Photoconductive Properties of Doped UO_2

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INTRODUCTION

Uranium is used as fuel for nuclear power plants and for weapons. The U.S. Department of Energy has initiated the Depleted Uranium Uses Research and Development Project to evaluate other potential beneficial uses of uranium. As part of the Project's evaluation of photovoltaic (solar cell) and thermophotovoltaic cell applications, the photoconductive properties of polycrystalline and single-crystal UO_2 were characterized. Optical absorption data in the visible and near-infrared range were obtained on samples that had been ion implanted [1] with 10^{17} to 10^{21} atoms/cm^3 of tellurium and antimony. Properties of UO_2 doped with aluminum, phosphorus, and boron were reported earlier [2]. 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 the temperature range -300 to 480 K.

EXPERIMENTAL

Samples were contacted either by pressing onto them indium strips placed under spring-loaded probes or by applying two lines (-4 mm long and 1 mm apart) of a fast-curing silver epoxy. Both methods resulted in the same current and current-voltage dependence. Results were obtained on dark and light currents measured under dc voltage biases. The illumination intensity was 1 sun; the illuminated surface area was . 1 cm^2. Dark current (I_d) is that measured when a dc voltage is placed across the contacts; light current (I_L) is the total current measured when the sample is illuminated and remains under the dc bias. For an undoped single crystal of UO_2, the peak values I_d and I_L were 0.039 and 0.067 mA, respectively.

ANTIMONY

For antimony-doped polycrystalline UO_2 at 10^{17} atoms Sb/cm^3, the maximum value for I_L was 0.464 mA, about an order of magnitude higher than that for an undoped single crystal. At a higher dopant concentration (10^{19} atoms Sb/cm^3), the maximum I_d and I_L were found to be lower (0.131 and 0.228 mA, respectively). At a concentration of 10^{21} atoms Sb/cm^3, the maximum I_L was 0.559 mA. These results show that doping has subtle, but not dramatic, effects on the conductivity of UO_2 and possibly affects carrier concentration and mobility.

TELLURIUM

As shown in Fig. 1, doping polycrystalline UO_2 with tellurium at a concentration of 10^{19} atoms Te/cm^3 gave I_d and I_L values of 0.570 and 1.00 mA, respectively. At a concentration of 10^{21} atoms Te/cm^3, I_L was 1.436 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 also true—the photocurrent, I_L, decayed in small time steps when the illuminating light was removed. Conventional photovoltaic materials respond rapidly. This slow, small time-step phenomenon may be due to a multivalley [3] release of electrons with different mobilities with time under a dc bias voltage and under a constant source of illumination.

In general, the doped polycrystalline samples exhibited a semiconducting conductivity of 20 Ω^{-1} cm^{-1} ±500% at room temperature. Slow changes toward a steady-state electrical conductivity occurred as the currents flowed for several minutes. Dark currents typically increased slowly to a steady-state value, an increase that was somewhat stepwise in nature. Because the dissipated power was minimal, such increase was not likely 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 to a steady-state level. Although some of the slow current increases upon illumination may have been slightly influenced by heating from the light source, 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.

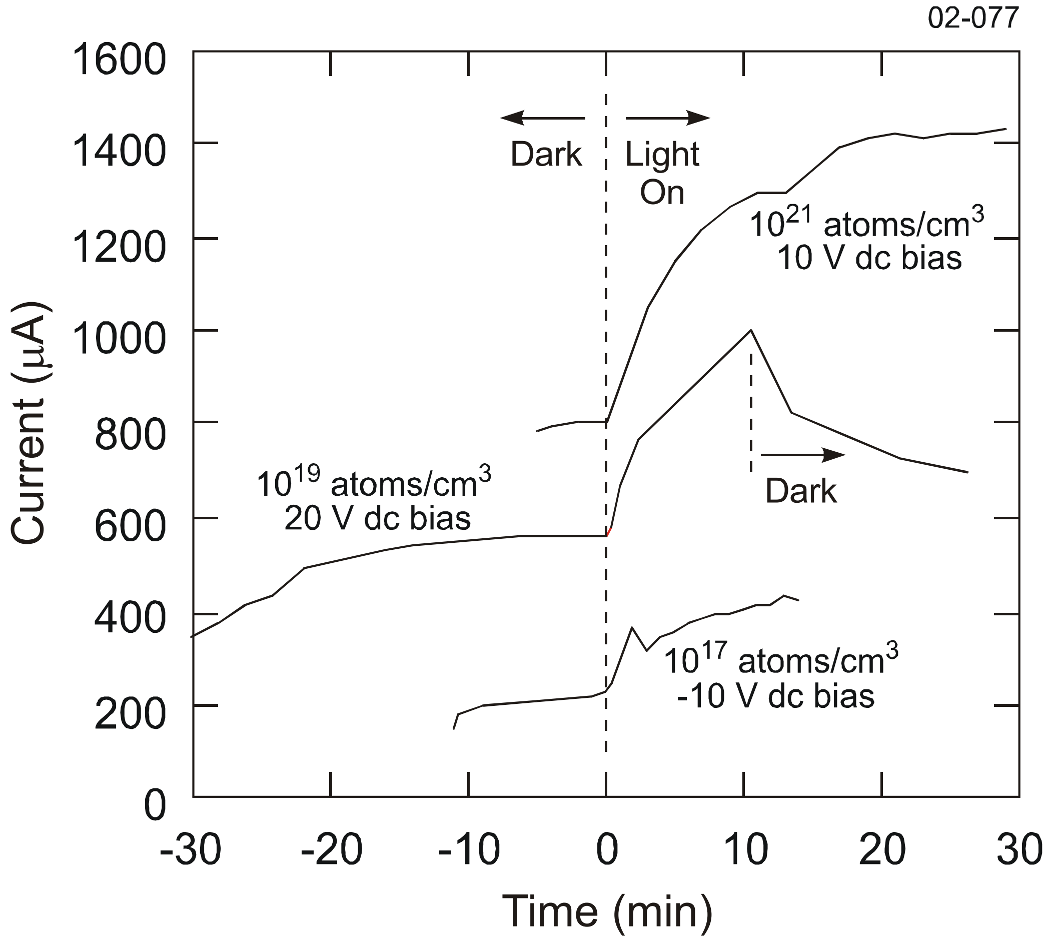

Fig. 1. Time dependence of dark (I_D) and light (I_L) current for tellurium-doped unannealed polycrystalline UO_2.

SUMMARY

In general, doped UO_2 exhibits electrical resistivities comparable with those of conventional photovoltaic materials (Si or GaAs). Doping UO_2 with antimony and tellurium increases light current over dark photocurrent by a factor of two to three. Doping UO_2 to a concentration of 10^{21} atoms Te/cm^3 gives a maximum photocurrent of - 1.5 mA, generated by illuminating a 1 cm^2 surface area under a constant dc bias of 10V, a very encouraging results. The current increased and decreased in small time steps upon application or removal of a bias voltage or light illumination 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.

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