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Metal Semiconductor Contact between Gold and Boron Carbide

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Introduction

Boron Carbides have been shown to be suitable for semiconducting devices and as a low K dielectric. An important part of any semiconducting device is the metal contact that connects with the semiconductor. Increasingly, there has been investigation of the interface of various boron carbides to various metals and the chemical interactions or band bending that may occur at the metal/semiconductor interface. However, understanding the metal contacts on the surface of these semiconductors presents a number of important challenges. Depending on the work function of the metal, such interface characteristics could lead to either rectifying or non-rectifying junctions which will affect device functionality. Low work function metals have attracted much attention, but are often seen to be quite reactive at the interface with boron carbide. A less reactive metal with high work function is an important juxtaposition. Here we extend this trend by investigating the interaction of gold, a very large work function metal, with a boron carbide fabricated by dehydrogenation of metacarborane (1,7-$C_2B_{10}H_{12}$)

Current-Voltage Measurements

Meta carborane is unique in that it is usually regarded as an n-type boron carbide material (boron carbides are usually p-type). To understand how well it works in a diode with a high work function contact such as gold, a current versus voltage characteristic curve was generated.

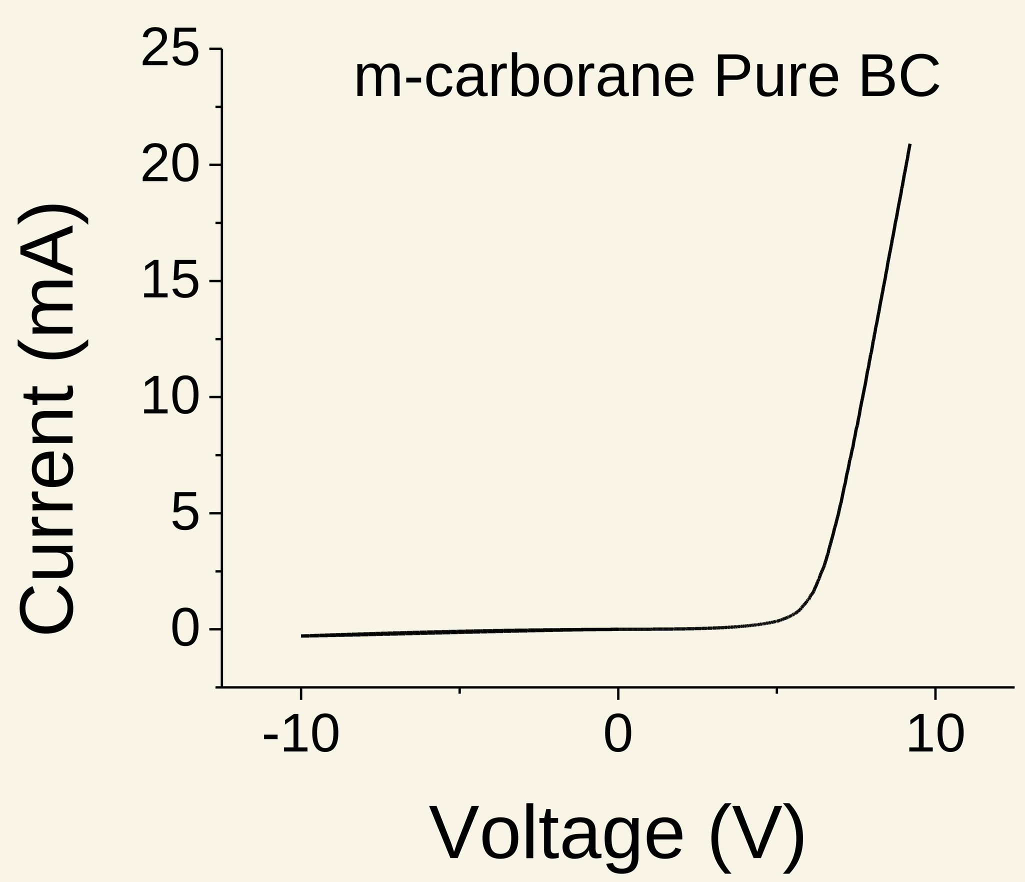


Figure 3. Current versus voltage of the n-type m-carborane boron carbide film on p-type Silicon

The less than 1 nA current at zero bias, the lack of a substantial dark current at reverse bias, and the steep increase in current during forward bias (close to 9.25 mA/V) indicates that the diode works extremely well. This implies that the n-type m-carborane boron carbide performs well with a high work function metal like gold. The I(V) curve also shows no evidence of any Schottky barrier formation.

