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My name is Sean Kilgrow. I work for Power Chips plc of Gibraltar.

Thank Ted for the opportunity to speak.

Power Chips is published in the latest issue of the GRC Bulletin. You may have read that article and are wondering, “What are Power Chips?”

Power Chips are a novel method of power generation. They are projected to offer high efficiency, high output power generation in a small package.

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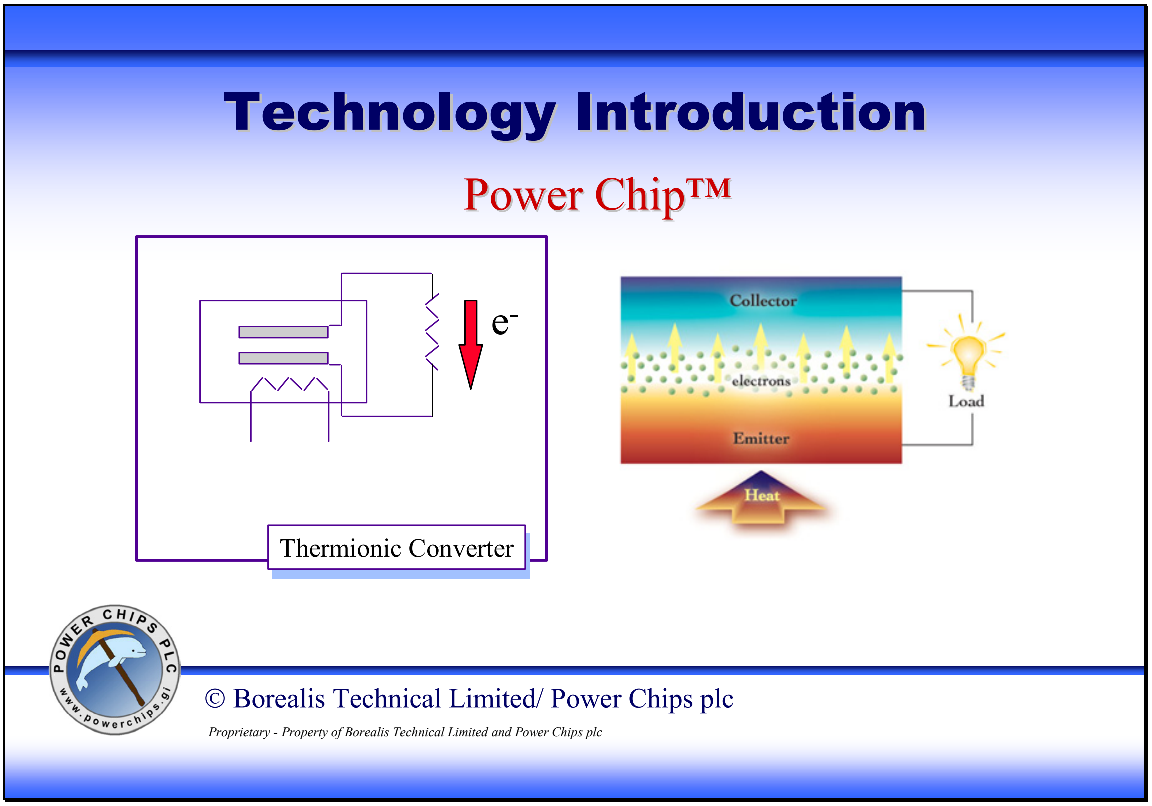
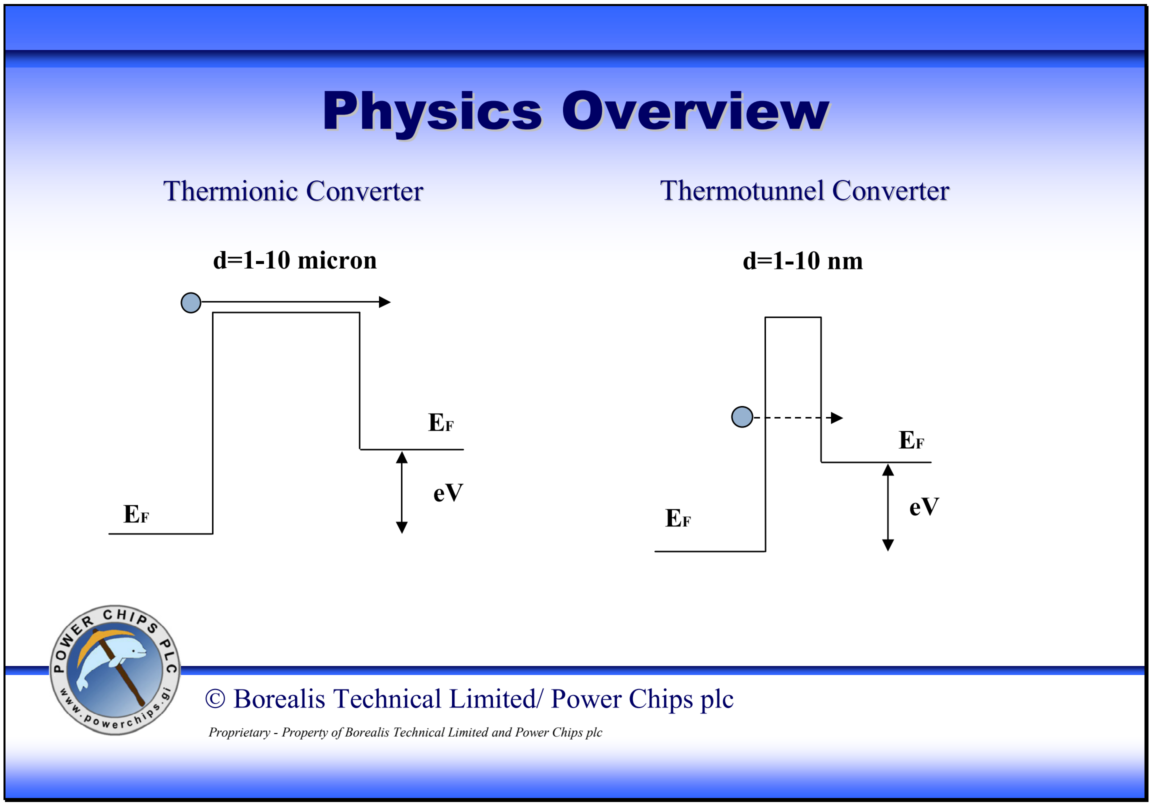


