# Impact of Thermal Neutrons on Boro-carbon-oxy-nitride (BCON)

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## Introduction

Thermal neutrons have an average kinetic energy corresponding to the average energy of the particles of the ambient materials [1]. These neutrons are relatively slow and possess a relatively lower energy. Hence they have a large area of cross section (Figure 1). The energy of a thermal neutron is about 0.025 eV. For thermal neutrons, gadolinium, boron, lithium, and hydrogen have a high neutron capture cross section. In this work, we have used boron nitride as our boron source because of its compatibility with graphene oxide (GO) to form a heterogeneous composite. Also, boron is within the detection limits of the X-ray photoelectron spectroscopy (XPS) technique used for the analysis.

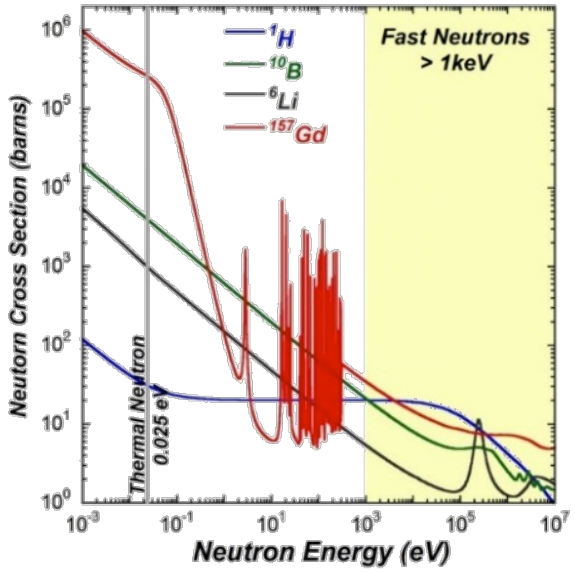


**FIGURE 1: Neutron capture cross sections**

In this particular work, the thermal neutron interaction with boro-carbon-oxy-nitride (BCON) is studied. BCON is composed of a heterogeneous composite mixture of graphene oxide (GO) and boron nitride (hBN) in variable hBN ratios. The material can be tuned with hBN concentration forming paper – ribbon like material as can be observed in Figure 2 (a) and (b). Boron in boron nitride has about 20% $B^{10}$, which is highly sensitive to neutron particles [2]. When a neutron particle interacts with boron, it decomposes into $^{7}Li$ and an alpha particle. About 94% of the time, a low energy gamma-ray is also released with the alpha particle [3]. The interaction of alpha particles and gamma-rays with GO and BCON produce changes in the chemistry. Hence, these changes can be used in studying the interaction of neutrons with BCON.

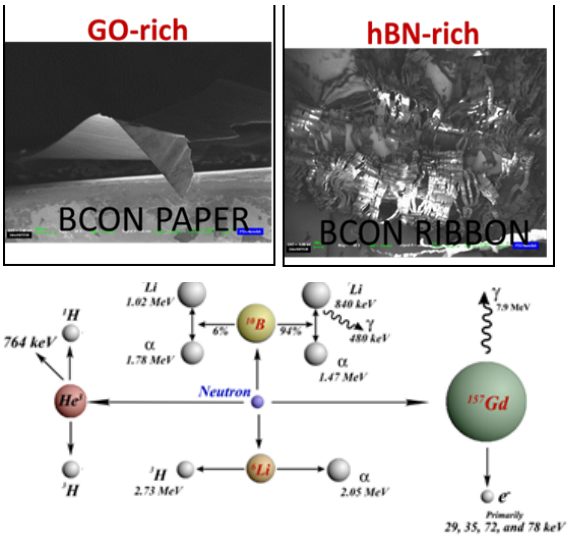


**FIGURE 2: BCON paper, BCON ribbon, and boron interactions with neutrons, producing gamma-rays and alpha particles [3].**

## Thermal Neutron Interactions with BCON

Neutron irradiation of BCON was performed at the Penn State Breazeale Reactor. BCON materials with a thickness of 10 µm was exposed to thermal neutrons with a flux of 1.3 x $10^{9}$ n/$cm^{2}$-s. The samples were exposed for four different times (1, 2.5, 5 and 10 minutes). The diameter of the neutron beam was 2 cm and the BCON paper was aligned with the center of the neutron beam. To maintain sample integrity, the samples were transported in vacuum bags sealed from UV light in order to reduce the impact of the surroundings during transport. In order to calibrate the measurements, a control sample was also placed along with the other samples for irradiation. X-Ray photoelectron spectroscopy (XPS) was used to determine the effect the neutrons on BCON.

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The interaction mechanism of a neutron particle in GO is not well known and therefore the attenuation coefficient and energy absorption coefficient are not well defined. The total neutron absorption of GO was negligible during the transmission analysis. With the addition of hBN, we expected to see a lot of changes in the BCON as the boron would capture thermal neutrons. In order to see these changes, the number of events that occur in the material should be high. From the neutron transmission data, the total flux obtained with and without the sample was nearly identical, indicating that the number of events where a neutron interacted with a boron atom occurrence was small.

