Improving K-Dielectric Semiconductors: Novel Boron Carbides tested as Neutron Voltaics

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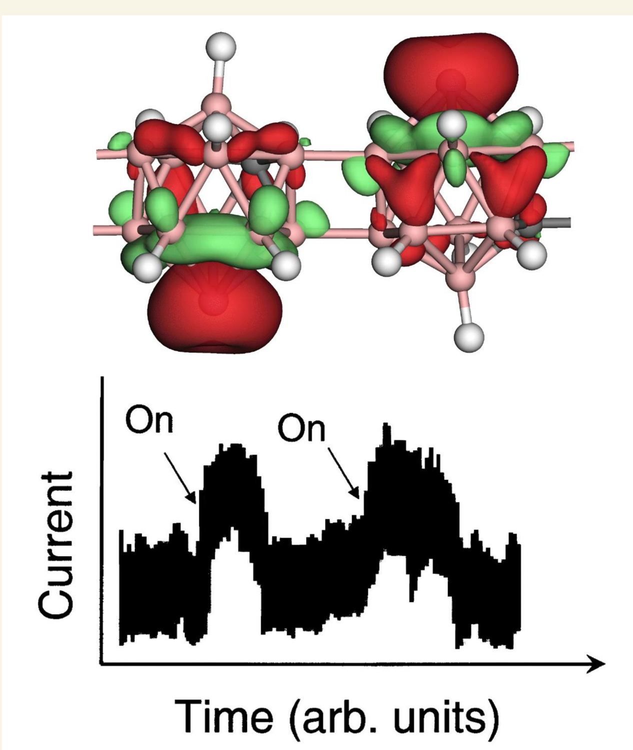
Introduction

The low k-dielectric boron carbide has a number of possible applications, some prosaic, some not. NASA announced in 2011 that it plans to build deep-space probes to explore the outer reaches of our solar system and beyond. There are problems, however, because the probes cannot be powered by solar energy, and they need to be protected from high neutron exposure from the power source. Our work on boron-carbide semiconductors seeks to present a solution to both of these problems by creating neutron-voltaics and protective neutron-absorbing coatings. Neutron-voltaics work just as photovoltaics do. The basis for boron-carbide neutron capture is as follows.

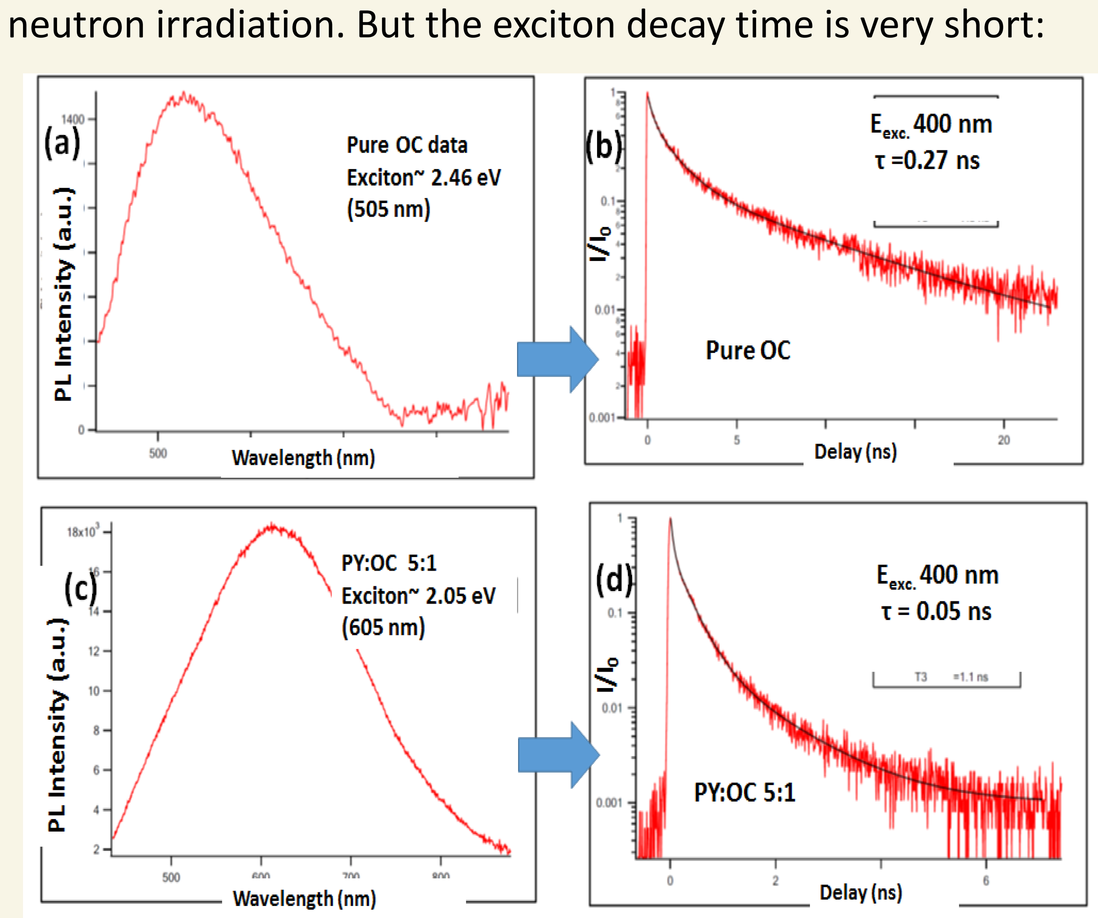
$^{10}B + n \rightarrow 7\,Li^{+}\ (0.84MeV) + 4He^{-}\ (1.47MeV) + \gamma\ (0.48MeV)$ (94%)

