Frequency Dependence of Amorphous Silicon Schottky Diodes for Large-Area Rectification Applications

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Schottky diodes can play a valuable role as rectifiers in Large-Area Electronics (LAE) systems and circuits. They can be used to recover a DC signal when an AC carrier is used to transmit signals between adjacent plastic electronic sheets through near-field wireless coupling [1], rectify DC power after AC transmission between sheets to provide power to sensors, and so forth. In this paper we describe: 1) the intrinsic frequency limits of Schottky diodes fabricated on hydrogenated amorphous silicon (a-Si:H); 2) circuit design strategies for using the diodes at frequencies far beyond their intrinsic limits; 3) and the application of these strategies to demonstrate, to the best of out knowledge, the first amorphous silicon (a-Si:H) full-wave rectifier, with an AC-to-DC power conversion efficiency (PCE) ranging from approximately 46% at 200 Hz to greater than 10 % at 1 MHz.

Schottky diodes were fabricated using PECVD at under 200°C, with a 100nm chrome back contact, 30 nm n+ a-Si:H, 200 to 1000 nm intrinsic a-Si:H, and a 100 nm chrome front contact (Fig .1). For low-forward voltages they have an exponential type current-voltage behavior (Fig. 2), associated with transport over the semiconductor/metal interface. At intermediate voltages they show a power-law relationship ($I \propto V^m$) suggesting that diode current density is restricted by space-charge-limited current (SCLC) in the presence of an exponential trap distribution [2]. Reducing the thickness of the intrinsic layer diminishes the effect of SCLC and allowed us to obtain higher current densities. A lower intrinsic layer thickness caused the capacitance (Fig. 3) to increase, due to the diode's specific capacitance C obeying $C = \varepsilon/d$ where d is the thickness of the intrinsic layer and ε is the dielectric permittivity [3].

In large-signal applications, the intrinsic frequency of a Schottky diode is limited by its internal RC time constant, where R is the effective series resistance given by $\sim V_{applied}/I_{forward}$ and C is the capacitance of the diode. R is large due to the low mobility of amorphous silicon and SCLC. It can be reduced by operating at high current densities, enabled by decreasing the thickness of intrinsic layer, which allows smaller device area and lower capacitance. Decreasing the intrinsic layer results in increased specific capacitance, but overall still significantly reduces the RC time constant (Fig. 4).

When a Schottky diode is used in a half-wave rectifier (Fig. 5(a)) it is limited by its RC time constant. For example, in Fig. 5(c), the power conversion efficiency for a half-wave rectifier using a $1mm^2$ diode drops to 3.2 % at 20 kHz. However, in a full-wave rectifier circuit, undesired capacitive currents in opposite directions through connected diodes can cancel out, and allow the circuit to operate at higher frequencies. For example, in the full-wave rectifier shown in Fig. 5(b) the inputs (V_{inp} and V_{inm}) oscillate in counter phase, so for node V_{outp} the undesired capacitive current through D1 is cancelled by an opposite current though D2. This concept was experimentally demonstrated using four integrated $1mm^2$ Schottky diodes with a conservative 1000 nm thick intrinsic layer to reduce reverse leakage. It enabled the full-wave rectifier to operate with far greater power conversion efficiency than the half-wave rectifier, as demonstrated in Fig. 5(c).

In summary, reducing the thickness of the intrinsic layer of an amorphous silicon Schottky diode decreases its internal RC time constant and raises its intrinsic frequency. Further improvements can be obtained by designing symmetric diode-based circuits, such as a full-wave bridge rectifier, which we have experimentally demonstrated can function at frequencies far beyond the intrinsic limit.

[1]Y. Hu et al., IEEE Symposium on VLSI Circuits (2012) submitted.
[2] S. Ashok et al., *IEEE Electron Dev. Lett.* **1**, 200 (1980).
[3] R. J. Nemanich, *Semiconductors and Semimetals*, **21**, 390 (1984)

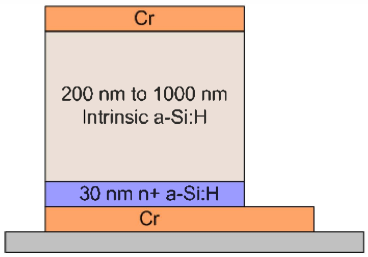

Fig. 1. Structure of a-Si:H Schottky diode.

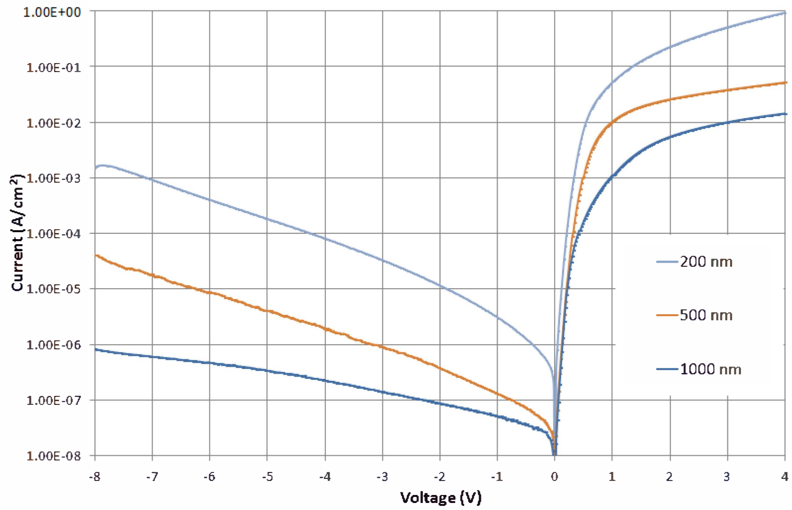

Fig. 2. IV curves of diodes with different intrinsic layer thicknesses.

