Densified, Fracture Resistant Boron Solids and Ultra-Hard Boron Coatings

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Outline

- Why a boron plasma source?
- HY-Tech programs related to boron.
- Relationship between boron solids/coating and vacuum arc technology.
- Vacuum arc cathodes made from consolidated boron powders.
- Fabrication of boron solids using microwave sintering techniques.
- MFE applications of boron solids and coatings.

Why boron?

Boron (B) holds great promise for advanced material applications

- Hardest elemental material other than diamond
- Potentially *self-lubricious*, because the surface oxide can react with atmospheric moisture to form boric acid, a solid lubricant.
- One of the lightest materials.
- Resistant to corrosion by acids.
- Its refractory properties make it ideal for high temperature applications.
- Cryogenic trapping of boron in solid molecular hydrogen for advanced rocket fuels (HEDM).
- Boronization for MFE applications.

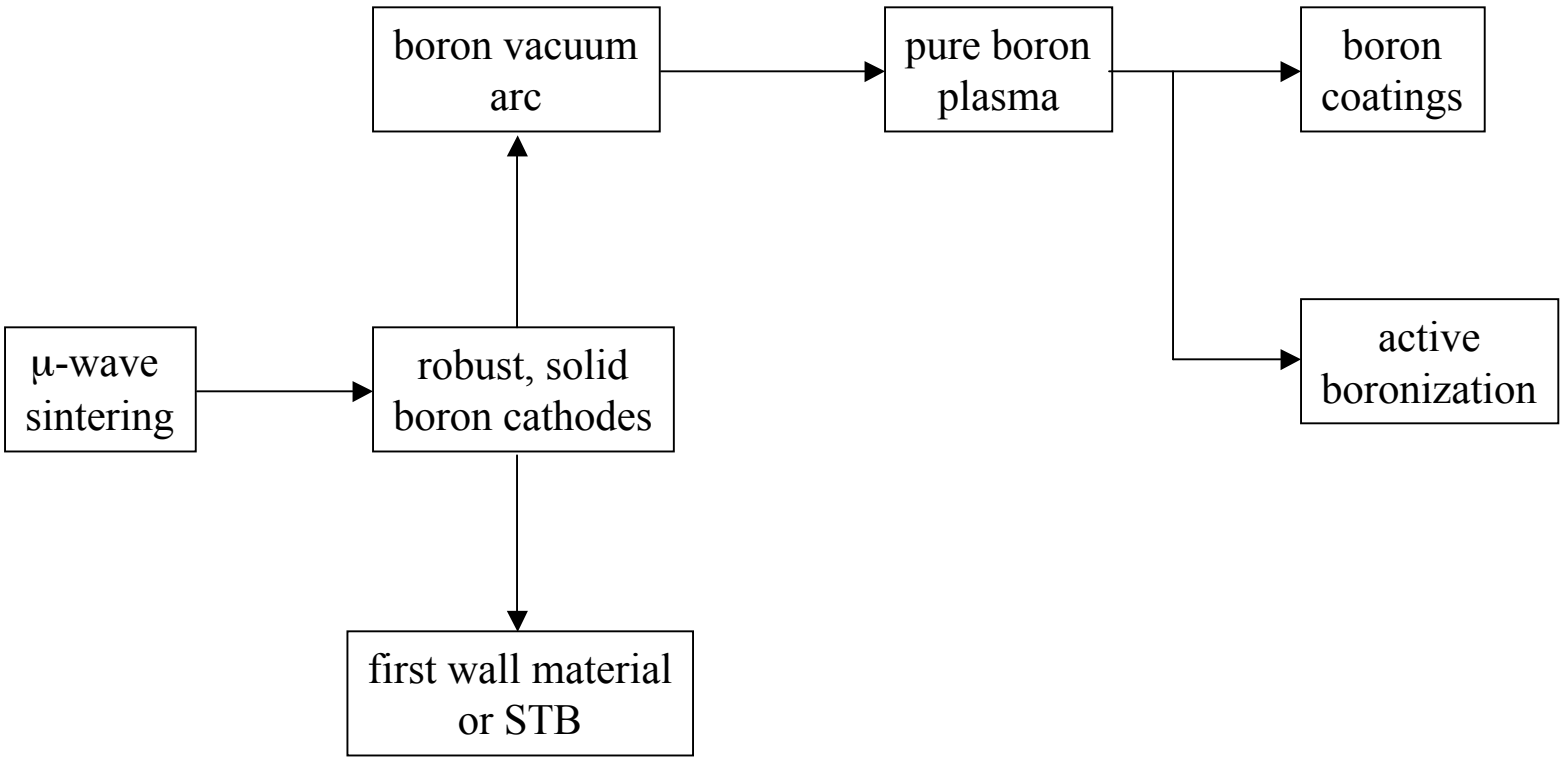
Previous HY-Tech programs related to boron