Power Chips™ can be shown as a simple schematic using a classic diode.

Power Chips operate by harnessing tunneling currents across a diode. Electrons, driven by their heat, are allowed to move from one side of a diode to the other, creating a voltage differential and power output.

The Thermionic Converter is an old technology; invented about 1900. Significant development occurred in the US during the 1950s and 60s by companies like GE and General Atomics. The development effort was virtually abandoned by the mid-1970s. The reasons were simple: the devices did not work efficiently and required very close spacing of 5 – 10 microns. Complicating this was the second factor: in order to function the thermionic converter required cesium in the annular space between the electrodes. Cesium is very difficult to work with in hand assembly. So while the technology was moderately efficient, it was not economic.

Borealis, Power Chips parent company, has solved both of these problems. We can mass-produce and can handle the materials issues.



The Thermionic Converter, to minimize space charge and to function properly, has a distance between the plates on the order of 1-10 microns. This is a gap which can be readily built using today's technology (Borealis has built centimeter-scale chips which have 0.5 micron gaps). The <u>manufacturing</u> problem which ended research in the West by the 1970's have been solved.

However, other problems remain. As Einstein discovered, in order to get an electron to jump over the gap, it must have a low work function. Work function represents the minimum energy with which and electron is bound in a metal. The lowest work function materials are Alkali metals such as cesium, and they approach 1 eV. Most metals are in the 4-5eV range. At 4-5eV, emission of electrons does not occur until the cathode is very hot -- hotter than 2000°K. Some metals melt before they emit electrons. Power generation at these elevated temperatures is not generally useful.

So thermionics require a very low work function material. The problem is that these materials have not been found, despite much searching. However, there is another approach which has all the same advantages as thermionics.

If the two electrodes are close enough to each other, electrons do not need to jump over a barrier. Under the well-known laws of quantum mechanics, they can 'tunnel' from one side to another. The distance must be on the order of 1-10 nanometers, or 1-10 billionth of a meter. This is much more challenging to build than a 10 micron gap. As these can be built, there are several key advantages:

No exotic low work function material is required. Standard materials are used.

If the spacing is right, the power density can in theory be as high as 10,000 watts/cm^2. As a practical matter Power Chips will generate in the hundreds of watts per cm^2

Lower temperature operation is possible, allowing power production at relatively low temperatures.

Since the electrons "tunnel" from one side to the other, there is no space charge. This leads to a large increase in the theoretical efficiency.

Physics Overview

Theoretical Efficiency

The Stanford paper calculated the theoretical output of a thermotunneling device with a vacuum gap+

- Third-party verification of theory
- Does not challenge Power Chips' ownership of the technology
- Does not pre-date Power Chips' work
- Paper published 4 years after Borealis/Power Chips' initial patent filings

+(Hishinuma Y, Geballe TH, Moyzhes BY, Kenny TW (2001) Refrigeration by combined tunneling and thermionic emission in vacuum: use of nanometer scale design. *Applied Physics Letters* **78**(17):2572-2574)

The theoretical concepts of thermotunneling are well established. There is considerable research showing tunneling characteristics through an insulator, and there is some work discussing tunneling across a gap. But with the exception of work done by Hishinuma et. al. at Stanford, there is no discussion in the literature about power generation across a gap using thermotunneling. The Stanford paper showed the relationship between the work function of the materials used, the spacing between the electrodes, and the resulting cooling densities which can be achieved. Although the paper is specific to cooling, The Stanford paper reviews the same principle concepts that relate to Power Chips. It is recommended that this paper be reviewed carefully when evaluating Power Chips™. A copy of this paper is available.