Strength of Metal-Semiconductor Interactions

	B – B bond		B – C bond		C – B bond		C – Au bond	
	BE (eV)	atomic % B	BE (eV)	atomic % B	BE (eV)	atomic % C	BE (eV)	atomic % C
Clean Sample	188.3	45	189.2	55	283.6	100	-	-
1st Au deposition	188.7	80	191.5	20	284.6	95	289.3	5
2nd Au deposition	188.8	83	191.9	17	284.8	95	288.7	5
3rd Au deposition	188.8	77	192.1	23	284.8	87	288.3	13
1st sputtering (15 min)	188.7	89	191.0	11	283.3	74	285.1	26
2nd sputtering (30 min	188.6	81	189.8	19	283.4	100	-	-
3rd sputtering (30 min)	188.4	58	189.3	42	283.4	100	-	-
4th sputtering (1 hour)	188.3	45	189.2	55	283.5	100	-	-

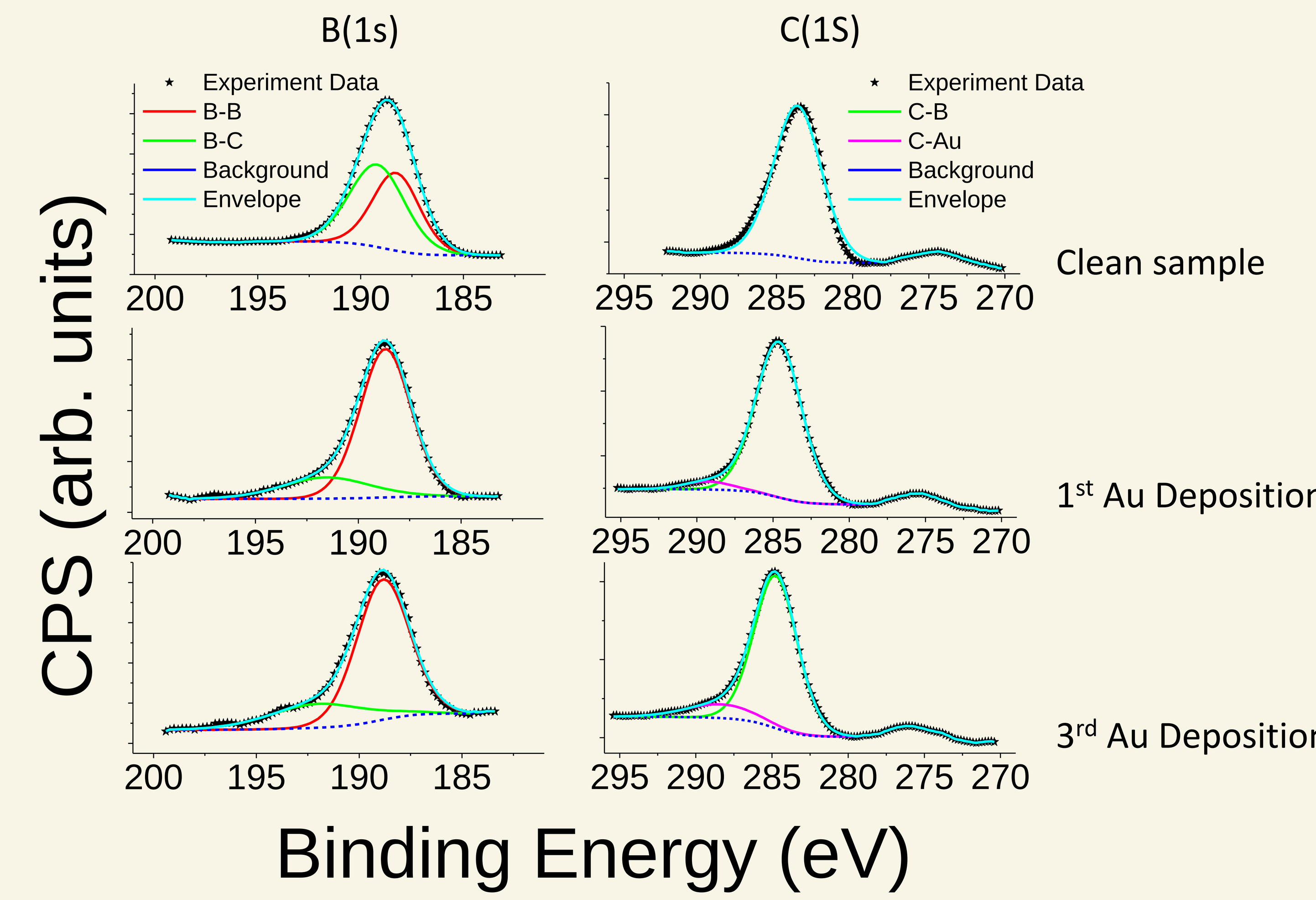
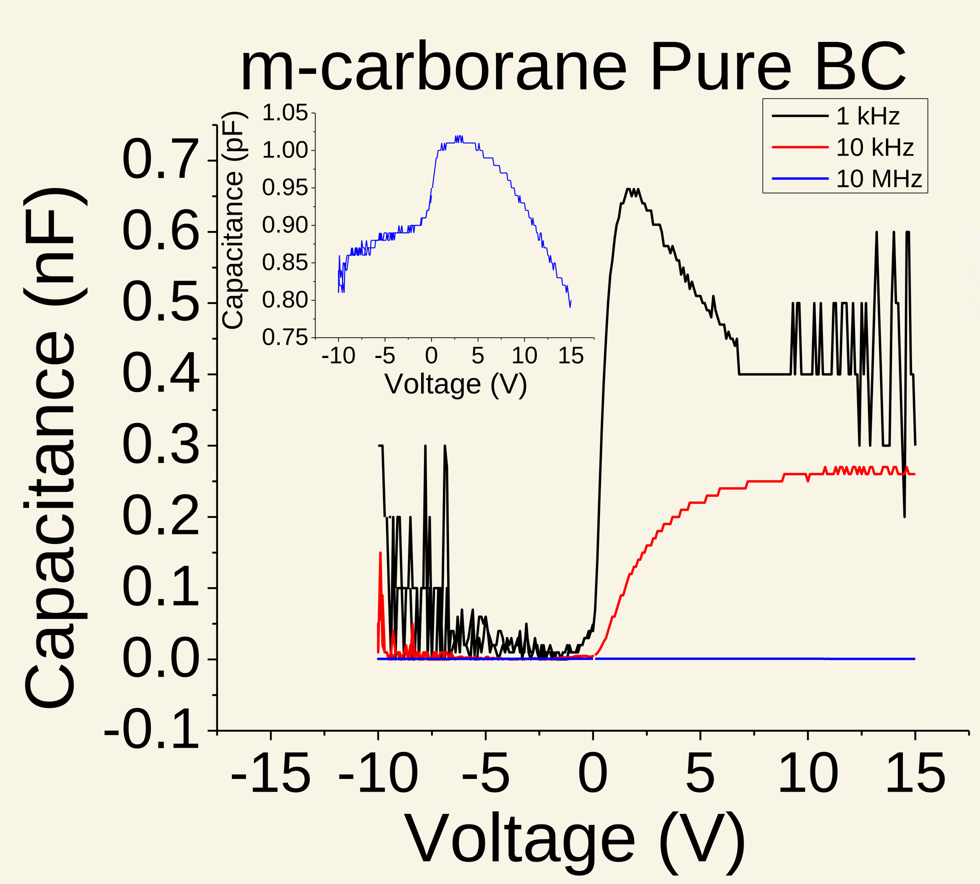


Table 1. First binding energy results from XPS measurements after Au depositions
Figure 2. Corresponding graphs for results in Table 1. First column corresponds to B(1s) spectra while the second column corresponds to C(1s) spectra. The top row corresponds to when the sample was still clean. The middle row corresponds to the sample after the 1st Au deposition while the bottom row shows spectra after 3rd Au deposition.

As gold is deposited, XPS shows that the B-C binding energy increases from 189.2 to 192.1 eV. At the same time, the B(1s) core increases by around 0.5 eV. The XPS shows a similar increase for C-B binding energies, and it shows an additional signal from 289.3 to 288.3 eV. This growth of a significant satellite feature, accompanied by the larger increase in binding energy of the C(1s) compared to the B(1s), with increasing of Au overlayer coverages, indicates that carbon reacts with Au forming C-Au bonds at the semiconductor-metal interface. This large increase in core level binding energy is significantly larger than observed for the B(1s) spectra, indicating that this affect cannot be ascribed to simple Au-induced band bending. This also suggests that Au-C interactions are stronger than Au-B interactions, so charge transfer is performed across C-Au bonds more often than across B-Au bonds.
The XPS measurements also shows that after around 2 hours and 15 minutes of sputtering, the gold is not only completely stripped from the semiconductor, but the binding energies and atomic percentages also return to pre-deposition levels. This indicates that boron carbide does not bind so strongly with gold that the gold cannot be removed.

