

Lessons Learnt Report: High temperature CST devices

Project Name: Fabrication of Thermionic Devices Using Directional Solidification/Sintering Processes for High Temperature CST Applications

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar Thermal
State/Territory:	NSW

Key learning

The primary learning relates to the synthesis and characterisation of electron emissive materials, design and construction of the high-temperature – high vacuum envelope and assembly of a working device. These were:

1. High purity electron emissive materials comprising of rare-earth hexaborides can be synthesized at reduced temperatures than previously thought.
2. Suitable gap forming material with good electrical and thermal insulation properties that is chemically compatible with rare-earth hexaborides materials has been identified.
3. A demountable enclosure with a maximum service temperature of 1400°C, constructed using commercially available products, to meet the ultra-high vacuum and oxidation resistance requirements for the thermionic prototype has been fabricated.
4. The efficiency of the thermionic device was affected by the low effective heat transfer rates (contact resistance) between the components and by the space charge build up across the 45micron gap.
5. The combination of the wide scope of the project coupled with a low starting TRL made the project challenging and at times difficult to meet set milestones.

Implications for future projects

The technology readiness level of thermionic energy conversion at the start of the project was low. Therefore, it would have been beneficial to reduce the initial scope of the project to maximise research in the development of emitter/collector materials with greater emission properties (lower work functions) and investigating techniques to reduce the gap thickness for improved efficiency. The development of the enclosure and working prototype could have been carried out as a second phase.

Thermionic energy generation is a direct conversion with potentially high theoretical conversion efficiency due to the high temperature process involved. The direct conversion process also has the

potential to reduce the infrastructure requirements and costs. It is ideally suited for renewable energy generation from concentrated sunlight as it can utilize the entire solar spectrum unlike photovoltaic cells (PV) which can only convert specific wavelengths.

This thermionic energy converter also features high levels of recyclability. The materials used in the converter include rare-earth hexaborides and refractory metals like tungsten, molybdenum or tantalum and are contained in small-volumes ensuring ease of recyclability in the future. It should be noted that thermionic energy conversion is still at the early period of development (TRL3) and at this stage it is not able to compete with PV or solar driven steam generation technology. However, this form of energy conversion should be pursued and a development path is outlined below.

Knowledge gap

Thermionic energy conversion is a method of converting heat directly to electrical energy. It involves heating materials, with the specific ability to emit electrons from their surfaces when heated (thermionic work function), to elevated temperatures. Electrons jump from a cathode, across a vacuum gap, forming an electrical current that is collected by the anode and circulated through an external load supplying electricity. This process has the potential for high conversion efficiency and is ideally suited for renewable energy generation from concentrated sunlight as it can utilize the entire solar spectrum. The main challenges for thermionic energy conversion are;

1. to develop cathode and anode materials with the specific capacity to emit/receive electrons and maintain their chemical stability under high temperatures - high vacuum conditions
2. to reduction of the build-up of electrons (space-charge) between the cathode and anode by physically maintaining a micron-sized gap
3. to develop a vacuum tight enclosure that can resist oxidation, thermal shock at elevated temperatures and provide adequate heating of the cathode, cooling of the anode and electrical paths.

In this project, significant advances have been made in the synthesis of high purity electron emissive materials, especially rare-earth hexaborides. A suitable thermionic prototype device has been developed to evaluate emitter/collector/gap combinations with the purpose of converting concentrated sunlight directly to electricity.

The knowledge gaps identified in this project relate to further development of cathodes and anodes with high emission currents at reduced temperatures and the investigation of alternative gap forming materials or application techniques. The following development path is proposed:

- additional development of low to moderate work function anode/cathodes and gap reduction techniques
- increase thermal conductivity between envelope hot face-cathode and anode-cooling circuit
- development of techniques to minimise the build-up of electrons within the gap (space-charge effects) and allow wide gap operation through the use of benign ionisable gases or combined electric/magnetic fields which do not detract from output efficiency
- development of vacuum enclosure materials able to operate at temperatures beyond 1400°C

- design enclosure geometry to minimise dimensional changes due to temperature/flux variations and creep

Background

Objectives or project requirements

The project requirement was to develop a working thermionic converter to convert heat directly to electricity. It consists of a high-temperature resistive envelope able to withstand high vacuum conditions to house two electron emissive materials, a cathode and anode, separated by a micron sized gap. Additional requirements included electrical and cooling paths to be incorporated in the design. Considerable work was also undertaken in the synthesis, densification (sintering) and characterisation of refractory electron emissive materials.

