Thermal Conductivity and Electrical Resistance of Radiation Damaged Pitch-based Fibers

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Introduction

Carbon Fibers produced from mesophase pitch possess thermal conductivities 3 times that of copper and are currently being used in a number of thermal management applications. It is customary to obtain the thermal conductivity of the fibers from an empirical relation between the thermal conductivity and the electrical resistivity[1]. This relation has been derived from electrical resistance measurements on fiber tows and then measuring the thermal performance of composite panels or components made from the fibers and backing out the thermal conductivity of the fiber. The above procedure is useful determine the translation of the original fiber properties through to the composite, but it is difficult to determine the fundamental properties of the fiber itself. To test this correlation, we have implanted K1100 fibers provided by Amoco Performance Products, Inc. with 12 MeV carbon ions and measured the thermal and electrical conductivity of the fibers as a function of ion dose. This carbon ion bombardment should produce vacancy defects in the fibers and thus reduce the fibers thermal and electrical transport properties. The thermal diffusivity of single filaments is then measured with a novel laser photothermal beam-deflection method and the electrical resistance is measured on the same filaments.

Experimental

A single carbon-fiber filament was mounted on a glass slide with dimensions of approximately 6 mm by 25 mm. The fiber was mounted on aluminum standoff with a conducting silver paste leaving ~1 cm of free-standing fiber. The resistance of the fibers was between 150-200 Ω. 4-probe resistance measurements were performed using an HP 4129A low-frequency impedance analyzer. The resistance as a function of temperature, current loading, voltage bias and frequency was studied. This allowed us to confirm that we were measuring the true resistance of the fiber. Isolation from air currents and a reasonably temperature-controlled room are necessary for accurate resistance measurements. The diameter of the fibers was measured with an SEM.

The thermal diffusivity (conductivity) was measured with a dual-beam transverse photothermal apparatus that was developed to measure the thermal diffusivity of single filaments and has been described previously[2-3]. The carbon fibers on the mounts described above are suspended in an optical cuvette filled with CCl_4 as a working fluid. The filament sample is heated with a focused, square-wave chopped Ar-ion pump laser beam incident normal to the fiber. Heat diffuses along the fiber and into the adjacent CCl_4 fluid. The synchronous ac thermal wave propagating along the fiber is detected by directing a weak He-Ne probe laser trough the refractive index gradient created in the fluid by the thermal wave. The probe laser is orthogonal (transverse) to both the pump laser beam and the fiber axis. The probe or pump beam is then scanned along the fiber axis to obtain the thermal profile along the fiber. The fiber remains near room temperature at all times during the measurement.

The carbon-ion implantation was performed using a NEC tandem Pelletron accelerating the C^{4+} ions to 12 MeV. The carbon filament sample, still on its glass slide mount, was mounted in the target chamber on a copper block with a copper ring on the contacts to prevent charge build-up. The sample was rotated in the ion-beam at ~ 2 Hz to allow for uniform irradiation. The stopping power and range of the ion beam was modeled using a Monte Carlo ion transport program (SRIM-96)[4].

Results and Discussion

The thermal conductivity and electrical resistance of a representative single filament sample of K1100 as a function of increasing carbon ion dose is shown in Fig. 1. (The fluence is the flux in number of ions/cm^2·s integrated over the time of the exposure.) No annealing of the damage was observed at room temperature. The Monte Carlo calculations tells us that the 12 MeV Carbon ions only penetrate 8-9 μm into the fiber. This, plus the fact that the ions do much of their damage at the end of their range, means that we are producing a non-uniform damage profile in the fiber. We need to take this into account in the determination of the number of vacancies produced per cm^2 and the relationship to the fundamental transport properties of the fibers.

Thermal-conductivity measurements have been reported previously on different families of carbon fibers and related to the microstructure and electrical resistance[5,6]. This can be contrasted to the present work where all the measurements are on the same or series of the same single filament of a fiber. Fig. 2 shows that the ER-TC relationship derived from this data is very similar to that reported for different classes of pitch-based fibers. This lends support to the existence of a universal ER-TC relationship since the damage we selectively produce in a high-performance K1100 fiber would not produce the same microstructure as exists in a lower conductivity fiber such as P100 or P120. This technique also be used to investigate the hypothesis that fibers with different cross-sectional geometry may follow a different ER-TC correlation[6].

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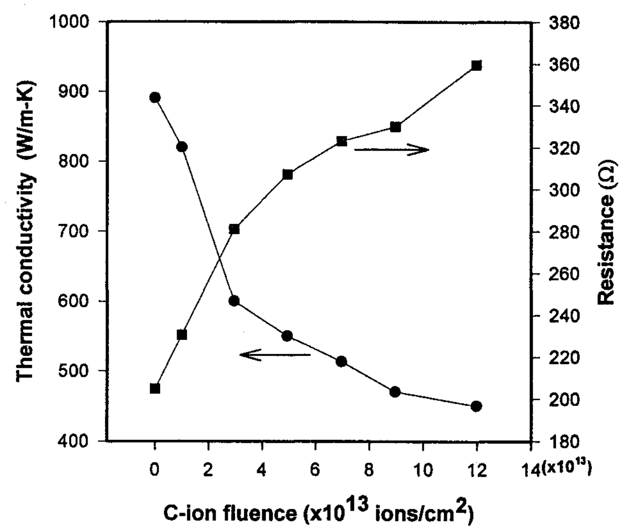

Fig. 1 The thermal conductivity (circles, left-hand axis) and the electrical resistance (squares, right-hand axis) of a single K1100 filament as a function of Carbon ion fluence.

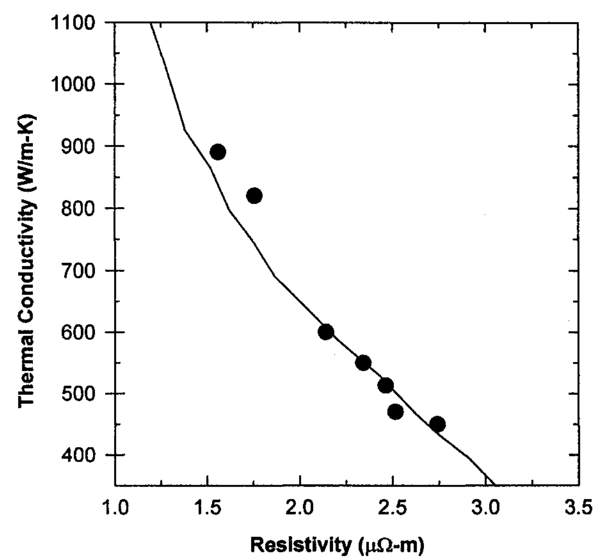

Fig. 2. The thermal conductivity vs the electrical resistivity for the implanted fiber from Fig.1 (circles). The curve is the widely used universal TC-ER relation.[1]