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High-Frequency ZnO Schottky Diodes for Non-contact Inductive Power Transfer in Large-Area Electronics

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Introduction: Besides traditional RFID [1], an emerging application of large-area electronics is hybrid systems [2], where we need to transfer power and signals from one flexible sheet to another. This is driven by manufacturing considerations: sheets providing different functionality, via different materials and devices, can simply be laminated together. Hard-wired metallurgical bonds between flexible sheets are expected to be problematic, especially for reliability, motivating the use of non-contact inductively-coupled interfaces between adjacent sheets [2-3]. For efficiency of such interfaces, high-frequency thin-film diodes (HF-TFDs) are required, since inductive losses are lower at high frequencies [3].

The relevant figure of merit is the cutoff frequency (f_c) [4-7], $f_c=1/(2\pi R_S C_D)$; R_S and C_D are the series resistance and depletion capacitance. Half wave rectifiers (HWRs) based on nc-Si (f_c=110 MHz) [4], IGZO (f_c=1.8 GHz, f_c=4.2 GHz) [5,6] and ZnO (f_c=20 MHz) [7] have been reported. We demonstrate Au/ZnO Schottky diodes with measured f_c=700 MHz, and power transfer between adjacent inductors.

Device Fabrication: As shown in Fig.1, 50nm thick Ti is evaporated and patterned on a glass substrate. 50nm thick ZnO is plasma-enhanced atomic layer deposited at 225°C. After oxygen plasma and UV ozone treatments the Schottky metal, a Ti/Au (2/200nm) stack is evaporated and patterned by liftoff. The active device area is 400μm^2.

Results: The diode has a rectification ratio of 10^3 (at ±1V) and a high forward current density of 100A/cm^2 at 1V, as shown in Fig. 2. The ideality factor, the barrier height, and R_S (at 1V) of the diode are 2.25, 0.58eV and 750Ω, respectively. Both the Ohmic contact resistance and undepleted ZnO layer contribute to R_S. C-V measurements show that at zero bias, only 20nm (40%) of the ZnO layer is depleted; at -2.5V the ZnO layer is completely depleted (Fig. 3). This suggests that in steady-state HWR operation the effective series resistance will be smaller than R_S because the diode will be mostly reverse biased. The DC output of a HWR with 1MΩ and 100pF loads shows a f_c = 700 MHz (Fig. 4).

A practical goal is to integrate a power source, power inverter, and inductor on one flexible sheet, for inductive power transfer to a second flexible sheet consisting of sensors and other functional blocks [3]. To characterize the performance of a power receiver on the second sheet, we employ a signal generator and inductor as the power transmitter. For controlled testing, the inductors are made on a separate large-area circuit board, as shown in Fig. 5. Their design (3cm radius, 85 turns, L_i: 210 µH, C_i:2.4 pF, R_i:25Ω, k=0.8) with a self-resonance frequency $1/(2\pi\sqrt{LC})$ of 7.1 MHz, is not yet optimized for efficient power transfer. The power transferred to the load peaks around 4 MHz. This corresponds to the resonant frequency of the power-receiver circuit, arising from both the inductance/self-capacitance of the secondary inductor, the capacitance of the HWR diode (Fig. 6), as well as additional capacitances of the SMA connectors. A DC output voltage of 1.4V is achieved, which is larger than the peak voltage (1V) of the input sine wave by exploiting LC resonance in the system [2]. Work in progress includes measuring input power to characterize the system's power-transfer efficiency (PTE), followed by optimizing the inductors to operate at higher frequency, to maximize PTE between sheets.

Conclusion: We achieved the highest cutoff frequency reported to date for a diode based on ZnO, of f_c = 700 MHz. The diode demonstrates promising performance for transfer power via non-contact inductive interfaces.

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References: **[1]** Tripathi et al., Appl. Phys. Lett. 98.16 (2011): 162102. **[2]** Verma et al., Proc. of the IEEE 103.4 (2015): 690. **[3]** Rieutort-Louis et al., IEEE Trans. CPMT 5.9 (2015): 1219. **[4]** Sanz-Robinson et al., IEEE EDL 35.4 (2014): 425. **[5]** Chasin et al., IEEE Trans. on Electron Devices 60.10 (2013): 3407. **[6]** Zhang et al., IEEE EDL 37.4 (2016): 389. **[7]** Semple et al., Small 12.15 (2016): 1993.

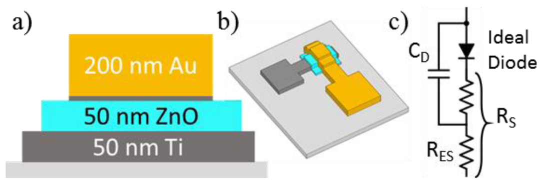

Figure 1: (a) Cross section, (b) device structure, and (c) circuit model for the ZnO diode.