$^{10}B + n \rightarrow 7\,Li^{+}\ (1.02MeV) + 4He^{-}\ (1.78MeV)$ (6%)

Neutron-voltaics have already been proven to work when made from boron carbides.



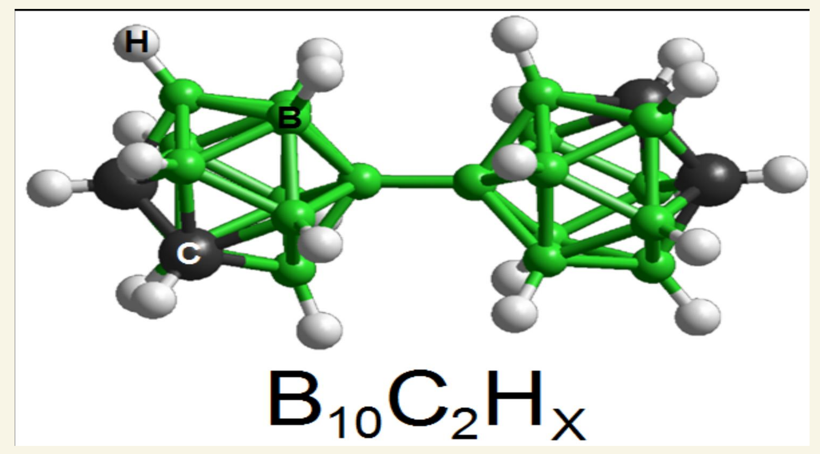
Boron-carbide semiconductors hold the most promise for neutron-voltaics. They are cheaper, faster, and more sensitive than currently available platforms. In addition, they are portable and lightweight, which is ideal for space applications. As neutron absorbers, they can also afford astronauts some protection from neutron irradiation. But the exciton decay time is very short:



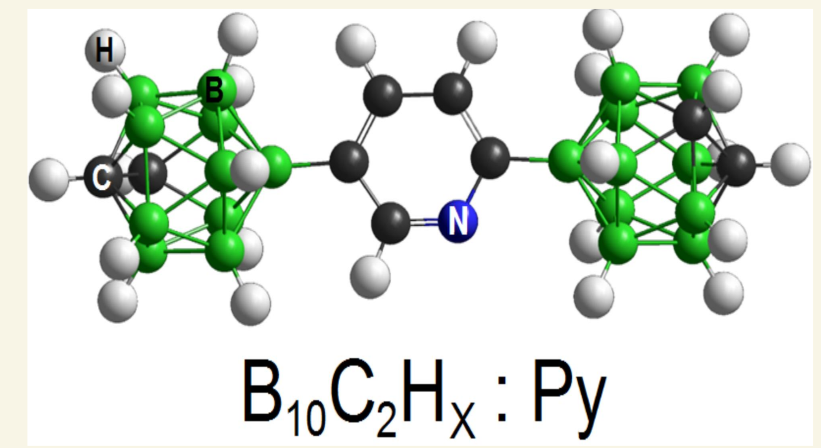
The very, very short exciton lifetime doesn't seen to apply because the exciton energy is larger than the indirect band gap and the carrier diffusion length appears to be reasonably longer.

