FLUX GROWTH OF CUBIC BORON PHOSPHIDE CRYSTALS FOR NUCLEAR WEAPON DETECTORS

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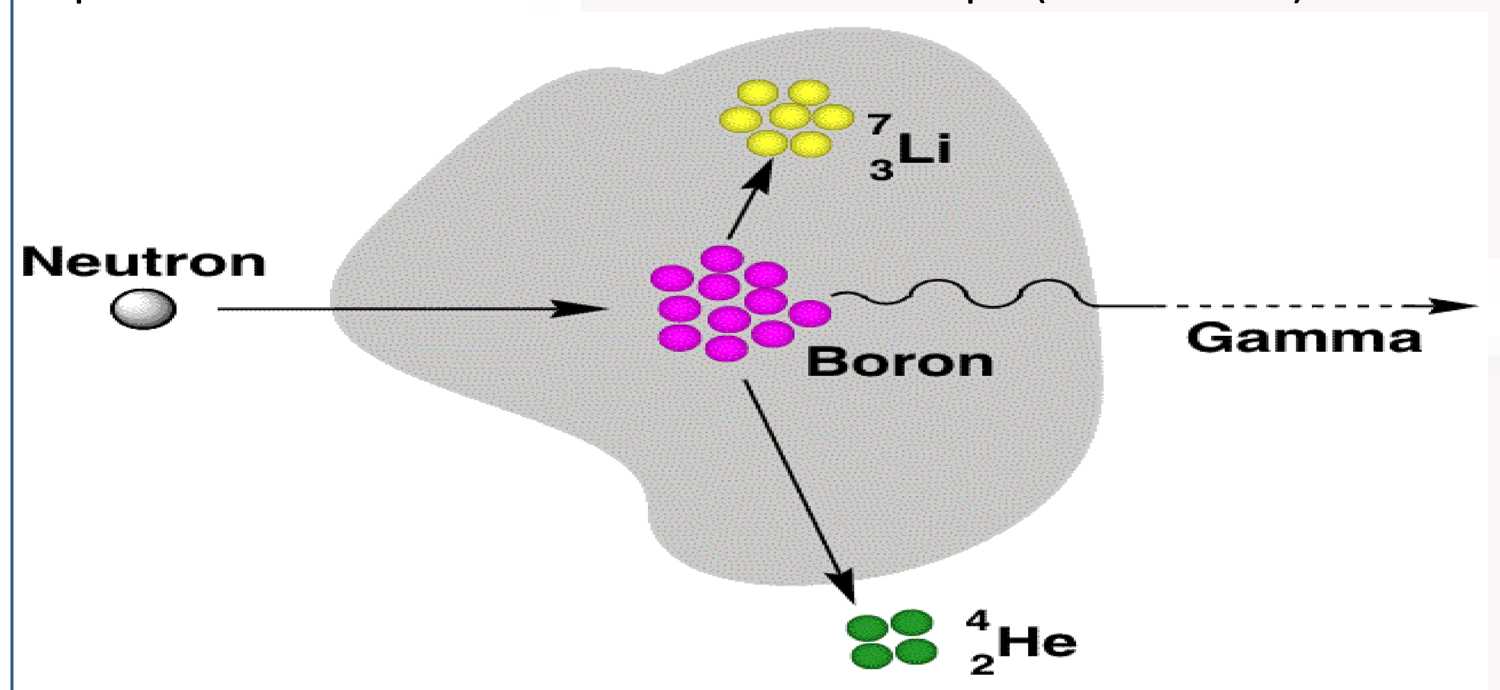
BACKGROUND

Boron phosphide, BP, is a compound semiconductor potentially useful in solid state neutron detectors because of the large thermal neutron capture cross-section of the boron-10 isotope (3840 barns)[1].



Boron-10, an isotope of boron , undergoes nuclear reaction with neutrons to emit helium nuclei (alpha particles) and lithium nuclei[2].

