Thermionic Coolers

Luis Esparza, Electrical and Computer Engineering, UCSB, lespar00@umail.ucsb.edu
PI: John Bowers, Electrical and Computer Engineering, UCSB, bowers@ece.ucsb.edu
Mentor: Christopher LaBounty, UCSB

Abstract:
Cooling in photoelectric and micro-electric devices is a big concern in information transfer. Cooling by thermionic emissions is experimentally modeled. Cooling over two degrees has been observed at 80°C, separated by a one-micron barrier.

Background:
Thermionic Coolers work by utilizing the long known physical principle of thermionic emissions. Coolers using thermionic emission have existed, but the applications were impractical for most. These coolers were developed at UCSB, and I spent my summer testing them. I worked closely with Christopher LaBounty this summer who taught me how they worked and how to test them. In solid-state cooling devices, there are no moving parts, no chemicals involved, and they tend to be smaller. These coolers can be made to any specified size offering an advantage some coolers can’t.

Device:
The devices I tested had a square area of 5000µm²-20000µm². The actual cooling part of the devices is roughly 2µm tall on top of a 100µm substrate (see fig. 1). The top of the device is covered with gold and a gold wire bond is attached. The cooling occurs at the top or bottom according to the bias, but it is best if the top cools and the bottom heats. In application, the top of the devices would be the part touching whatever needs to be cooled. The extremely large substrate helps in distributing the heat that is pumped from the top to the bottom. The materials do vary, but figure 1 is made of InGaAs and InGaAsP on an InP substrate.

A series of these devices, usually ten, varying in square area, are placed on what is referred to as a package (see fig. 2). The gold wire bonds are attached to the individual device and in the picture not all devices are bonded. The set of devices are soldered on to the package and this allows us to then subject the devices to a bias. The packaging allows us to, via wire bonds and solder, probe particular coolers to induce current. Micro-thermal couples then take a differential measurement to measure cooling. Currently, the packages no longer look like figure 2. The new package also allows for shorter wire bond lengths, which helps to minimize the joule heating. Joule heating is always of concern inside the coolers as well as the packaging.

The physics behind thermionics can best be explained with band theory. Imagine a hetero junction in the conduction band (see fig. 3). The dots represent electrons in the conduction band, and the arrows depict the path that they will take. In order for thermionic emissions to cool efficiently, a known energy junction is needed and must be abrupt but not too selective. Only the electrons above the average in the InGaAsP will be able to pass over when subjected to a bias. This leaves a void of electrons where lower energy electrons move up in their place. This occurs through thermal excitation and by removing energy from the heated lattice cooling is achieved. Once the electrons pass over the barrier region (InGaAsP) they want a state of lower energy. The energy is passed back into the lattice heating the other end. The heat is pumped over...
a micron barrier. The thermal resistivity of the barrier material is experimented with to impede the heat transfer back to the cold side. A temperature dependant law governs thermal resistivity, so as the ambient temperature increases so does the thermal resistance. Thermionic cooling is linearly related to current and joule heating is governed by $T=RI^2$ (T=Heat, R=Resistance, I= current) so a compromise has to be reached to achieve an efficient maximum.

**Conclusion**

In closing, I would like report on the current status of the devices. I have observed over 2°C of cooling over a micron barrier at an ambient 80°C, which is the internal temperature of many electronic devices. As the ambient temperature increases cooler performance also increases. The reason for this improvement lies in that there are more high-energy electrons to pass over the barrier leaving a larger void. Another is that the thermal resistance of the barrier material increases, separating the hot from the cold. The coolers are showing promise, and along with improvements in packaging, we should see cooling of 10 degrees soon. Other members of the group are experimenting with different materials with hopeful applications in silicon products.