- **NASA SBIR Phase I** - initiated the vacuum arc program to develop a boron source for HEDM applications.

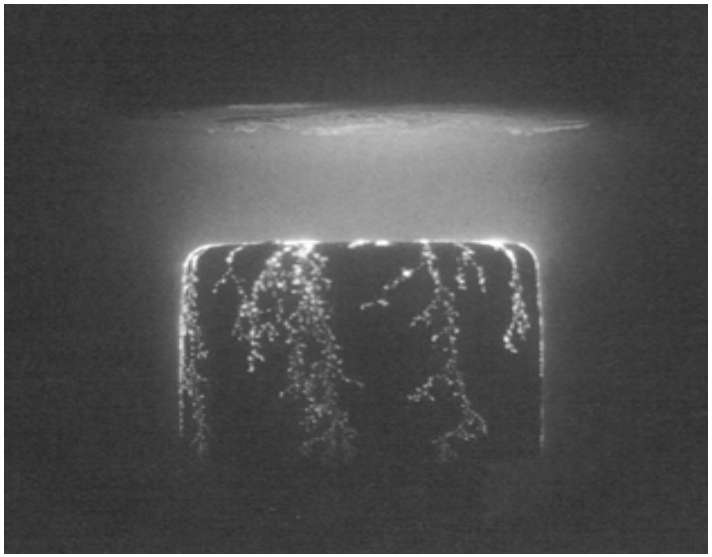
- **DOE STTR Phase I/II** - developed vacuum arc technology to produce boron-carbide (B_4C) coatings for rf antennas in MFE systems. A number of advantages compared to plasma spraying were identified.

- **NSF SBIR Phase I/II** - used pure boron vacuum arc to investigate ultra-hard coating applications. To the best of our knowledge boron cannot be plasma-sprayed.

Boron vacuum arc requirements forced the development of fracture resistant solids