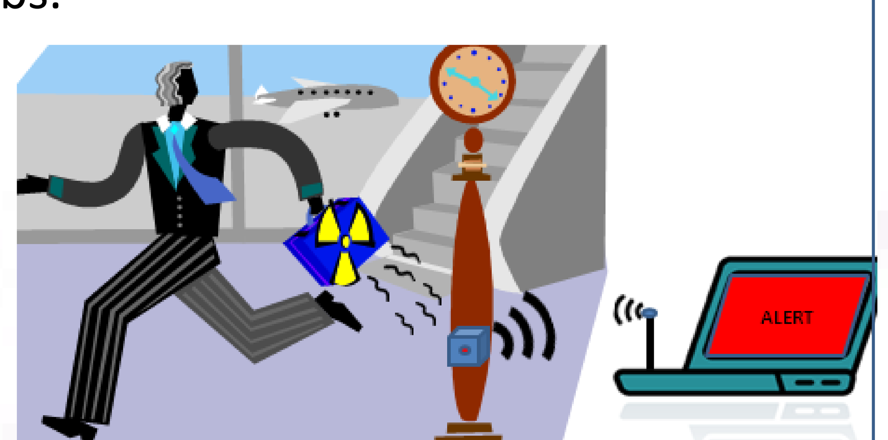
$$^{10}B + {}^{1}n \longrightarrow {}^{7}Li^{3+} + {}^{4}He^{2+} + \gamma + 2.4\ \text{MeV}$$

The produced alpha particles can then be detected using electronic sensors.

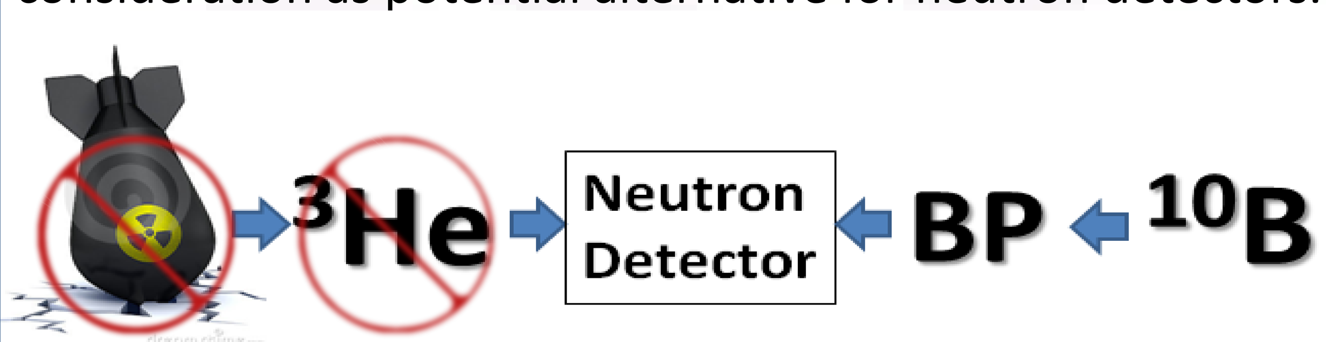
MOTIVATION

The ability to intercept attempts to smuggle nuclear weapons into the United States is critically important for homeland security. New types of neutron detectors are especially needed, as current devices employ a rare helium isotope (^{3}He), which was a byproduct of the production of hydrogen bombs.

As the production of hydrogen bombs has largely ceased and the need for homeland security has grown, demand for ^{3}He has greatly exceeded supply[3]



The high thermal neutron capture cross-section of boron isotope in crystalline boron compounds like BP, BN, and $B_{12}As_2$ are under consideration as potential alternative for neutron detectors.