Approach

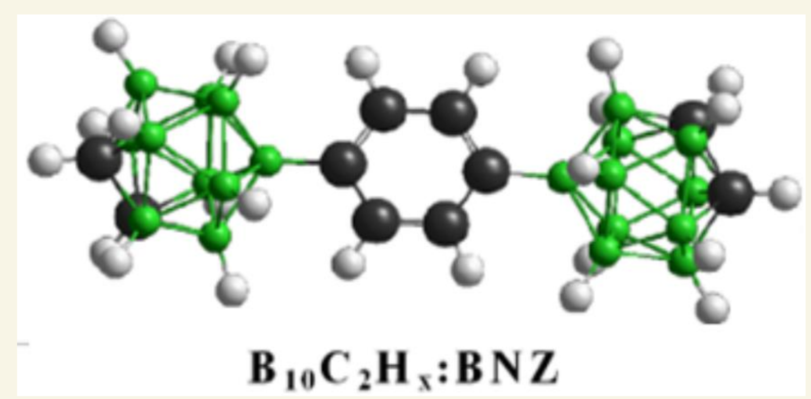
Four types of boron carbides were made into heterojunction diodes with silicon for this study, each one made out of a different boron carbide film.



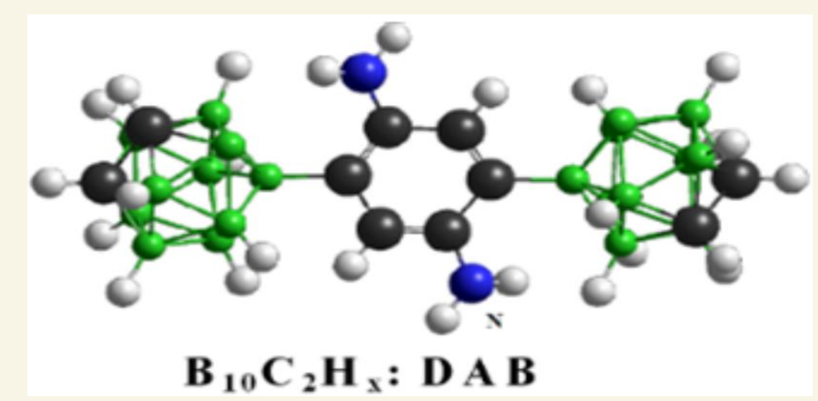
Cross linking in Pure Boron Carbide



Cross linking in Boron Carbide with Pyridine



Cross linking in Boron Carbide with Benzene



Cross linking in Boron Carbide with Diaminobenzene

Each of these films was created through plasma-enhanced chemical vapor deposition (PECVD). Current-voltage, I(V), and capacitance-voltage, C(V), curves were created for each diode to study how each film behaved while external voltages were applied to them individually. The C(V) curves used AC currents at frequencies of 1, 10, and 100 kHz as well as 1 and 10 mhz. In order to evaluate the current in the I(V) curves independently of the size of the films, the ratio between the forward-bias gradient and the reverse-bias gradient was calculated.