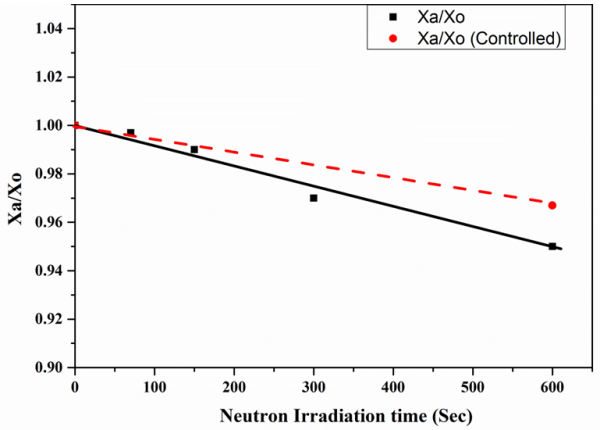


**FIGURE 3: XPS measurement of the O/C ratio for GO after thermal neutron irradiation and a control sample.**

The total X-ray exposure time for the XPS measurements of BCON pre-neutron irradiation and GO post-neutron irradiation was 600 seconds, which yields a $O/C_{x600\_s}$ =0.93. Both the BCON control sample and the BCON neutron irradiated sample are shown in Figure 3 with the X-ray corrected value. The small change in the O/C of the controlled sample could be ignored as there was no statistically significant change observed by analyzing the high resolution spectra of C1s (Figure 4 (a)) and O1s (Figure 4 (b)). The difference in the O/C change between the control sample and the neutron irradiated sample was only 0.02.

Although there is no change observed in C 1s and O 1s, slight change in the B 1s peak structure can be observed. This small change could be because of the interaction of neutrons with the B 1s. This slight change in the peak structure of the B 1s and the reduction of the boron bonding with oxygen in the sample was the only indication of neutron impact events. Also, the total B 1s content in the sample was too low (~1 atomic %), and no noticeable lithium formation was observed in the survey scan for XPS.

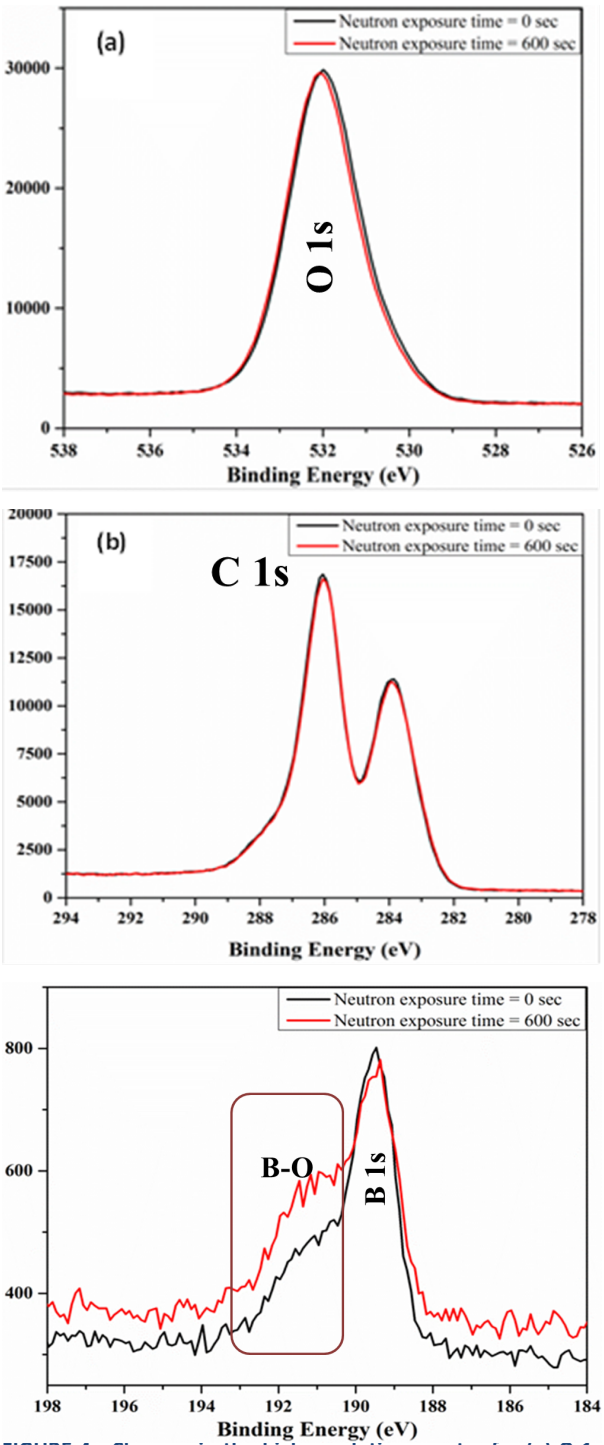


**FIGURE 4: Changes in the high resolution spectra for (a) O 1s and (b) C 1s showing a minimum change in the peak structure indicating that there was no change before and after the neutron exposure. (c) A slight change in B 1s indicating that the concentration of boron atoms should be higher in order to see any statistically significant change.**

## Acknowledgements

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## References

1. https://www.euronuclear.org/info/encyclopedia/n/neutron-thermal.htm
2. Cember, H. & Johnson, T. E. *Introduction to Health Physics*. (McGraw-Hill Companies, Inc., 2009)
3. Boron Neutron Capture Therapy. at http://www.cnea.gov.ar/xxi/bnct/eng/

## Publications

Synthesis and Radiation Response of Boro-carbon-oxy-nitride (BCON), *in preparation*.