For intellectual property reasons it is important note that the Borealis work in thermotunneling predated that of Stanford by several years.

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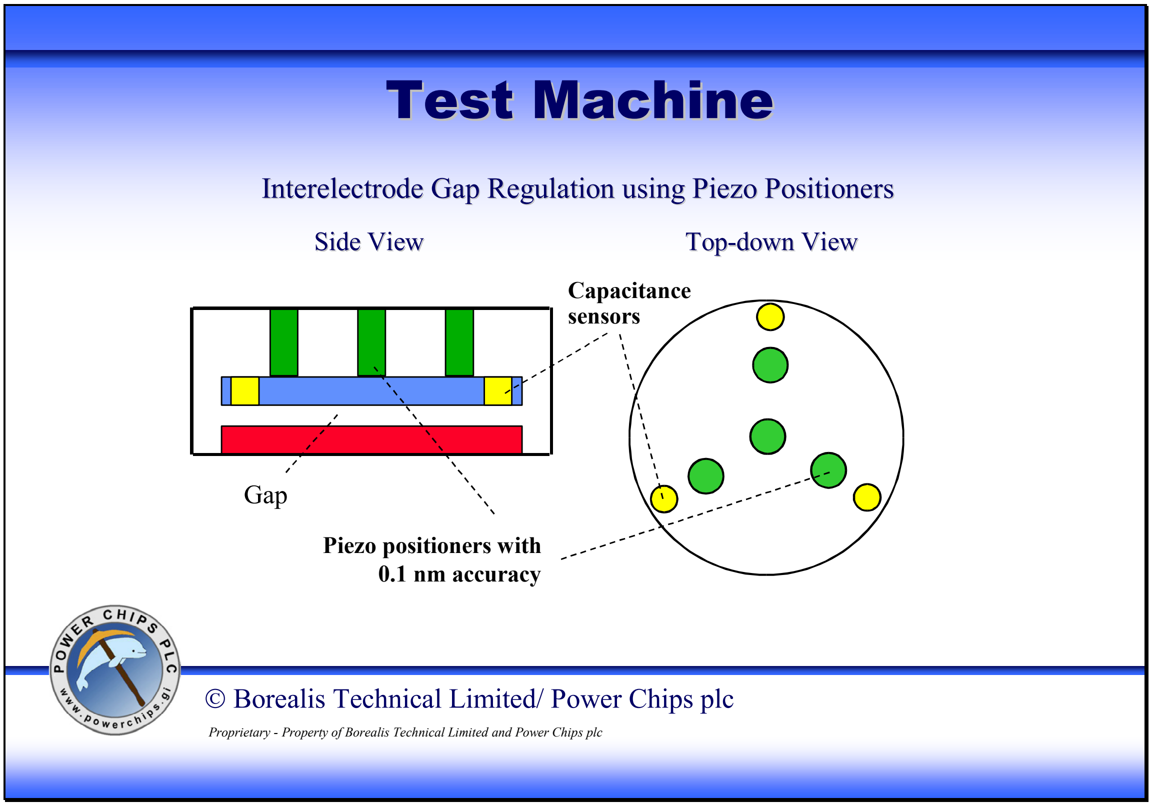

The critical notion then, for understanding what makes Power Chips™ unique, is that it uses quantum thermotunneling across a gap.

The gap itself, however, is very small. Nanometer spacing is very difficult to achieve, and even once it is achieved maintaining the gap can be problematic.

The solution uses the same technique as a standard Scanning Tunneling Microscopes (STM). In those devices, a very small tip is controlled by a piezo element. Piezo elements are single crystal quartz structures which change their shape extremely rapidly and precisely in response to applied voltages. The STM uses a feedback loop to keep the tip close to, but not touching, the surface. The closer two surfaces come to each other, the more current flows across the gap. Capacitance sensors measure that current flow and provide feedback through an analog loop to control the voltages going to the piezo.

The Test Machine, which was completed a few years ago (pictures can be seen on the web page), uses this same technique, albeit on a larger scale. The piezo elements (shown as green) change their length to keep the electrodes close to each other, but not touching.

The speed, accuracy, and reliability of piezo units for this solution means that the device can withstand any extreme vibration (short of crushing) and thermal gradients between the electrodes of up to 400° C (750° F) . It is a very rugged solution.

This is good news for the geothermal industry. Power Chips can be applied to any know geothermal source (including The Geysers) and are able to withstand the types turbulent flow that we will expose them to.