Results

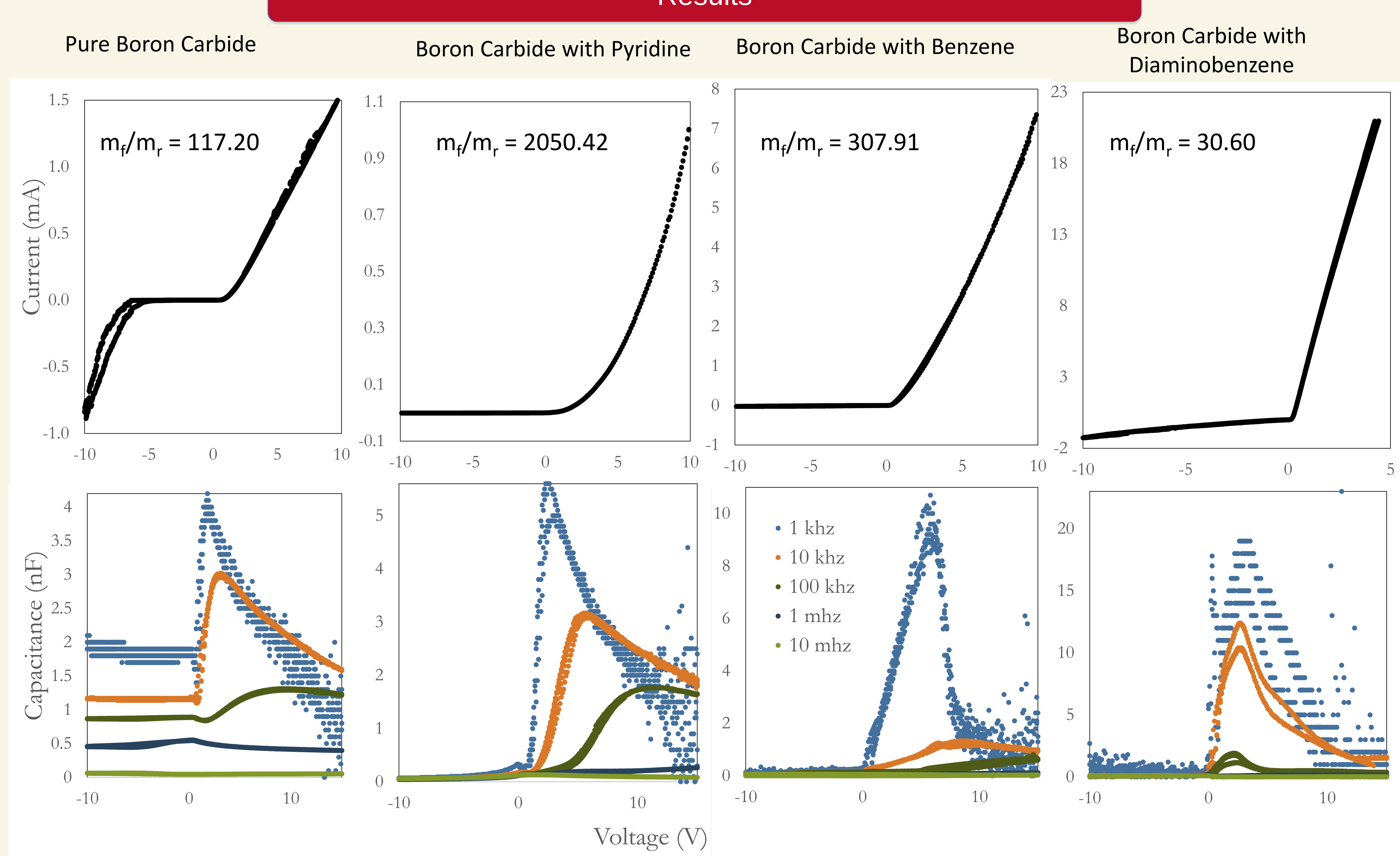


Figure 4. The I(V) and C(V) measurements for various boron carbides. The different C(V) curve colors correspond to different alternating current frequencies. It may not be immediately obvious, but the best performance overall comes from the boron carbide made with pyridine as an additive.

Problem Description

Past work demonstrates that while using pure boron-carbide devices is promising, introducing boron-carbide to other moieties from the family of aromatic compounds, like pyridine, yields better results. Charge collection is more efficient as seen in the zero bias neutron voltaic response.