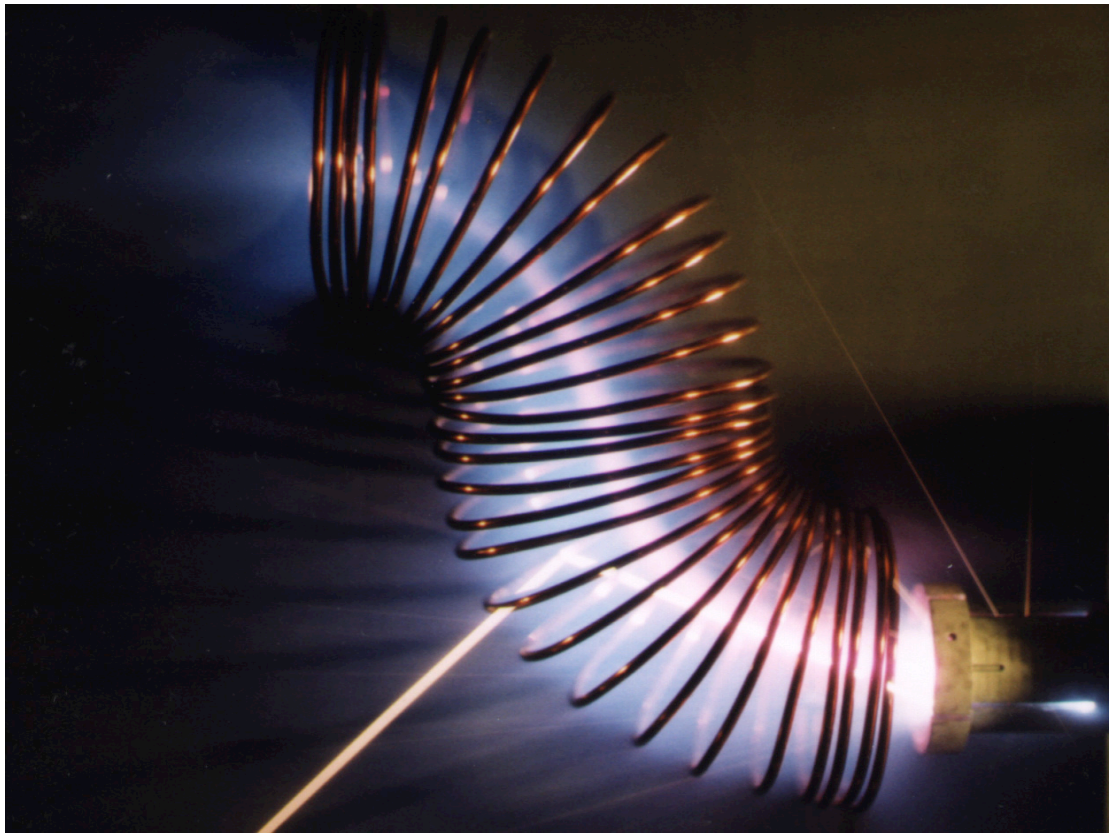
Vacuum arc basics



[Boxman, Sanders, Martin (Eds.), Handbook of Vacuum Arc Science and Technology, Noyes, 1995]

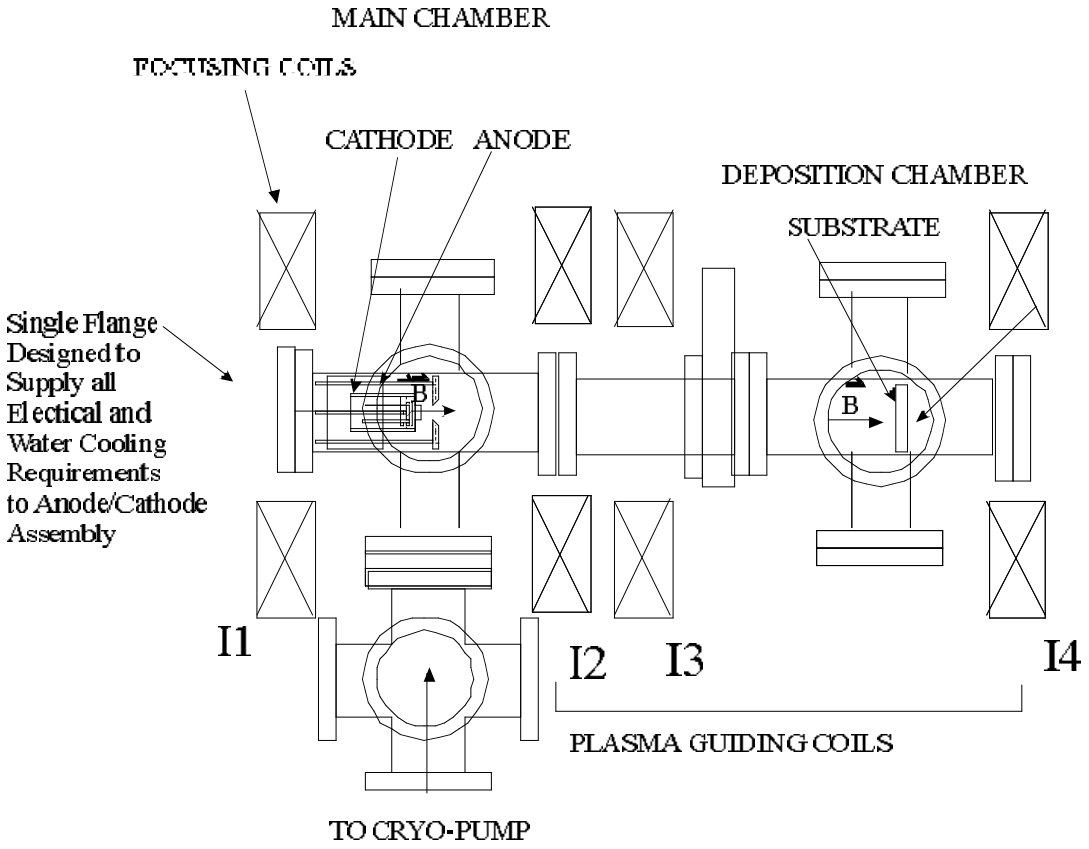
1. Arc discharge mode: Low voltage/high current (typical is 20-40V, 100 to 1000A)
2. All the current is carried in non-stationary cathode spots, with current densities of 10 MA/cm^2 or higher.
3. Output: fully ionized, hyper-thermal plasma from evaporation of the cathode. Also characterized by μm sized macroparticles.
4. The boron vacuum arc is UHV compatible