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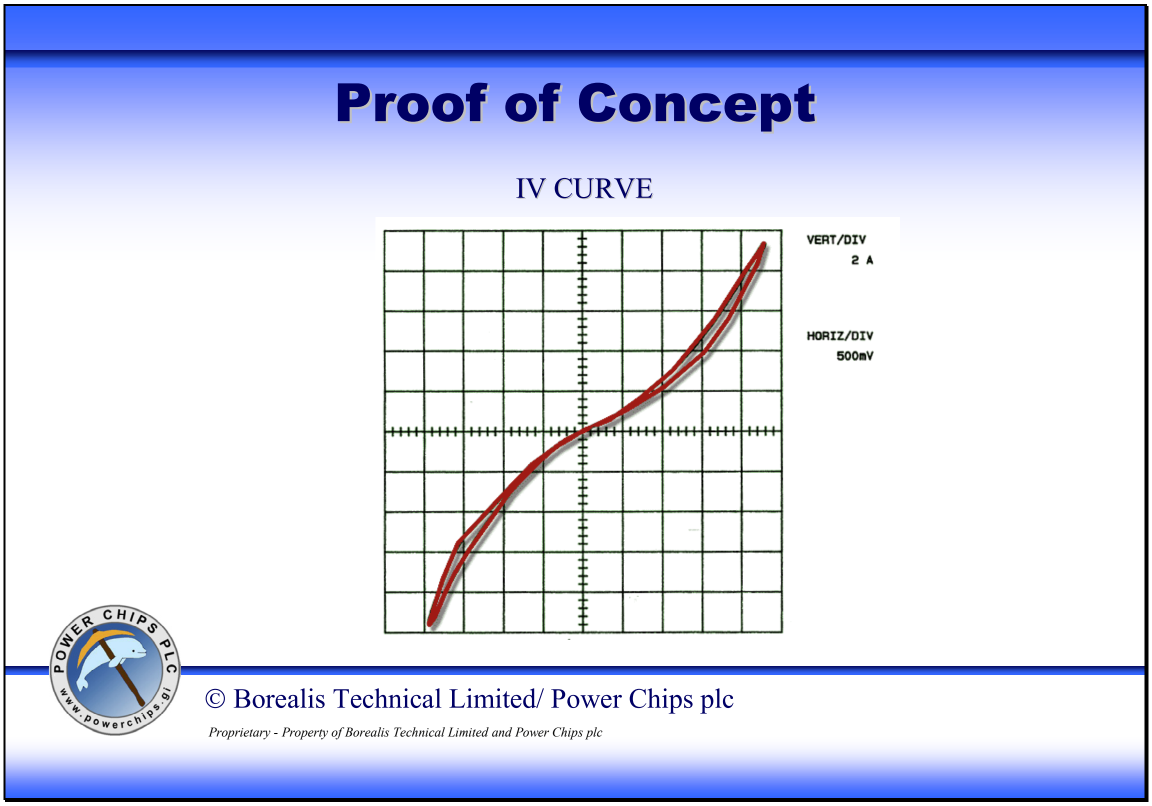
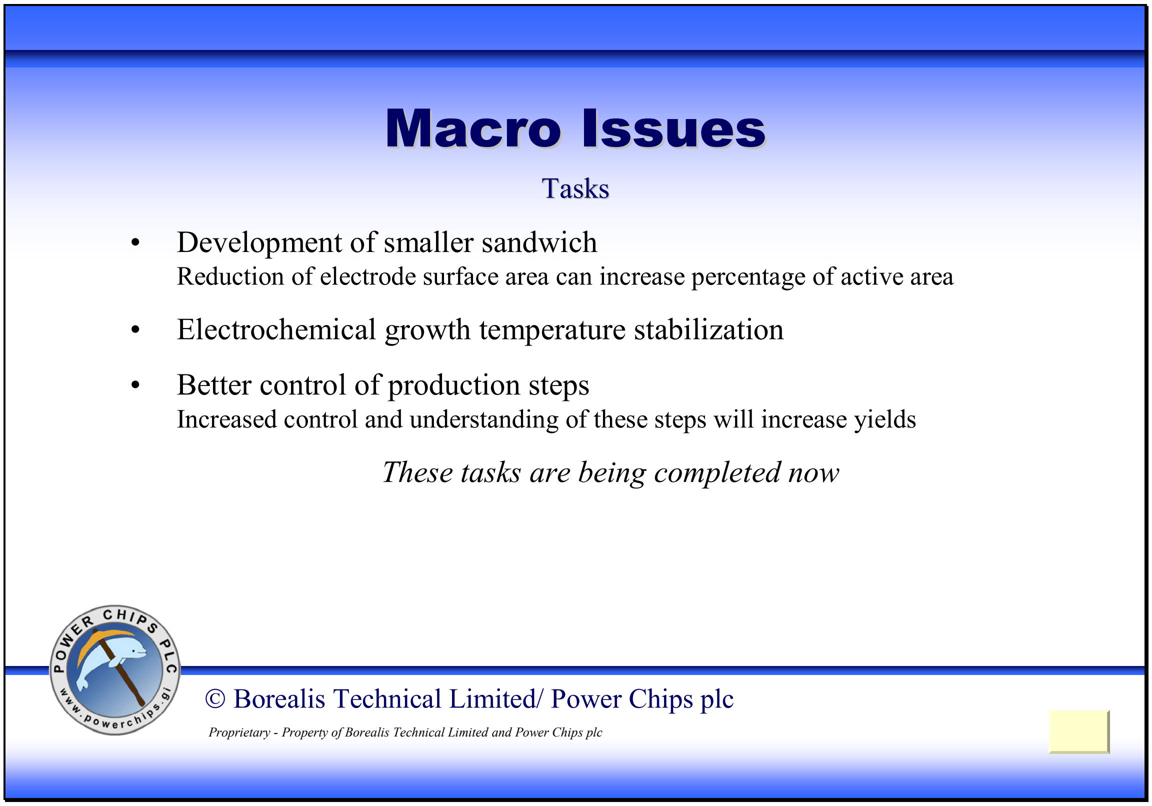