MATERIALS AND METHODS

CRYSTAL GROWTH

- Flux Growth Method

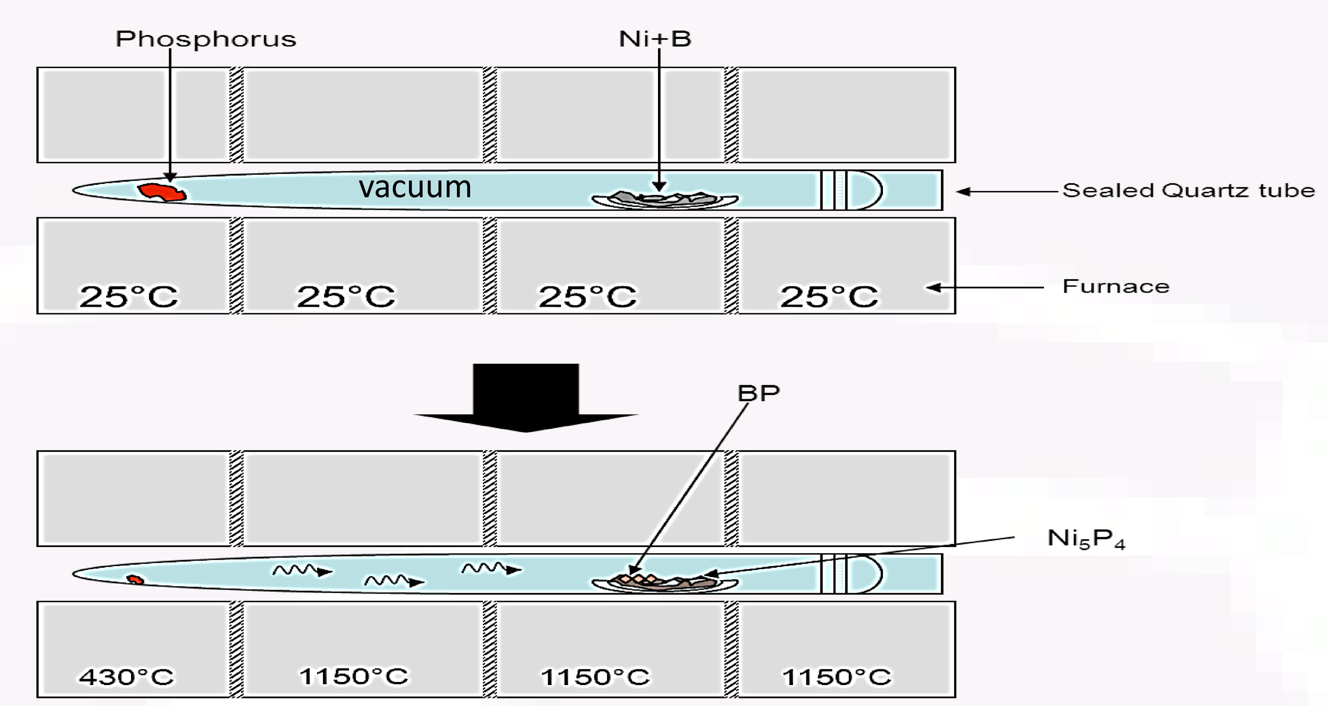


Figure. 1

BP crystals precipitate from the nickel solution during cooling at rate of 3°C per an hour. The nickel was then etched from the crystals using aqua regia (a mixture of nitric acid and hydrochloric acid, at volumetric ratio 1:3).