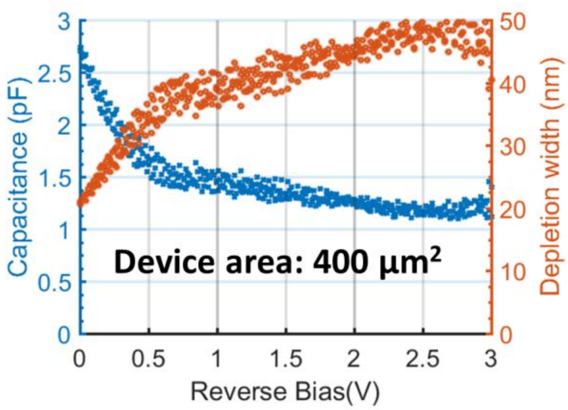

Figure 3: C-V characteristics and depletion width of a 50nm thick ZnO diode.

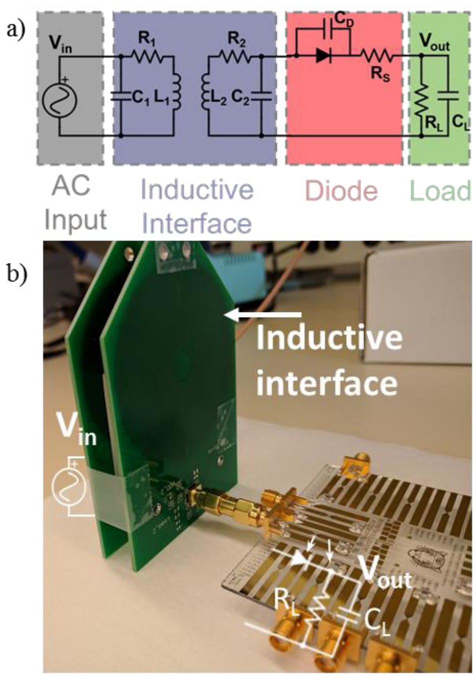

Figure 5: (a) Circuit for demonstrating power transfer to a DC load from one large-area sheet to another using non-contact inductive interfaces. **(b)** Experimental setup with large-area inductors, and HWR on glass substrate.

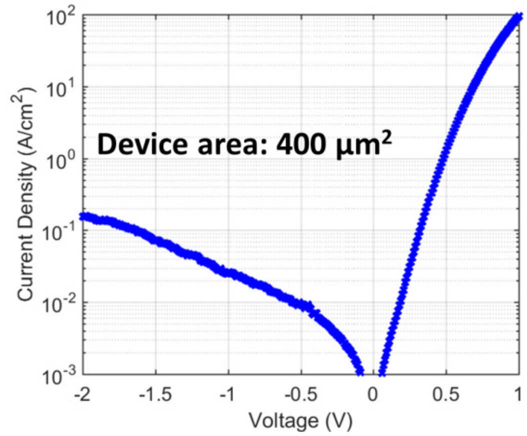

Figure 2: J-V characteristics of a ZnO diode.

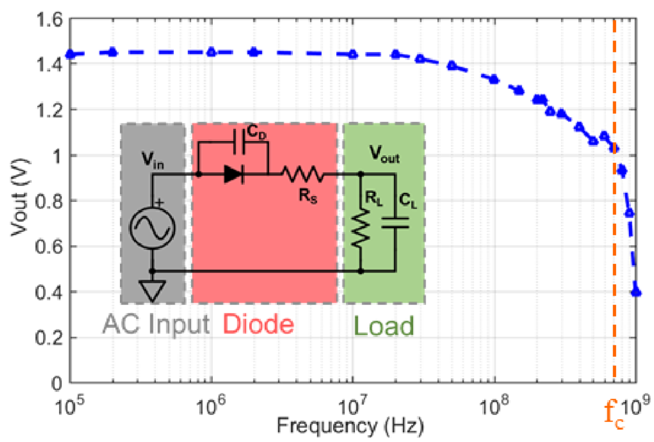

Figure 4: DC output voltage of the half wave rectifier as a function of input frequency ($Vin_{(p\text{-}p)}$= 4 V), with f_c=700 MHz. The inset shows the circuit diagram of the HWR, R_L= 1 MΩ and C_L= 100 pF.

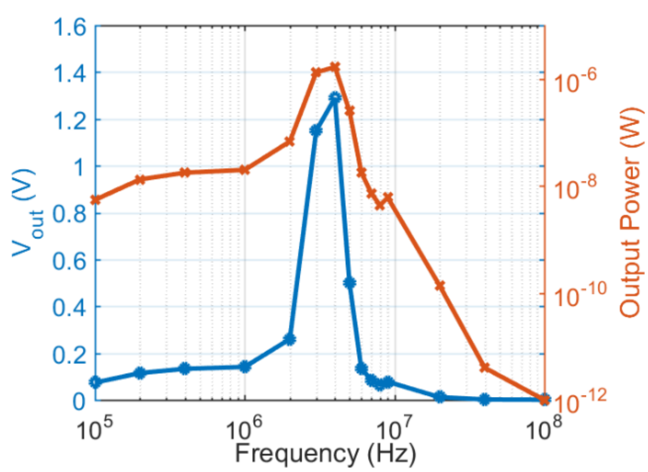

Figure 6: HWR output DC voltage and power, from the inductive interface of Fig.5 ($Vin_{(p\text{-}p)}$= 2 V). Using diode size of 20 μm x 20 μm.