The expanding plasma needs to be magnetically guided



- Shown is an open S-filter, many other configurations exist
- Used to filter “macroparticles” that emanate from the arc.
- In this case the arc is operated with a graphite cathode (LBL ‘98)

The present system at HY-Tech

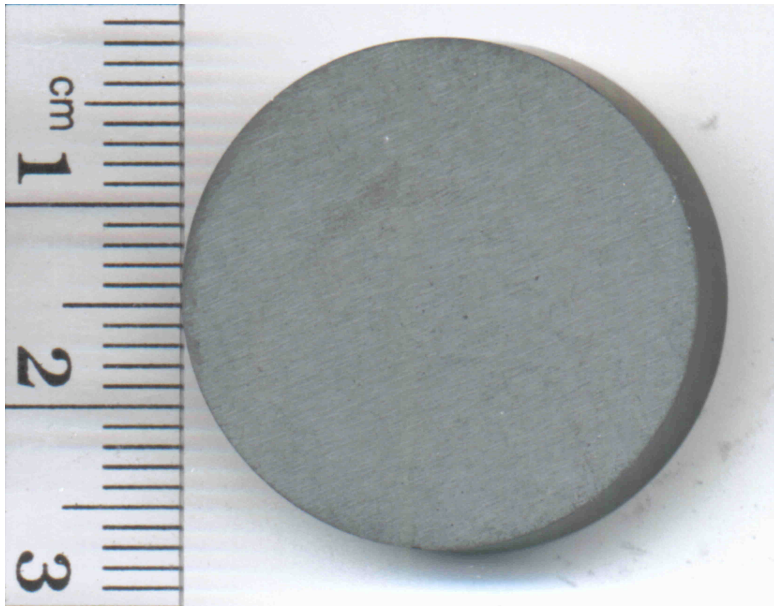


Operation of a pure boron vacuum arc poses some significant engineering problems

- The cathode needs to be a good conductor. Thus, it is very difficult to operate a vacuum arc with semiconductors such as silicon or boron. Boron needs to be at ~1000° C to be used in a vacuum arc.
- The cathode spots, where the current is very concentrated, result in very high local thermal stresses. Therefore, to prevent fracturing in this environment, the solid boron must be resistant to thermal shock.

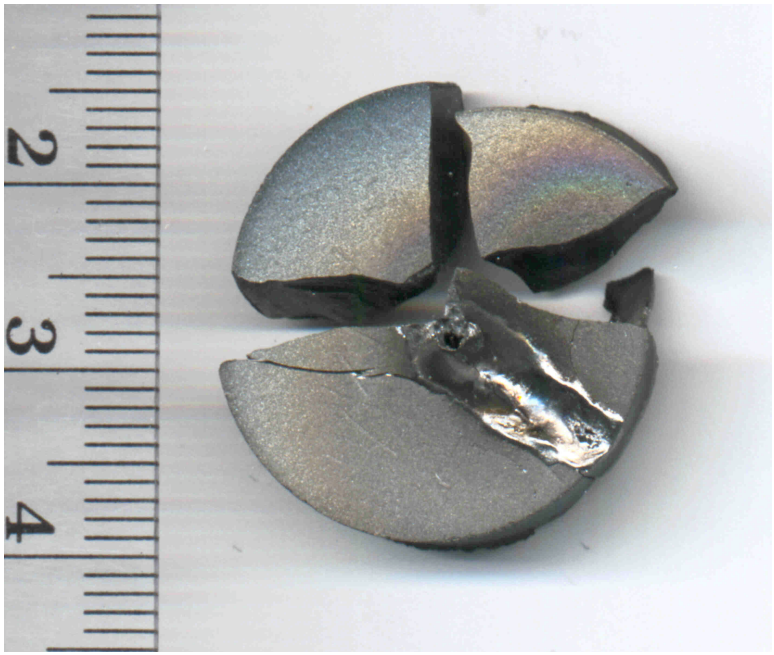
Commercial, hot-pressed, boron or boron-carbide cathodes fail

- The hot-pressed B and B_4C cathodes behaved similarly.