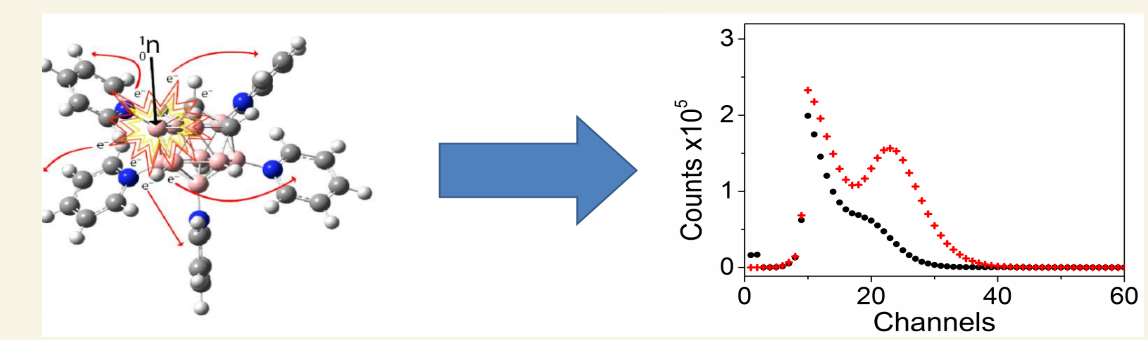
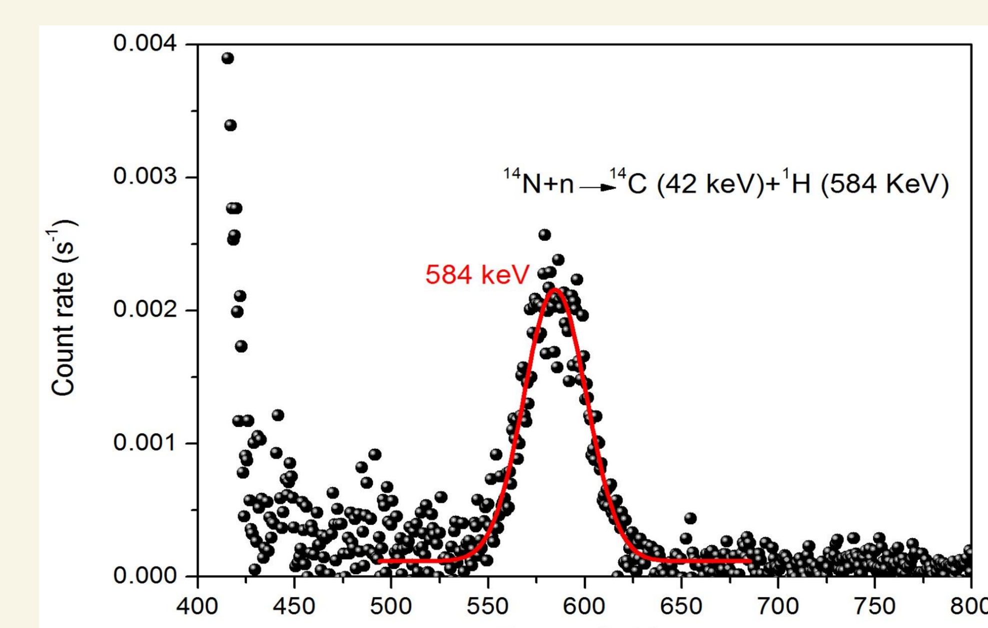


Figure 5. Left: Schematic neutron capture by functionalized boron carbides. Right: Experimental neutron pulse height spectra of $B_{10}C_2H_X$ (black filled circles) and $B_{10}C_2H_X$ with pyridine (red plus symbols) at zero bias.

This demonstrates that boron carbide neutron detection can be improved by the incorporation of pyridine or similar groups that enhance electron-hole separation and, possibly, better carrier mobilities and total charge collection. The capacitance result indicates that the capacitance is better preserved in high frequency regimes in the boron carbides with pyridine. This indicates that high carrier mobilities exist with this type.

Interestingly enough, the nitrogen in the pyridine also captures neutrons, as indicated by the characteristic neutron capture experiment below.



Conclusions

The experiments suggest that films that incorporate either pyridine or benzene into the boron-carbide semiconductors have significantly better electron-hole separation than pure boron-carbide films do. This agrees with previous studies which show that boron-carbide films modified with aromatic groups perform better and can generate more usable electricity for neutron-voltaics. Pyridine is the best in this experimental group, so future studies will need to further analyze the characteristics of boron-carbides with pyridine to see which concentrations, carborane types, and substrates may enhance the performance of the semiconductors.

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