The Proof of Concept was achieved when tunneling currents on the order of 10 amps were measured across a gap. This is several orders of magnitude more current than has ever been reported before.

The active area for these sandwiches remains pretty small (<1 CM^2), but is vast in comparison to the 80 – 100 angstrom spacing in the other dimension.

Once the Proof of Concept was completed, the task was to increase the active area, so that a significant percentage of the electrodes had the required spacing.

At the same time, with an eye on production, Borealis has been working on designing a solution which can be mass-produced inexpensively. They must be easy to fabricate in a dedicated facility. This work moves in parallel with increasing the output of the devices. We currently have two dedicated facilities starting the next generation production runs with two more in the planning stages.



At present, we have completed what we term the "Macro Issues". We completed the sandwich recipe such that when the electrodes are separated, and then brought back close together, they are broadly conformal. The electrodes need to have a good conformal fit to allow for electron tunneling.

We are currently ramping up 2 lines of 1 cm^2, having closed down the 9 cm^2 chip production lines.

In other steps, temperatures need to be stabilized, and the overall quality of the process needs to be improved. Note that all the work completed to date has been done in an standard lab environment -- not a clean room. Even a Class 100 clean room would certainly improve yields and results. The same is true if better equipment were to be applied. The two facilities in the planning stages have Class 100 clean rooms.

Still, while there is room for improvement, the Macro Issues clearly have been solved. The rest must be done, but it is not challenging science; it is engineering.