This was achieved using materials with reasonable prospects for mass production with the aim of wide-scale deployment when sufficient conversion efficiency was attained. The working prototype is an excellent test bed to evaluate various combinations of cathode, anode and gap materials in order to optimise conversion efficiency. This work is continuing under a PhD scholarship programme.

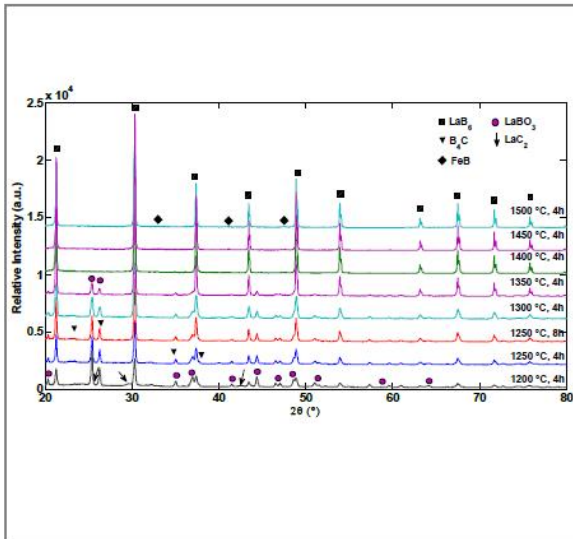
Process undertaken

There were two separate processes involved in the project. Firstly, the synthesis of inexpensive emitter/collector materials involved the preparation of electron emissive compounds and their characterisation using scanning electron microscopy, X-ray diffraction and Schottky chamber testing to ascertain the purity and properties of the materials.

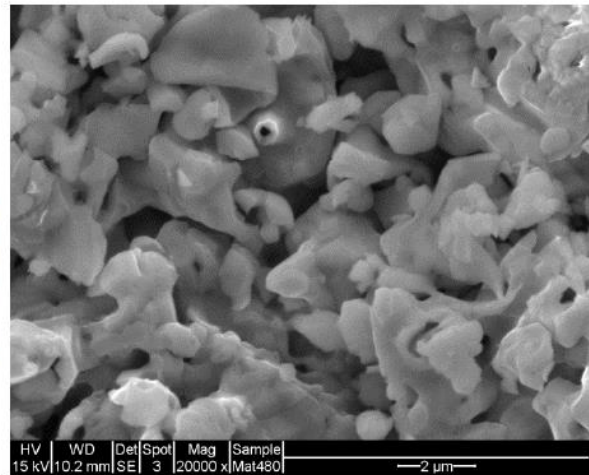
The second stage involved the fabrication of a re-usable high-temperature, ultra-high vacuum envelope and cooling system to house the emitter/collector/gap combination. This required the development of a set of operating criteria and the subsequent application of design and materials selection philosophies to achieve a functional outcome.

Supporting information

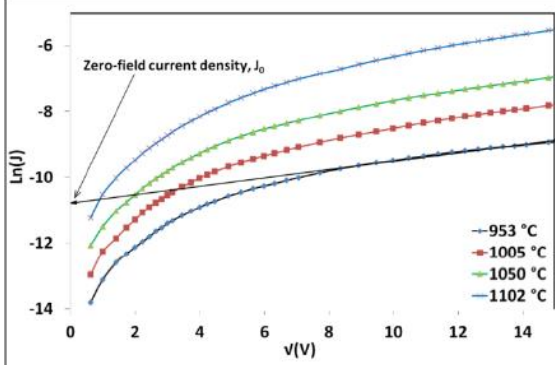
The following graphic indicates some of the steps undertaken in this project.



(a) Evaluation of synthesis procedure for LaB_6 production using X-ray diffraction



(b) Electron microscopy of cathode material (LaB_6)



(c) Characterisation of electron emissive properties of LaB_6 using the Schottky plot technique



(d) Development, fabrication and testing of prototype device