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ABSTRACT:

Equilibrium Rectifying Junction Enabling Large and Stable Resistance Variations

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Semiconductor diodes are essential components of modern electronic technology, enabling efficient, rapid, and precise current rectification. Traditionally, they operate based on either p-n junctions formed between two semiconductors or Mott-Schottky barriers at metal-semiconductor interfaces, the latter known as Schottky diodes. These devices rely on frozen doping profiles, making them inherently non-equilibrium systems that are incompatible with equilibrium thermodynamics. Over time, especially at elevated temperatures or during prolonged operation, dopants tend to redistribute toward an equilibrium state, which significantly impacts device performance and reliability. Recognizing this problem, several researchers searched for equilibrium devices without satisfying results [1].

In this work, we investigate an equilibrium rectifier that exhibits no drift even when miniaturized to the nanoscale, regardless of extreme operating durations. The concept hinges on the use of mobile "dopants" with mobilities high enough to respond to electric fields, yet low enough to avoid competing with the electrons in terms of conductivities [2]. To realize such a device, we employ TiO_2 films in contact with Ru, which are capable of storing Li at the interface through a job-sharing mechanism - Li^+ ions accumulate on the TiO_2 side, while electrons accumulate on the Ru side [3]. At zero bias, Li-ion accumulation and electron depletion occur at the interface, forming a built-in space charge potential that can be reversibly tuned - increased, reduced, or even inverted - by applying an external electric field.

This equilibrium rectifier offers several notable advantages: low-temperature fabrication, low series resistance, facile tuning of electrical characteristics through Li content adjustment (allowing operation within a low voltage window, $\gtrsim$0.1 V, ideal for low-power applications), and chemical stability under ambient conditions (as long as the Li content remains below 25%). Furthermore, at high frequencies where ionic movement is effectively frozen, the device operates analogously to a conventional space charge diode - yet remains free from drift.

[1] I. Lyubomirsky, V. Lyakhovitskaya, J. F. Guillemoles, I. Riess, R. Triboulet, D. Cahen, Journal of Crystal Growth, 161, 90 (1996).

[2] C. Xiao, J. Maier, A Nanoionic Diode: Equilibrium Rectifying Junction Enabling Large and Stable Resistance Variations, in preparation (2026).
[3] C. Xiao, H. Wang, R. Usiskin, P. van Aken, J. Maier, Science, 386, 407 (2024).