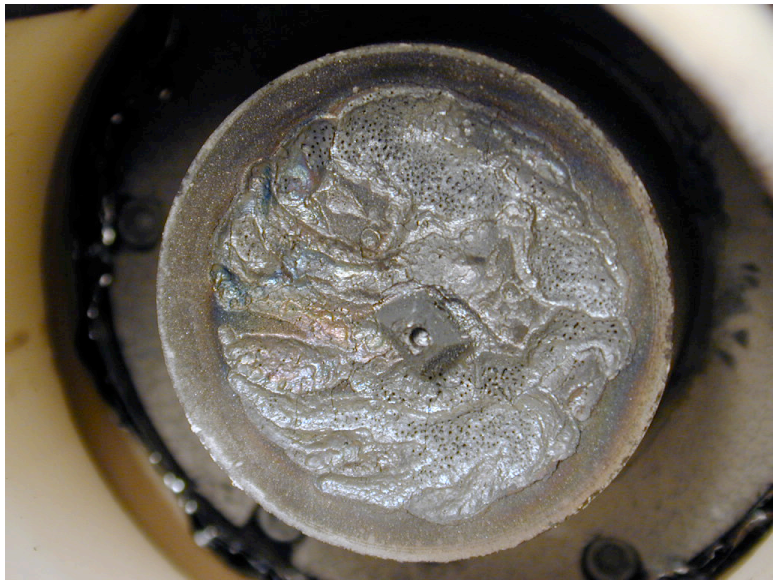
A brand new, commercial boron carbide disk

A boron carbide disk after one short pulse of the vacuum arc electrical discharge



HY-Tech's microwave sintering technique produces cathodes that survive the arc discharge

A pure boron cathode after exposure to the cathodic arc electrical discharge for a number of coating runs.



C.C. Klepper, J.M. Williams R.C. Hazelton, J. Niemel, E.J. Yadlowsky, *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films* **20**, Issue 3 (May 2002) 725-732.

Only a few densified boron cathodes have been made to date

- Process used 24 GHz sintering oven at ORNL (HTML)
- Process and equipment are very expensive, only a few acceptable cathodes have been fabricated.
- Efforts to use 2.4 GHz radiation have been unsuccessful for reasons that are not fully understood. It would be more cost effective to sinter at the lower frequency using in-house facilities.
- A program to investigate the sintering process, in particular using 2.4 GHz, may result in improved and more readily available material.

Potential MFE applications utilizing a boron plasma

- Coating of first wall components, such as rf antennas, using B or B_4C. The arc deposited B_4C film exhibited better bonding and density than sputtered or plasma sprayed films.

- Adding boron to tokamaks between discharges to boronize vessel, or coat specific sections. Alternative to the plasma assisted CVD process.

Potential MFE applications utilizing densified solid boron materials

- May be used as a first wall material and mounted at strategic locations to boronize the vessel.
- The solid boron could be formed into edge plasma probes for solid target boronization.

HY-Tech is actively seeking funding to further develop boron solids and coatings

- A proposal is pending (DOE) that deals with studying the solid boron sintering process at 2.4 GHz and material characterization. Specifically targeted for MFE applications.

- HY-Tech is also seeking funding for industrial applications of boron, or boron-carbide coating.

Summary

- The boron vacuum arc technology is well developed. It produces a pure boron plasma with macroparticles that need to be filtered.

- The formation of densified solid boron has not been fully investigated. Presently, the procedure is very expensive and specialized.

- Material tests of the solid boron cathodes have not taken place. Survival in the arc has been the only benchmark for these materials. Their properties need to be characterized.