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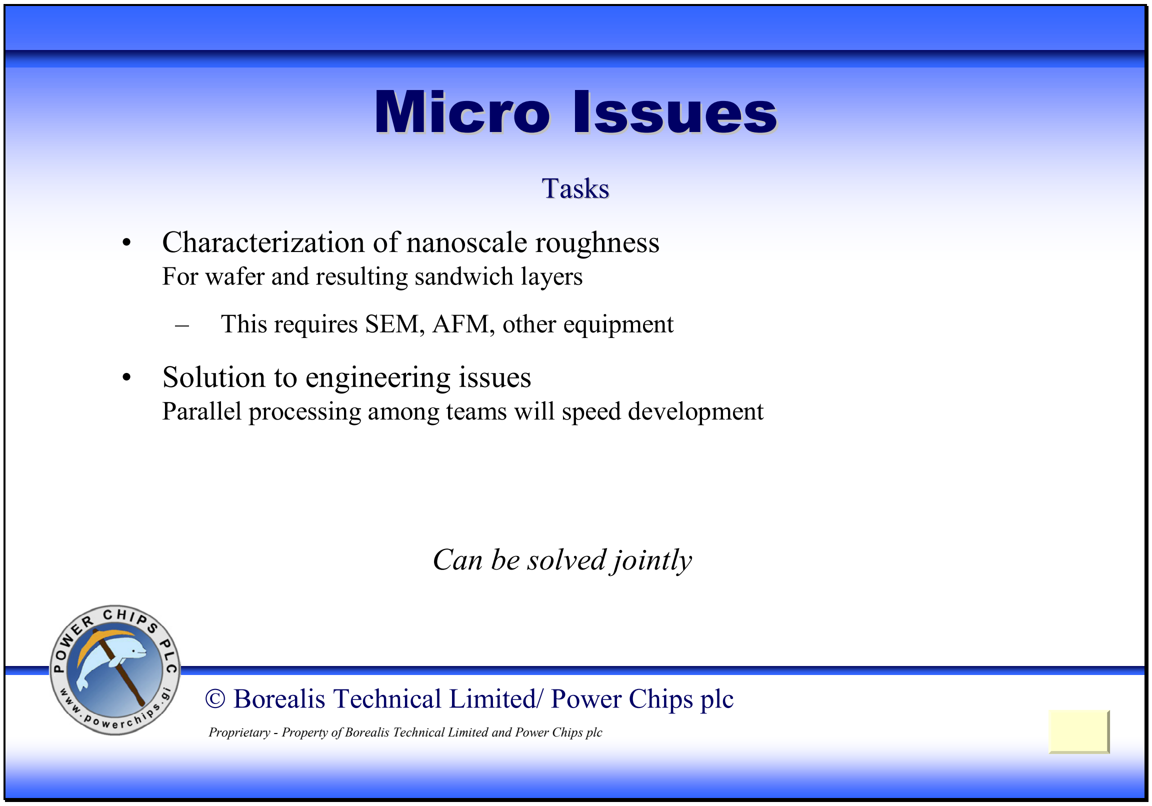
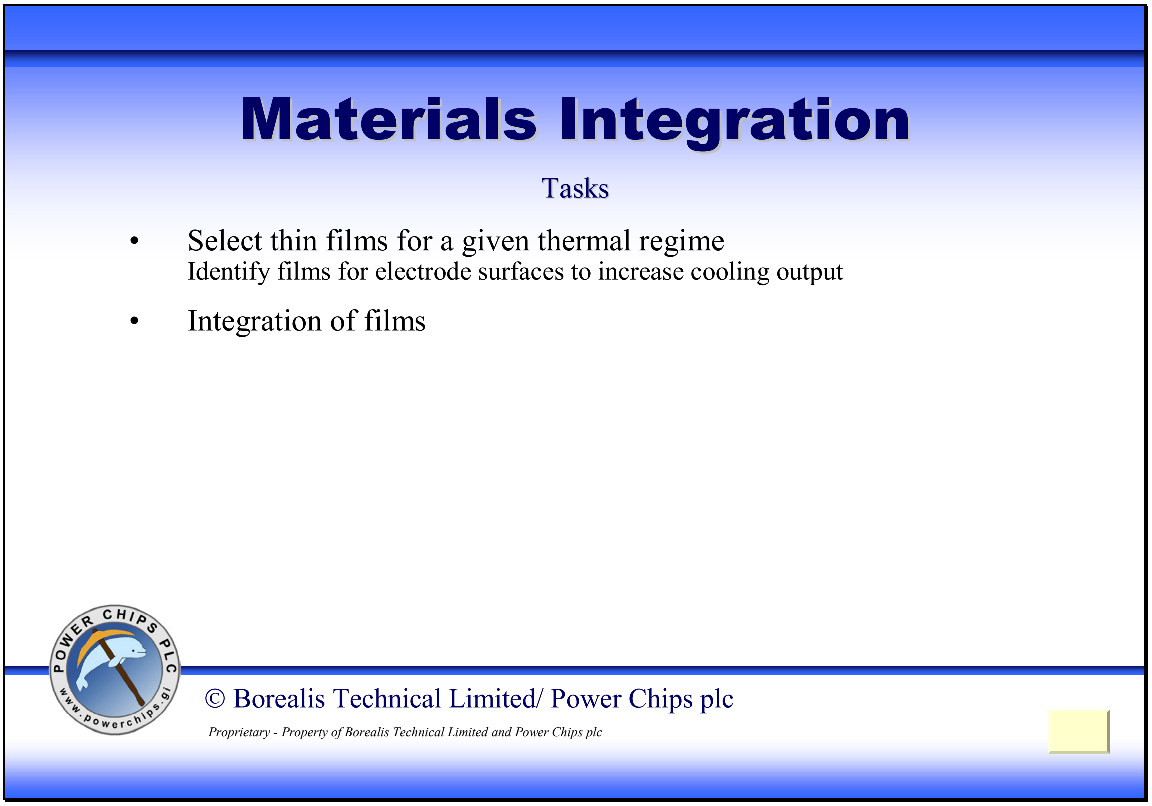


The research now moves onto the micro issues. The sandwiches are broadly conformal, but micro structures and very localized roughness limits output.

The work here is to characterize the faults in sandwiches and to apply standard silicon know-how to eliminating those faults. It is expected that a semiconductor company will join Borealis in this work to help define and solve these problems. A major World class laboratory facility is currently completing contracts to join this work.