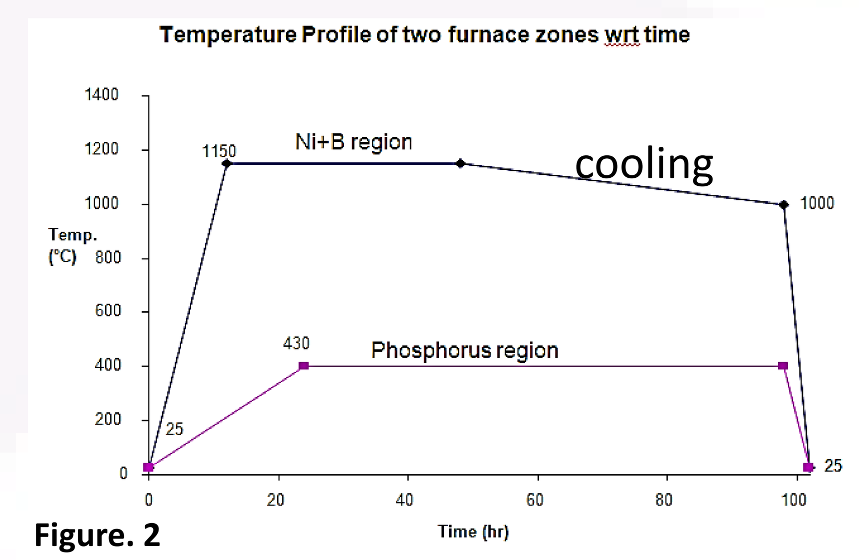


Figure. 2

RESULTS

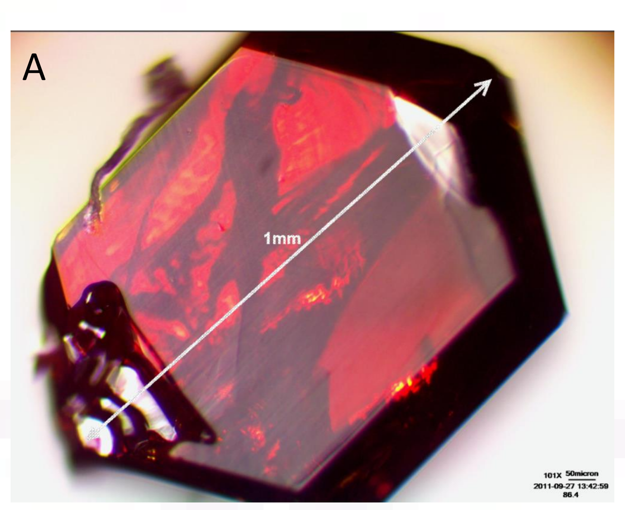


Table. 1

Cooling rates (°C/hr.)	2°C/hr.	3°C/hr	10°C/hr	100°C/hr
Crystal width	1-2mm	1mm	<1mm	<100μm
Lattice (Å)	4.534	4.543	4.550	-

Table. 2

ELEMENT	WEIGHT %	ATOMIC %	RATIO
BORON	74	49.8	1
PHOSPHORUS	26	50.2	1

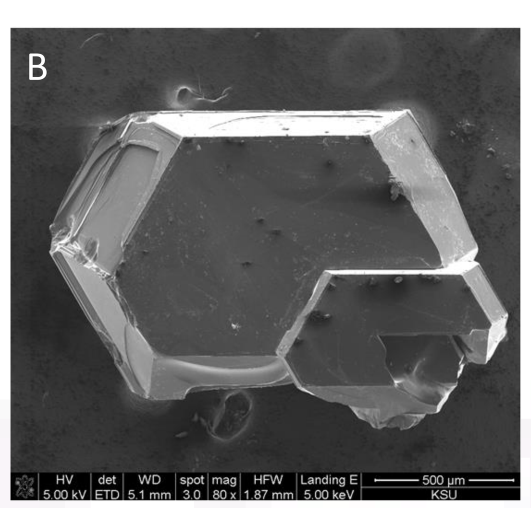


Figure 3: **A** - Image of a red BP crystal under a microscope revealing the color, shape and average size. **B** - SEM image showing the morphology of a 1.5mm single crystal with flat facets. Table 1: shows variation of crystal sizes at different cooling rates and lattice constants. Table 2: EDS results showing the stoichiometry ratio of BP

