Fresh Approaches To Enhance Organic Semiconductors

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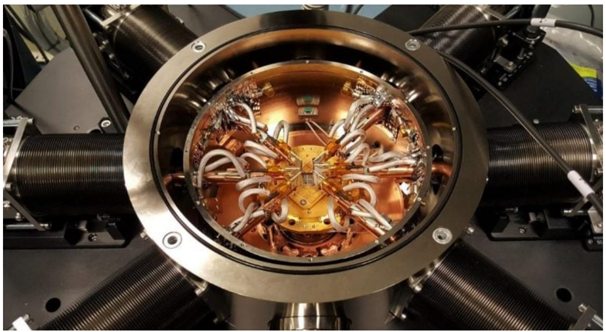


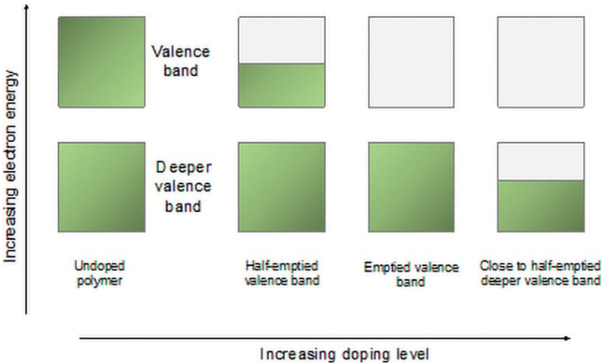
Courtesy of SynEvol
Credit: Dr. Martin Statz, Sirringhaus Lab

Scientists from Cavendish have found two novel approaches to enhancing organic semiconductors. By using unanticipated features in the non-equilibrium state, they were able to extract more electrons from the material than had previously been conceivable, improving its performance for use in electronic devices.

"Our goal was to precisely identify the process that occurs when polymer semiconductors are heavily doped," stated Dr. Dionisius Tjhe, a postdoctoral research associate at the Cavendish Laboratory. Doping is the technique of boosting a semiconductor's electrical current carrying capacity by either adding or deleting electrons.

Tjhe and his colleagues describe in detail how these new insights may assist to improve the performance of doped semiconductors in a work that was recently published in Nature Materials.

Solids have arranged their electrons into energy bands. Electrical conductivity and chemical bonding are two of the major physical qualities that are governed by the highest-energy band, also known as the valence band. In organic semiconductors, doping is accomplished by taking out a little portion of the valence band's electrons. Then, electricity can flow and conduct through holes, the lack of electrons.



Courtesy of SynEvol

Credit: Sirringhaus Lab

According to Tjhe, "a typical organic semiconductor has only ten to twenty percent of its valence band electrons removed, which is already much higher than the parts per million levels typical in silicon semiconductors." We were able to totally empty the valence band in two of the polymers that we looked at. Surprisingly, we can even remove electrons from the band below in one of these materials. It might be the first time that has happened.

It's interesting to note that the conductivity in the deeper valence band is much higher than in the upper one. It is hoped that deep energy level charge transmission would eventually result in thermoelectric devices with better power. These are responsible for converting heat into electricity, according to co-first author of the paper and postdoctoral research associate at the Cavendish Laboratory, Dr. Xinglong Ren. "We can turn more of our waste heat into electricity and make it a more feasible energy source by finding materials with a higher power output."

The valence band should be able to empty in other materials, according to the researchers, although polymers may exhibit this behavior the most readily. "We believe that our ability to accomplish this is a result of the arrangement of energy bands in our polymer and the disordered nature of the polymer chains," Tjhe stated. In contrast, because it is more difficult to empty the valence band in these materials, other semiconductors, like silicon, are probably less likely to host similar phenomena. The critical next step is to understand how to replicate this outcome in various materials. For us, this is an exciting moment.

Doping increases the quantity of ions, which restricts the power, while simultaneously increasing the number of holes. Fortunately, by employing an electrode called a field-effect gate, scientists can regulate the number of holes without changing the amount of ions.

"We discovered that we could modify the hole density using the field-effect gate, and this produced very different outcomes," said Dr. Ian Jacobs, a Royal Society University Research Fellow at the Cavendish Laboratory. The natural relationship between conductivity and hole count is for conductivity to rise with increasing hole count and decrease with hole removal. This is shown when we add or remove ions to alter the number of holes. But we observe a different impact when we use the field-effect gate. A conductivity gain always results from adding or deleting holes!

These surprising results were eventually linked by the researchers to a well-known, but infrequently observed, characteristic of disordered semiconductors called a "Coulomb gap." Remarkably, at room temperature, this impact vanishes and the anticipated trend resumes.

According to Jacobs, Coulomb gaps are infamously difficult to detect in electrical tests since they are only apparent when the material is unable to assume its most stable state. However, we were able to observe these effects at significantly higher temperatures—roughly -30°C—than we had originally predicted.

Ren stated, "It turns out that the ions in our material freeze; this can happen at relatively high temperatures." When the ions are frozen, the material is in a non-equilibrium condition if we add or remove electrons. The ions are frozen, which prevents them from rearranging and stabilizing the system as they would like. We can now observe the Coulomb gap as a result.

Thermoelectric power production and conductivity typically trade off with one another, increasing as the other decreases. However, because of the non-equilibrium effects and the Coulomb gap, both can be increased simultaneously, improving performance. The field-effect gate's current restriction is that it only impacts the material's surface. The power and conductivity would rise to even greater heights if the majority of the material was impacted.

While there is certainly room for improvement, the study paper presents a well-defined approach to enhance the efficiency of organic semiconductors. The group has left the door open for additional research into these features, which present great prospects in the energy industry. "This non-equilibrium state of transport has once again shown itself to be a promising pathway toward improved organic thermoelectric devices," Tjhe stated.