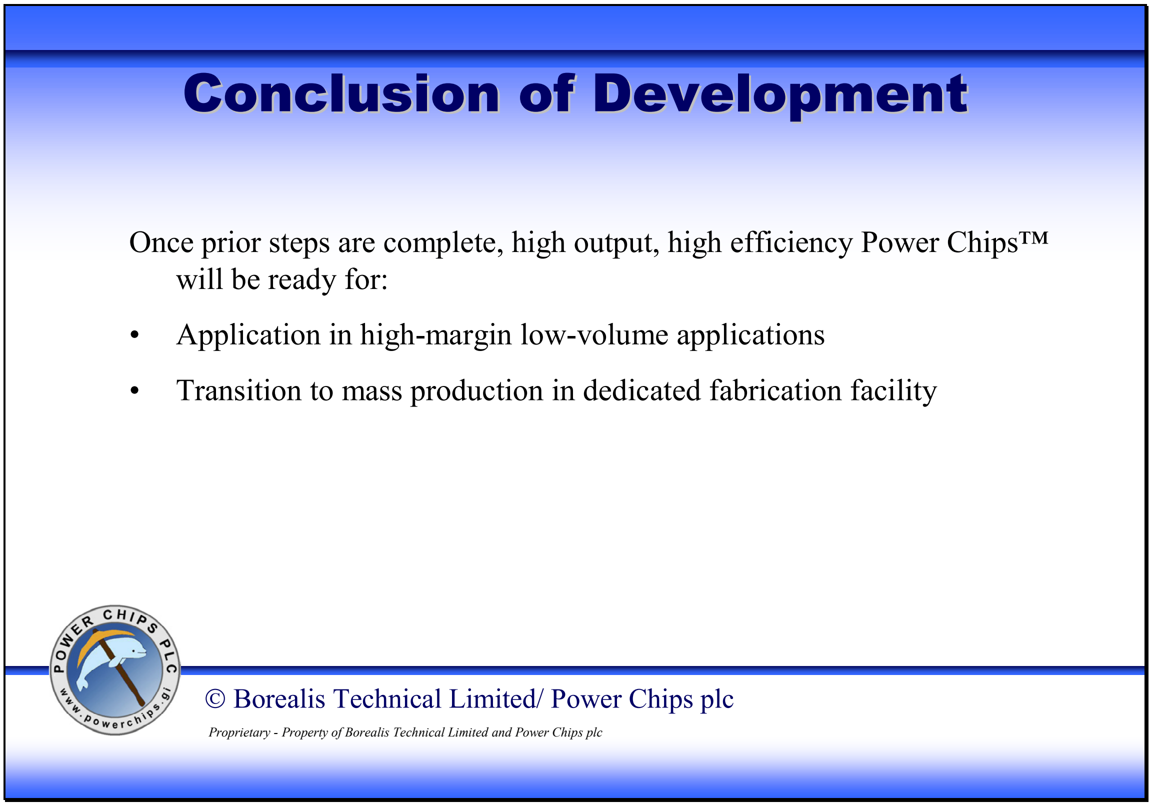
This work lends itself to a larger research effort with four facilities Worldwide. These issues are being addressed.



Once the sandwiches are conformal (both on the macro and on the micro scale), and tunneling currents on the order of hundreds of amps are observed, the last step is to lower the work function of the electrodes.

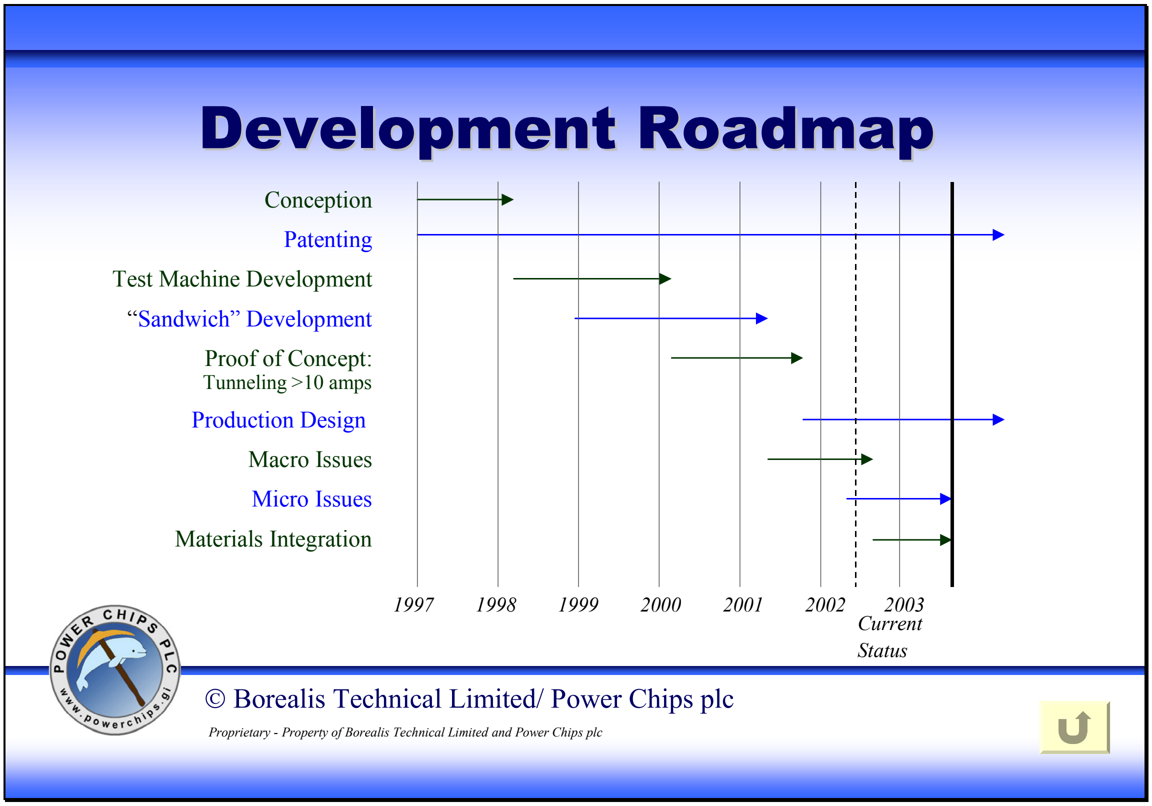
Because the technology relies on tunneling and not thermionics, the work functions required are on the order of 1-1.2 eV (which are off-the-shelf), and not 0.3 eV needed for thermionics (which may not exist).

