0.285 mA, respectively. These results show that doping has subtle, but not dramatic, effects on the conductivity of UO_2 and possible affects carrier (hole) concentration and carrier mobility.

Doping polycrystalline UO_2 with phosphorus at a concentration of 10^{17} atoms P/cm^3 gave an I_d value of 0.24 mA and an I_L value of 0.450 mA. With a bias voltage placed across the samples and the samples illuminated, the current slowly increased in small time steps until a steady state was reached. The reverse was true also—the photocurrent, I_L, decayed in small time steps when the illuminating light was removed. This interesting phenomenon may be due to a multivalley release of electrons with different mobilities with time under a dc bias of 20 V and under a constant source of illumination. Again, as with aluminum, increasing the phosphorus concentration to 10^{21} atoms/cm^3 resulted in a decrease in I_d and I_L, to 0.257 and 0.279 mA, respectively.

In general, the polycrystalline-doped samples exhibited a semiconducting conductivity of 20 Ω^{-1} cm^{-1} ±500% at room temperature. Slow changes in the electrical conductivity occurred as the currents flowed for several minutes. Dark currents typically increased slowly to a steady-state value. The slow increase was marked by a somewhat stepwise character. Because the dissipated power was minimal, it is unlikely that such increase was due to I^2R heating. When the light was turned on, the same stepwise increase in photocurrent was observed up to a peak current. When the light was switched off, the current decreased in a stepwise manner down to a steady-state level. Experimentally, some of slow current increases upon illumination may have been caused by heating from the light source. However, in most samples, convincing evidence existed for modest genuine conductivity increases as a result of the illumination.

Currents were measured over a temperature range from room temperature (300 K) to .480 K. The slope of the resulting data is related to the activation energy required for electrical conduction. Activation energies ranged from 0.2 to 0.25 eV. At temperatures of 474 K, 378 K, and room temperature, and with a bias of 2 Vdc, polycrystalline UO_2 doped with 10^{19} atoms B/cm^3 exhibited currents of 4.91, 3.33, and 0.25 mA, respectively. Upon increasing the dc bias to 8 V (at 474 K), the current increased to 31.8 mA. This same sample was examined at various dc bias voltages and was found to behave in a nonlinear (nonohmic) manner. All doped polycrystalline samples were found to behave in a nonohmic manner (which did not depend on the polarity of the applied voltage). Undoped polycrystalline UO_2, under a dc bias of 10 Vdc, exhibited a current of 146.7 mA at 475 K, which decreased to 5.13 mA upon cooling to 301.3 K. When the dc bias at 475 K was reduced to 2 Vdc, the measured current was 20.4 mA (nonohmic). Polycrystalline urania doped with 10^{21} atoms B/cm^3 exhibited a thermal current at 460 K under a dc bias of 2 V, giving a current of 5.68 mA, which decreased to 0.66 mA at 310 K. When doped with 10^{21} atoms P/cm^3, and under a dc bias of 2 V at 467.5 K, a thermal current of 9.27 mA was measured. The thermal current decreased to 0.44 mA at 296 K. At 289.6 K under 2 Vdc, the measured current was 0.23 mA. When the bias was increased to 10 Vdc, the current measured was 2.1 mA. Values of thermal current measured for a doping level of 10^{19} atoms Al/cm^3 and at 2 Vdc were 6.62 mA at 474.4 K and 0.6 mA at 305 K. When doped at 10^{21} atoms Al/cm^3, the thermal current measured at 475 K (2 Vdc) was 12.5 mA and at 300 K it was 1.03 mA.

In summary, the current increased and decreased in small time steps when a bias voltage or light illumination was applied to or removed from the samples. A distinct nonohmic behavior for current-voltage characteristics was observed. A weak, slow decrease of the electrical resistance was observed while the samples remained under illumination.