Extracting Environmental Heat Using Electron Emission in Vacuum

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The use of electron emission in vacuum as a means of cooling, hence extracting environmental heat energy, is already known. Thermal emission of electrons from cathodes at a high temperature can either heat of cool the cathode depending on the energy of the emitting electrons. If, on overcoming the work function potential barrier, the escaping electrons retain lower energy than the average Fermi energy of the conduction electrons within the cathode, the net result is an increase in cathode temperature. This is known as the Nottingham effect, and the rise in temperature can cause cathode damage, especially in Spindt tipped cathodes where the tips become eroded. However above a certain emission threshold the escaping electrons have energy above that Fermi level, resulting in a cooling of the cathode, which is known as the inverse Nottingham effect. The electrons are allowed to condense onto a cold anode, where they are then extracted electrically via an external circuit. Thermionic generators therefore act somewhat like refrigerators, the electron gas being the working fluid. Such hot cathode devices are proposed for energy recovery where waste heat is at high temperature, e.g. steam turbines. A disadvantage of such systems is the low output voltage (around 0.5V)

Thermal electron emission at room temperature requires cathode materials with low effective work functions. Much work has gone on in recent years using nano-technology to obtain low work function, and non-vacuum silicon devices are being pioneered as coolers for computer chips. In these silicon devices, tuning out the low energy electrons from the tunnelling process, so as to achieve inverse Nottingham effect cooling, is done by layered barriers having different band gaps.

Some recent vacuum work is of significant interest, in particular that of Wu and Ang[1] where consideration is given to electron emission into a vacuum where there exists both an electric field aiding the emissions and a crossed magnetic field. By adjusting the amplitudes of these two fields the system can be tuned so as to cause the low energy electrons to be returned to the cathode, while the high energy ones cross that selective barrier to reach the anode, thus achieving Nottingham effect cooling of the cathode. This technique shows promise for refrigeration not only at 300 K room temperature but also down to 10 K, with impressive cooling power densities at the emitting tips quoted as 600 kW/cm^2 at 300 K. Clearly this technique is suitable for larger scale systems, having a structure not unlike a magnetron. These could find industrial use.

A room temperature cathode that has not yet found use in coolers utilises ferroelectric emission. It has been known for some time that energized ferroelectric devices can emit electrons, perhaps the best example being the piezo-electric spark igniter for gas flames. In recent years ferroelectic cathodes have been used in a number of systems, see for example[2]. Quoting from[3] "*The spontaneous electrical polarization of ferroelectric materials can be changed either by reversal or by phase transition from a ferroelectric into a non-ferroelectric state or vice versa. If spontaneous polarization changes are induced with fast heat, mechanical pressure, laser or electric field pulses on a submicrosecond time scale, strong uncompensated surface charge densities and related polarization fields are generated, which may lead to the intense self-emission* *of electrons from the negatively charged free surface areas of the ferroelectric sample. Hence, electron guns can be built with extraction-field-free ferroelectric cathodes*." Because zero or a low amplitude extraction field can be used it would seem that this type of cathode is ideally suited for use as a room-temperature thermionic generator, and it would produce usefully high output voltages well above the 0.5V of existing high temperature systems. Note also that mechanical pressure pulses can be used to create the emission.

Thus the coupling of two technologies, (a) a ferroelectric emitting cathode and (b) crossed-field selective electron-energy transfer, could produce a viable industrial cooler/thermionic-generator that could find application in many fields, but particularly in waste heat-energy recovery. One particularly interesting application is in improved energy conversion for internal combustion engines where waste heat energy is already channeled by fluid flow, and where mechanical energy in the form of pressure pulses is also available.

Figure 1 shows a schematic, where waste heat from the engine and the exhaust gases is taken by the water flow to the ferroelectric cathode. Exhaust gas pressure drives a fluidic resonator to provide ultrasonic pulses to the cathode. Waste heat going to the environment is almost totally eliminated, it being converted to electrical energy via the thermionic cooler.

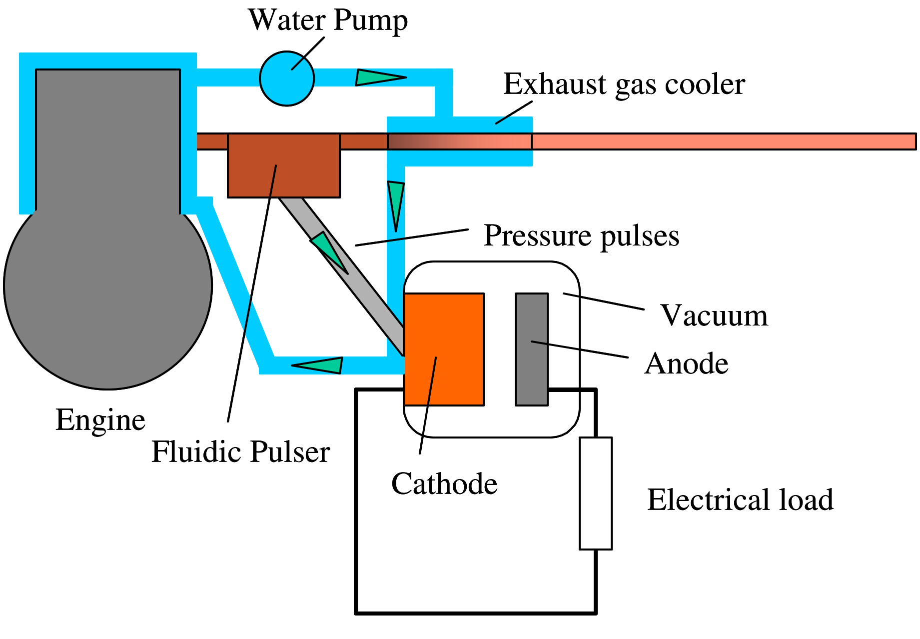

Figure 1. Schematic

References.

[1] L. Wu and L. K. Ang, **Low temperature refrigeration by electron emission in a crossed-field gap**, APPLIED PHYSICS LETTERS **89**, 133503 _2006_

[2] M. Einat, E. Jerby,a) and G. Rosenman, **High-repetition-rate ferroelectric-cathode gyrotron,** APPLIED PHYSICS LETTERS VOLUME 79, NUMBER 25 17 DECEMBER 2001

[3] H. Riege, **Ferroelectric Electron Emission: Principles and Technology,** EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN LHC/97-13 (DLO)