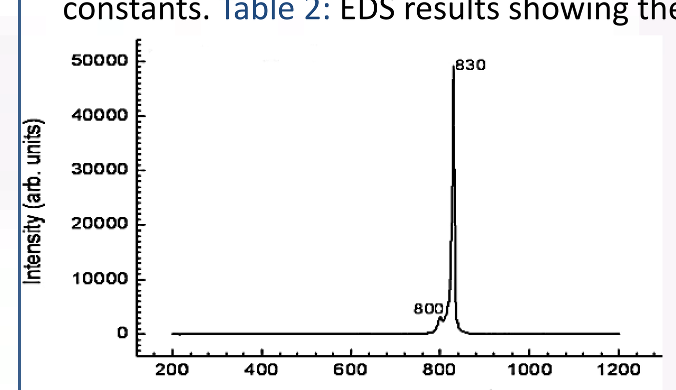


Figure. 4

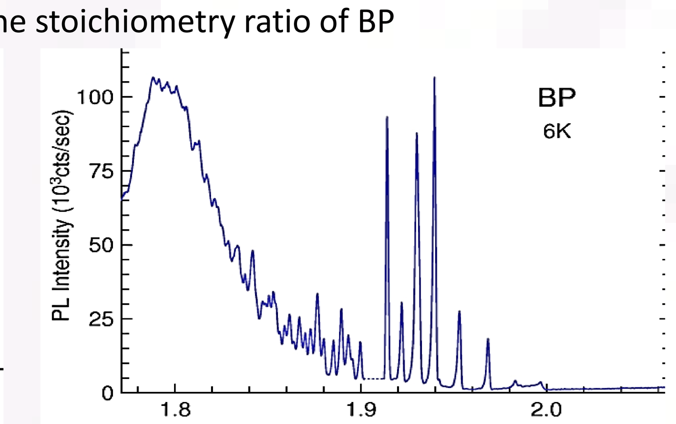


Figure. 5

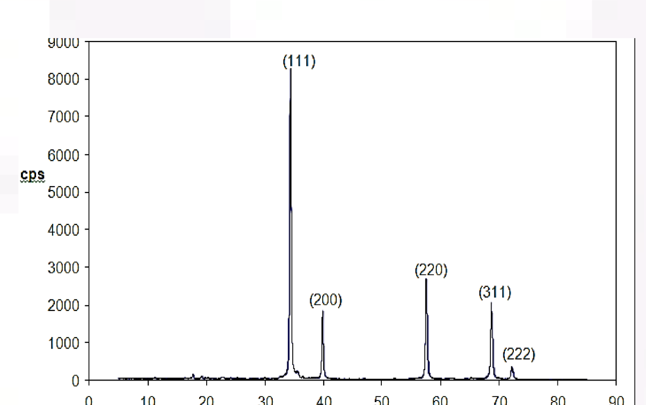
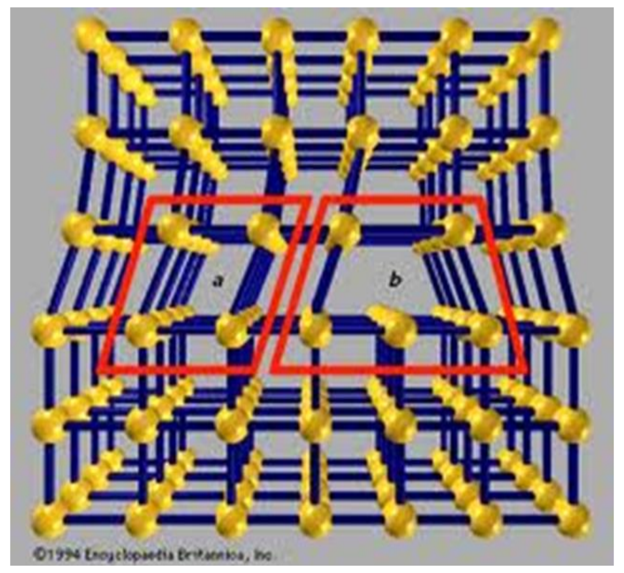


Figure. 6

Figure 4: Raman spectrum showing typical characteristic band peaks of BP.
Figure 5: Photoluminescence energies of emission band peaks of BP crystals at 6°K
Figure 6: XRD result depicting characteristic plane peaks for cubic BP crystal

CONCLUSION

- Good bulk cubic BP crystals were produced via this technique at low temperature of 1150°C.
- XRD and Raman shows that there are no other phases besides BP.
- Although EDS did not detect any elements besides B and P, the Photoluminescence suggests there might be other elements present at low concentrations.
- The cooling rate of crystal growth was critical to crystal size , and it also affects the lattice constant (*distance between unit cells in crystal lattice*) of the crystals. This could be because of the increase in growth rate actually caused defects on the lattice.



FUTURE DIRECTIONS

- Improve the technique to reduce impurity and defects
  - Use high purity source materials
- Larger BP crystals (~>1cm)
  - Increase source materials
  - Increase quartz tube reactor size
  - Cooling at slower rates
- Study electrical properties
  - Current- voltage measurements
  - Capacitance-voltage profiling
  - Resistivity as a function of temperature
  - Hall effect measurements for electro mobility
- Fabricate a Neutron detecting device
  - Construction
  - Testing

ACKNOWLEDGEMENTS

This project is supported by Department of Energy (DOE). Photoluminescence spectra from Paul Klein is greatly appreciated.

BIBLIOGRAPHY

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