Phonon recycling in LEDs

Abstract: **In LEDs, phonons are emitted in nonradiative losses including Shockley-Read-Hall and Auger recombination, and here we consider electron-phonon excitations capable of harvesting the energy of these emitted phonons before they become waste heat. We consider graded *n*-type AlGaN phonon absorbing heterobarriers that create conditions favorable for passing electrons to absorb optical phonons prior to their injection into the LED active region. The mesoscale electron-phonon interaction in the barrier is analyzed by self-consistent Monte Carlo simulation at the conduction band-edge. Meanwhile, drift-diffusion equations are solved to evaluate macroscale device behavior. It is expected that the heterobarriers will help manage the localized heat generation at the LED junction, improve power efficiency by enhanced electron capture and potential gain, and enhance the device's emission spectra.**

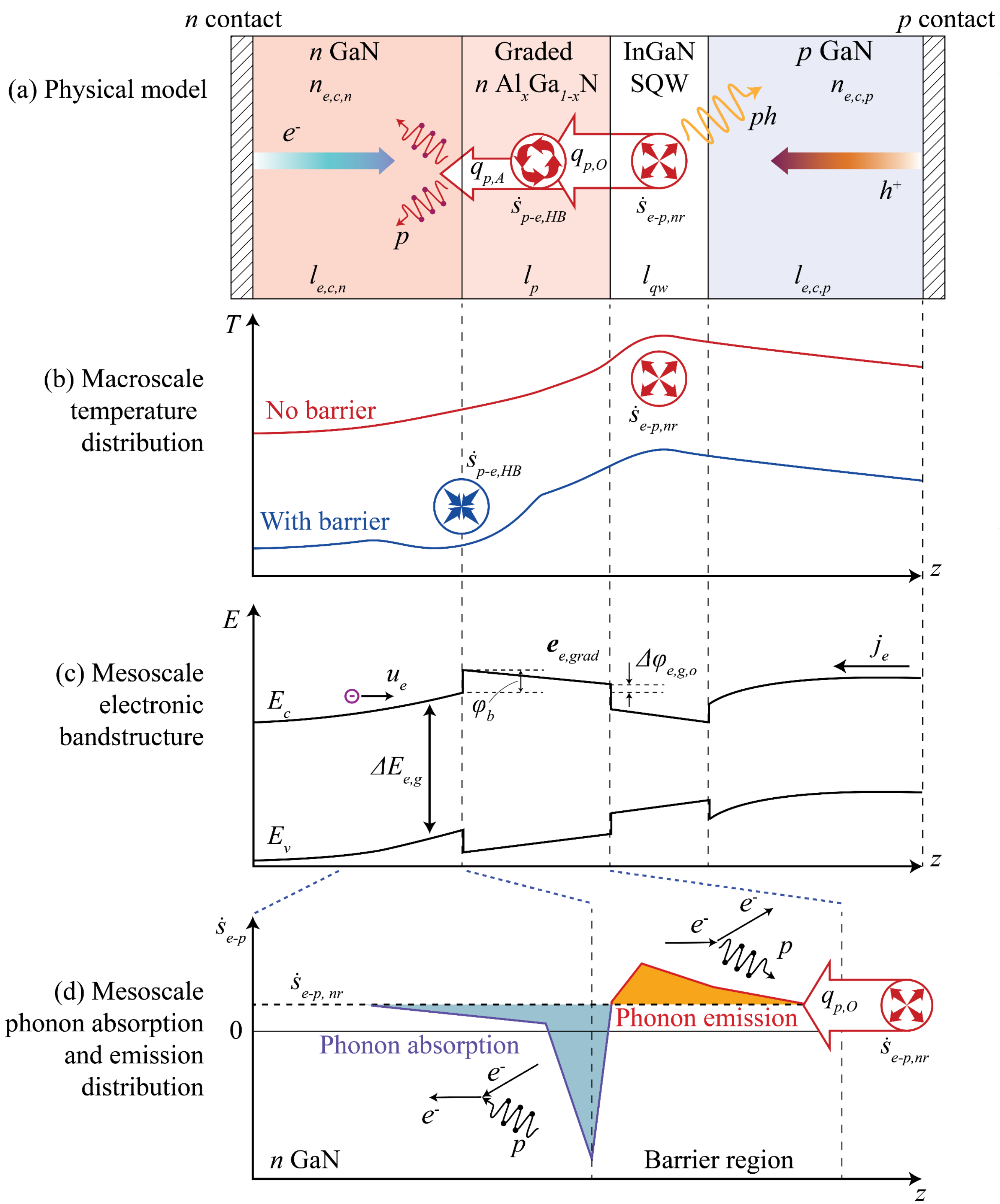

Fig. 1. Proposed phonon-recycling GaN LED

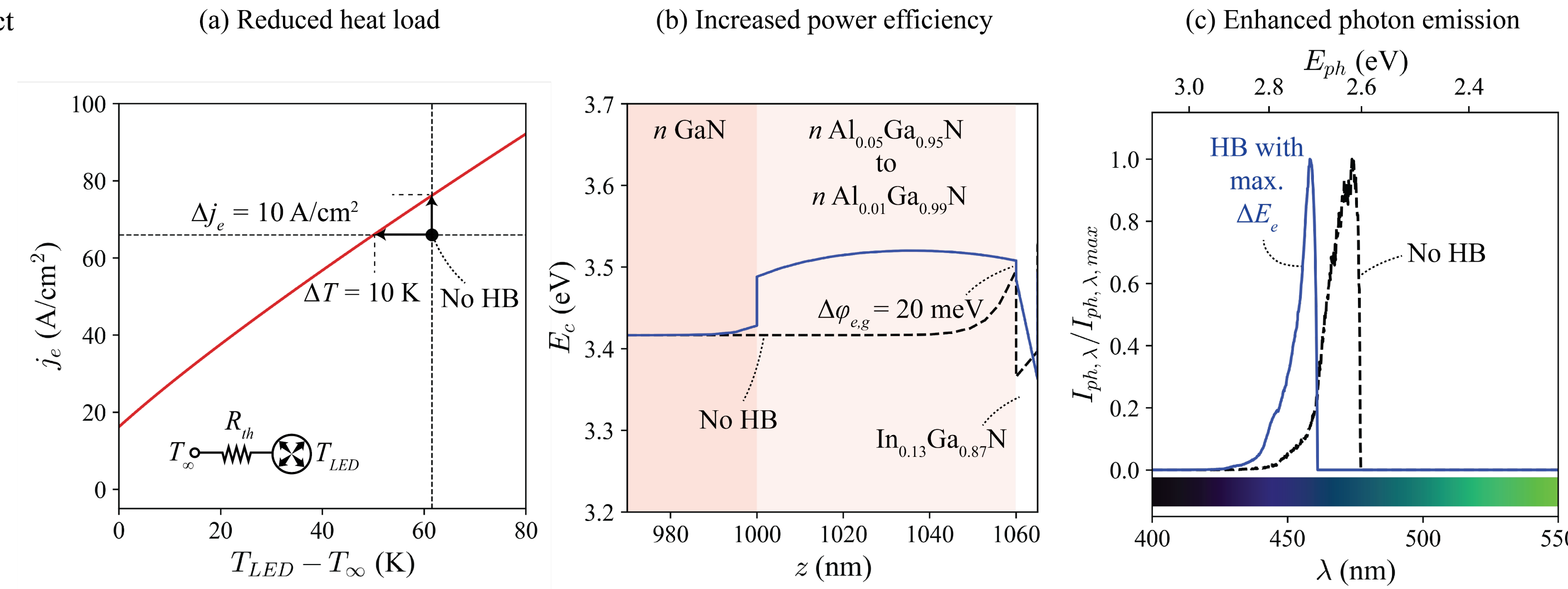

Fig. 2. Preliminary results, anticipated impact of phonon recycling in LEDs

Motivation: Light-emitting diodes (LEDs) typically convert electricity into light with less than 50% efficiency. The remaining supplied power is undesirably transformed into waste heat. Most of this heat originates from atomic vibrations, i.e., phonons, generated by nonradiative electron-hole recombination (which does not emit light). Recovering this waste heat back to power has seldom been explored in LEDs, despite the opportunity for large efficiency gains. This is because current solid-state heat harvesting technology is typically expensive, inefficient, and not suited for micron-scale LED chips. For example, standard thermoelectric generators require large temperature gradients that are unavailable in LEDs due to their size and high thermal conductivity. **Since heat is not believed to be a commodity for LEDs, it is released into the environment using heat sinks. The high-level goal of this research is to explore innovative ways of recycling phonons in LEDs to improve their energy efficiency and performance.**

Design: We propose the first gallium nitride (GaN) LED design that targets *in-situ* recycling of optical phonons before they are thermalized, as shown in **Fig 1**. Compared to a conventional LED, our structure introduces a graded, *n* doped AlGaN heterobarrier which will target absorbing phonon losses generated in the adjacent InGaN quantum well. Besides reducing waste heat and improving electrical efficiency, the barrier may promote electron capture by the quantum well, thereby increasing the lighting characteristics (**Fig. 2**). Compared to the thermoelectric generator, the heterobarrier requires no external structure and is easily integrated with conventional LED structures, making experiments realizable.