Sustaining the enhanced electrical conductivity of chemically doped carbon nanotube wires

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Dopant degradation mechanisms illustrating dopant decomposition into other viable dopants, referred to as a "dopant cascade," and dopant desorption. Credit: Karen J. Soule

Modern technologies continue to become lighter, smaller, and faster, although the conductors used to power these technologies remain relatively unchanged. Conventional metal conductors, largely copper, are used to power the newest consumer electronics and are on board the most technologically advanced space and defense systems. Carbon nanotube (CNT) conductors have emerged as a lightweight, strong and conductive alternative to conventional metal conductors. CNTs have a density approximately 89% less than that of copper, allowing for greater payloads and reduced fuel costs for applications where CNTs can replace copper conductors.

The electrical conductivity of an individual carbon nanotube is greater than copper, but has not yet been realized in bulk CNT networks due to junction resistance between the individual CNTs. Recent work has demonstrated that chemical doping of CNT conductors can result in mass-normalized electrical conductivities approaching those of conventional metal conductors. The flexibility, corrosion resistance, and mass savings of CNT wires, along with continuing advances in electrical conductivity, indicate that CNT conductors are becoming a viable alternative to conventional metal conductors.

At the NanoPower Research Laboratories at the Rochester Institute of Technology (RIT) in Rochester, New York, I realized that as the electrical conductivity of these doped CNT conductors approaches metals, an understanding of the long-term and high current stability of these materials must be understood. Conductor failure is the result of Joule heating at increased applied current densities. For metals, the temperature increases until the conductor eventually melts. For CNTs, the temperature increases until the conductor thermally oxidizes in air. The doped CNT conductors are also affected by dopant degradation, which reverses the benefits of improved electrical conductivity due to chemical doping of CNT conductors. The effects of this intermediate current degradation of the dopants and the resulting changes in electrical conductivity must be better understood for the adoption of these CNT conductors.

At RIT, I developed two current cycling procedures that allowed us to probe the electrical performance retention of doped CNT conductors as a function of increasing applied current density and repeated current exposure. This work determined that $KAuBr_4$ chemical doping is capable of improving the electrical conductivity of commercially available CNT wires by six times and is able to maintain this improved electrical conductivity at current densities around three times greater than where the as-received CNT wires begin to degrade.

This work went on to relate the thermal stability of the $KAuBr_4$ chemical dopant and its high current and repeated current stability. At increased temperatures, $KAuBr_4$ degrades into $AuBr_3$ and AuBr, other viable CNT dopants. This is referred to as a dopant cascade, and results in improved electrical conductivity despite the CNT conductor reaching temperatures where dopant degradation occurs. This dopant cascade allows for $KAuBr_4$ doping to be more stable than other dopants that would simply desorb from the CNT conductors. Therefore, $KAuBr_4$ doped CNT wires have emerged as lightweight conductors capable of retaining their improved electrical properties during long-term, high-current applications, thus motivating the future adoption of stable $KAuBr_4$ doped CNT wires in a variety of advanced wire applications.

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Bio:

Karen Soule is a Ph.D. Candidate at the Rochester Institute of Technology. Working at the NanoPower Research Laboratories has allowed her to merge her materials science and chemical engineering background to develop improved electrical conductivity, stable carbon nanotube conductors. Currently she is finishing her dissertation titled "Electrical Performance Retention of Doped Carbon Nanotube Conductors for High Current Applications."