The solution is to apply cesium to the interior of the chip. Cesium's work function (at 1 eV) allows for 5000 watts of power production at 5 nanometer spacing. Before we reach that theoretical maximum, other external limits would apply, such as external heat flux and conformal area.



Every stage discussed to date occurs in a lab, including lab-scale production of production Power Chips™ is what we are doing now. The product of lab assembly will be used for testing, applications engineering, and operation within certain high performance applications.

Initial sales for these applications (including geothermal applications) will bring the project cash flow positive even before a dedicated fabrication plant is on line.



The Development Roadmap shows what has been achieved and what lies ahead. Borealis has been working on thermionic power generation since 1994. The thermotunneling concept was a result of that earlier work.

The basic invention of thermotunneling across a gap was completed several years ago, and patenting commenced then.

To date, we have completed “Sandwich” development and testing inside the test machine.

The proof of concept experiment, showing tunneling currents across a gap on the order of 10 amps, was completed in the first half of 2001.

We are now working on ramping up production of very high value Power Chips.

Currently work is basically completed on macro issues (and functional macro sandwiches have been completed indicating that we will have this stage completely put to bed).

Micro issues have also begun. Still ahead is work on final materials integration.

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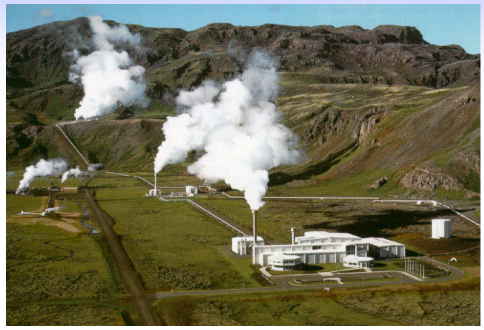
Waste Heat Recovery

Advantages

• Retrofit any existing plant increasing power output and overall plant efficiency.



•*Source: International Geothermal Association*

More:

- Efficiency
- Reliability
- Design flexibility

Borealis Power Chips

creating electric power from waste heat:

We are projecting that high output devices will be ready for deployment in 12 – 18 months. We are now selling into the high value commercial and military markets.

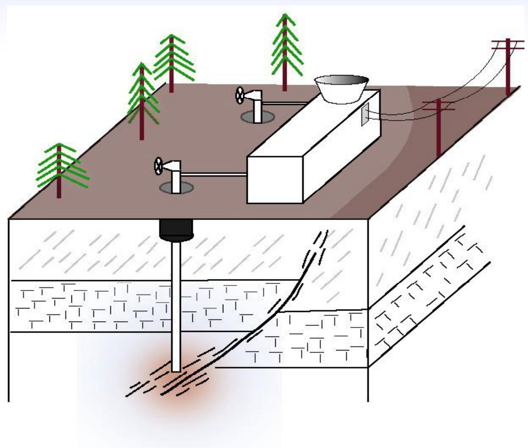
Once devices are on the market, one immediate application for Power Chips is to harness the waste heat of existing geothermal plants. By integrating Power Chips into the existing heat cycle, plants will increase power output and overall efficiency.

The design of Power Chip arrays are very flexible. Any existing plant can be retrofitted with an array.

New Geothermal Plant

New Plant Design

- Generate power from geothermal sources with temp well below 200^0 F.
- Does away with all turbine and binary plant designs.



Geothermal plants dedicated to Power Chip arrays will be much different than existing plants. As you have seen, no magnetic induction is required to generate electricity. Power Chips require no moving parts- just heat. The Power Chip geothermal plant of the future will make turbine driven and binary plants inefficient and obsolete.

We expect to run these plants at 60% - 70% efficiency. Operating at these efficiencies changes the economics of geothermal development giving developers more electricity to sell per unit of geothermal heat. The increase in monetary return will have a ripple effect creating a greater demand for exploration and field service work.

Power Chips will allow for the exploitation of geothermal resources with temperatures well below 200 F. This changes many of the rules we as an industry have previously lived by. With the ability to produce power at these relatively low temperatures, Hot Dry Rock power production and the Enhanced Geothermal program become much more realistic endeavors.

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In conclusion, we expect Power Chips to be an inexpensive and highly efficient way to produce electricity from the heat sources currently available. By bringing Power Chips to the geothermal market we also anticipate creating additional power production opportunities with lower temperature resources.

Borealis is actively seeking partners to bring this product to market. We look forward to working with members of the geothermal community to make this clean, renewable power source the preferred choice of power production in the geothermal industry.