Capacitance-Voltage Measurements



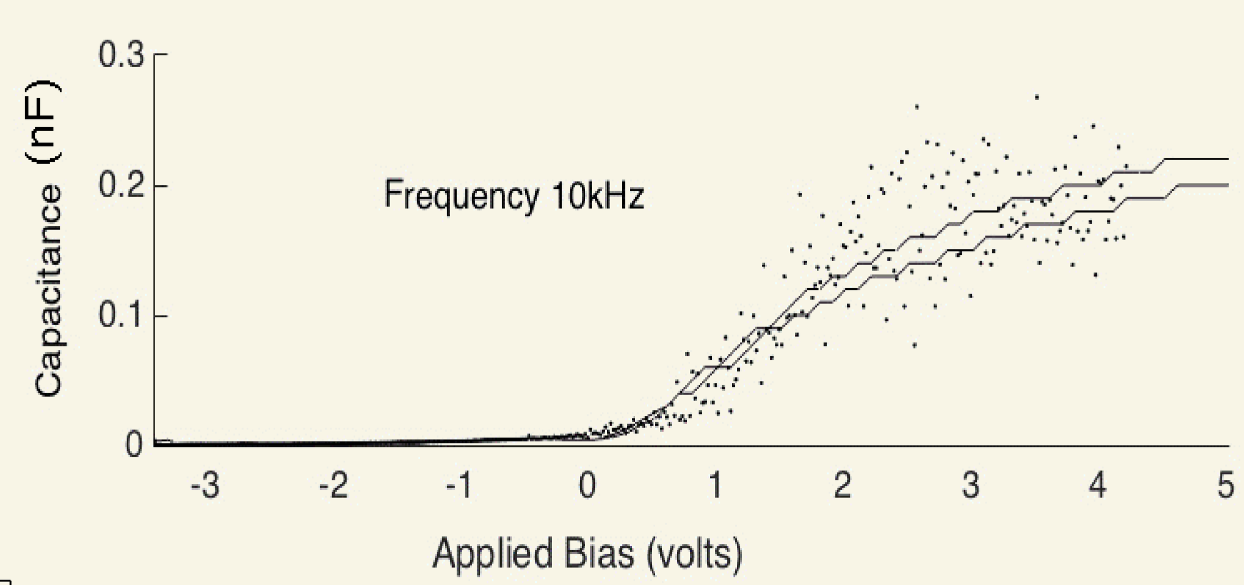


Figure 4. C(V) curves done at 1 kHz, 10 kHz, and 10 MHz. The inset shows the C(V) curve for 10 MHz at a lower capacitance scale
Figure 5. A model of diffusion capacitance, C_D , overlaid on C(V) data at 10 kHz.

The capacitance versus voltage measurements indicate how responsive the charge carriers in the diode are to rapid changes in bias. Because the observed capacitance in Figure 4 drops drastically as frequency increases, the charge carriers can no longer respond to the perturbation signal.
By modeling the C(V) curve at 10 kHz in Figure 5, the carrier lifetime was calculated to be around 50 ns. This is about 10^3 times smaller than that of o-carborane boron carbide, which functions similarly.

Conclusions

The characteristic B (1s) and C (1s) core levels of boron carbide were observed to increase, as the Au the gold overlayer concentration increased. This was especially significant for the C (1s) core level, suggesting gold interaction with the carbon was significant. The absence of the typical signatures of Schottky barrier formation, yet the strong interactions evident in the core level shifts and addition of a core level satellite features suggests at least some extrinsic interface doping of the boron carbide by gold or formation of a metal-induced gap state at the interface.

Additionally, I(V) characteristics indicate that the n-type boron carbide performs exceptionally well with gold. This provides further evidence that Schottky barrier formation is absent. C(V) characteristics show that the carrier lifetime is around 50 ns. This is a short lifetime. Since the short carrier lifetime doesn't predict the performance seen in the I(V) curve, future studies will aim to explain how and why m-carborane can interact well with gold despite the short carrier lifetime.

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