Master's Internship proposal – Applied Materials Science

Surface and perimeter passivation of Light-Emitting Diodes for Electroluminescent Cooling

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Electroluminescent cooling (ELC) is the phenomenon where cooling can be achieved by the emission of light in response to an electric field. Fundamental thermodynamics reveals that the chemical potential of light can be used for refrigeration.[1,2] Optical cooling can be achieved when the optical energy carried away by the light is larger than the amount of electrical energy deposited in the light emitter, enabled by the additional absorption of thermal energy from the lattice.[3]

In comparison with the conventional mechanical compressor (MC) and thermoelectric (TE) cooling technologies, the use of light as a refrigerant allows a fundamentally different approach with huge benefits (see Figure 1). In contrast to charge carriers acting as the refrigerant in TE devices, light propagates freely even through vacuum. Therefore it is immune to the key challenge of the dominating solid state refrigerator, i.e. the thermoelectric cooler, which must combine high electrical conductivity, large Seebeck coefficient and low thermal conductivity in a single material. Moreover, light does not have harmful effects on the environment, in contrast to the hydrofluorocarbons of MC refrigerators. As such, optical cooling provides a detour around the main limitations of the existing solutions, enabling efficient, compact and pollution free refrigerators, access to cryogenic temperatures and on-chip cooling.[1]

The possibility of ELC was acknowledged already more than 60 year ago, but at the time the quality of the contemporary materials obstructed developments towards actual applications.[3–8] Therefore even today it is still not widely realized that ubiquitous devices such as light emitting diodes (LEDs) are not just simple electricity-to-light converters but also solid-state thermodynamic machines capable of continuous and reversible energy conversion between electrical, thermal and optical energy.

However, in order to demonstrate ELC, the LEDs are required to function very efficiently (>95 % quantum efficiency). All non-radiative processes need to be eliminated, as non-radiative recombination not only means that no heat is extracted from the cell via generation of light, it also directly counters any successful radiative recombination by releasing its energy as heat. Non-radiative recombination is generally caused by defects within the cell structure, as these defects lead to additional energy levels that can be occupied within the semiconductor bandgap. The surface and perimeter of LEDs represent the largest source of defects, as the sudden stop of the crystal lattice results in broken symmetry and dangling bonds.

An important strategy for increasing the efficiency of LEDs is therefore the passivation of surface and perimeter defects, in order to decrease the amount of non-radiative recombination. In this Master's internship project, you will be investigating various passivation strategies for both the surface and perimeter of III-V semiconductor LEDs for ELC, with the goal of maximizing the quantum efficiency for the demonstration of electroluminescent cooling. It will consist of the manufacturing (processing) of p-i-n double heterojunction GaAs/InGaP LEDs in our Clean Room using lithography, chemical etchants and electron-beam physical vapor deposition of metals. The passivation strategies could include wet-chemical solution based passivation, dielectric passivation by thermal evaporation and plasma based strategies. The longevity of the passivation methods will also be studied, as some strategies have the added benefit of forming a protective layer on the cells.

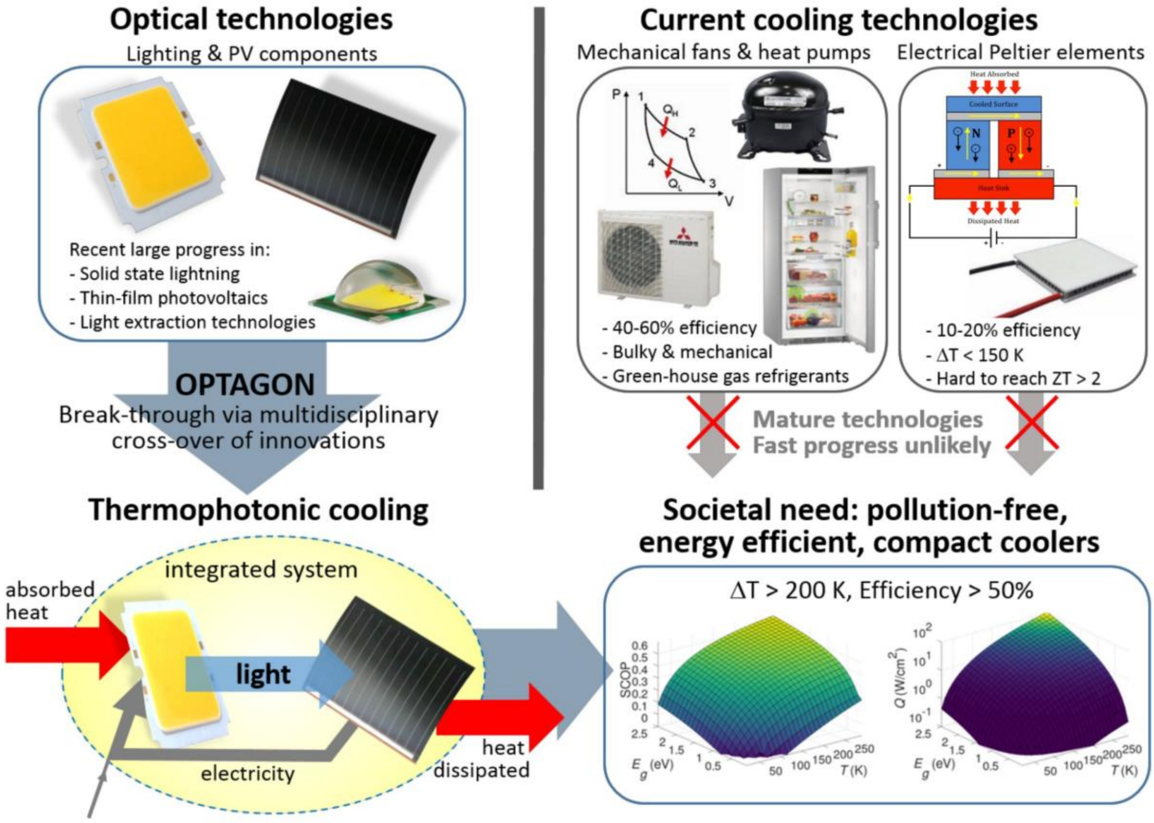

Figure 1: An Optical Approach to next generation refrigeration (OPTAGON). Fast progress in the existing cooling technologies is unlikely, but optical technologies allow a way around the traditional obstacles of these technologies.

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