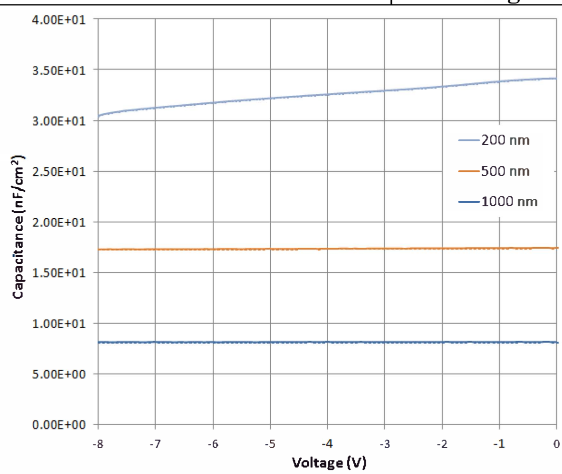

Fig. 3. CV curves for diodes with different intrinsic layer thicknesses

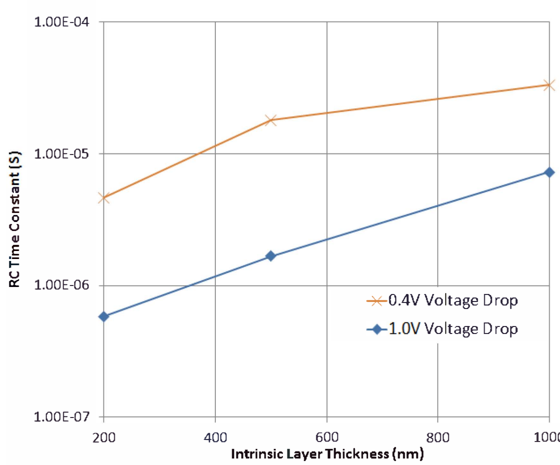

Fig. 4. RC time constant for diodes with different intrinsic layer thicknesses.

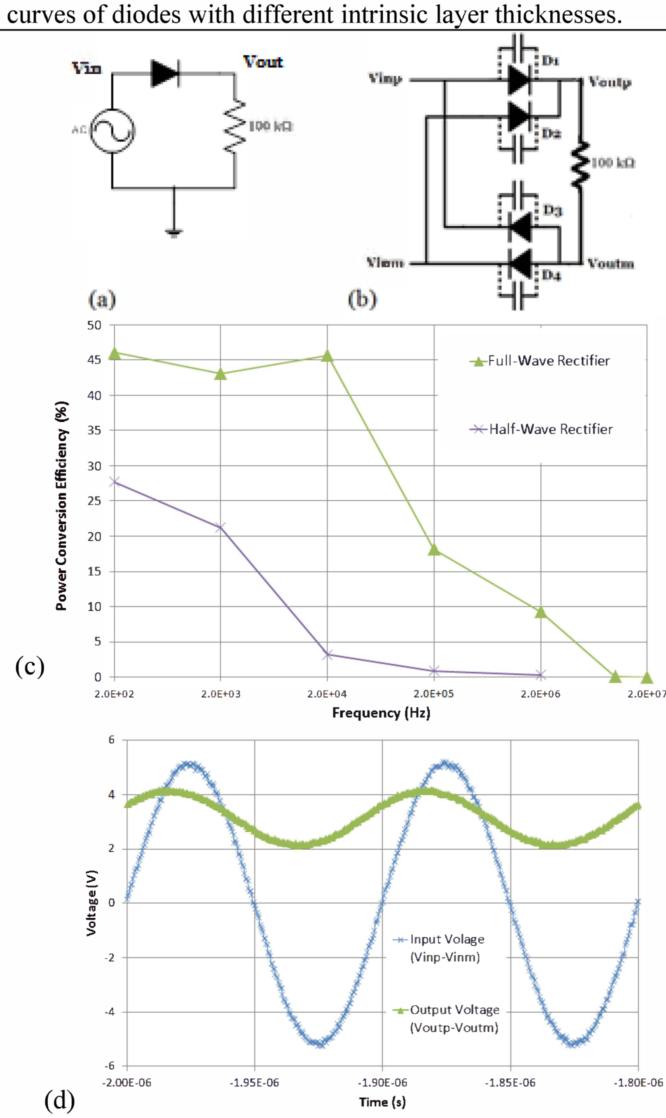

Fig. 5. (a) Half-wave rectifier (b) Full-wave bridge rectifier (c) Power conversion efficiency of full and half-wave rectifier (d) Full-wave rectifier at 10 MHz. The load in (c) and (d) is 100kΩ.