Ultra-High frequency rectification using organic diodes

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Abstract

In the present work, we demonstrate a plastic diode that can operate in the Ultra-High Frequency (UHF) band and rectify an incoming ac voltage at those frequencies.

Introduction

Research towards organic radio-frequency identification (RFID) tags is one of the main drivers of the field of organic electronics, because low-cost plastic RFID tags could replace barcodes in the future. Recently complete 64-bit inductively-coupled organic RFID tags on foil have been shown operating at High Frequency (HF), i.e. 13.56 MHz (1,2). It has been predicted (3) that the 3 dB cut-off frequency of organic Schottky diodes could exceed 1 GHz when using a high-performance organic semiconductor layer with a charge carrier mobility exceeding $0.1 \text{ cm}^2/\text{Vs}$ for a thickness of 150 nm. To this date, however, no plastic diode has been shown with such performance.

To achieve this would not only be a scientific breakthrough but it is also of large technical importance, because UHF antenna's have a lower cost than HF antenna's, such that the ultimate low-cost tag likely should be a plastic tag working at UHF (433 MHz, 869 MHz, 915 MHz) (4).

Experiments and Discussion

UHF measurements of a discrete organic diode

We made crossbar diodes using a 160 nm thin film of purified pentacene sandwiched between a Au bottom electrode and an

Al top electrode on glass. The Au lines have been structured by photolithography while the pentacene as well as the Al electrode have been evaporated through a shadowmask (Fig. 1).

Figure 1. Schematic of discrete cross-bar diode with pentacene

The diodes have a reverse breakdown voltage exceeding 25 V and a charge carrier mobility of $0.15 \text{ cm}^2/\text{Vs}$ extracted assuming space-charge limited current (3). This charge carrier mobility is remarkable for an organic semiconductor, and was achieved by a device geometry and deposition conditions that ensure that the charge carrier transport occurs through a parallel network of single crystals of pentacene located between the bottom and the top electrode, as shown in Fig. 2.

Figure 2. SEM image of cross-section of pentacene as used in diode

The resulting IV-curves can be seen in Fig. 3 on linear (current density on right axis) and logarithmic (current on left axis) current scale.

Figure 3. IV characteristics of a discrete pentacene diode on glass ($A = 2\text{ mm} \times 50\mu\text{m}$)

Subsequently, this diode has been measured in a rectifier configuration (Fig. 4) whereby a discrete load-capacitance ($C_L = 100\text{ nF}$) was added at the probe needles and an oscilloscope, terminated over $1\text{ M}\Omega$ as load of the rectifier, was used to measure the rectified dc voltage.

Figure 4. Schematic of rectifier measurement setup

The ac signal at the input of the rectifier is provided by an HP8350A signal generator and amplified by a broad band power amplifier (LA-10M, T&C Power Conversion, Inc.). The amplifier is terminated with a $R_T = 50\ \Omega$ resistance attached to the probe-head. All measurements have been done in N₂-purged glovebox connected to the evaporation system

in which the pentacene and Al were evaporated to form the diode. In this way, the diode was not exposed to air prior to measurement of the rectifier. Applying an ac amplitude of 15 V to the rectifier (Fig. 5) at 13.56 MHz results in a dc amplitude of 9.8 V, which is a sufficient supply voltage to drive an organic circuit in state-of-the-art technology (1). Even at 433 MHz the rectified dc voltage is not reduced.

Figure 5. HF (13.56 MHz) and UHF (433 MHz) Rectification of a discrete pentacene diode on glass with discrete capacitor (dotted line – input ac signal, solid line – rectified dc signal)

UHF measurements of an integrated rectifier on foil

Our next step was to realize a flexible integrated rectifier, containing both diodes and capacitors, on PEN foil (see Fig. 6).

Figure 6. Integrated rectifier on foil (PEN – Polyethylene naphthalate) ;
(a) schematic cross-section, (b) processed foil, (c) measurement socket

The electrical characteristics of the components of the integrated rectifier, i.e. the organic diode and the capacitor, are shown in Figs. 7 and 8.

Figure 7. IV-characteristics of a pentacene Schottky diode on foil
($A_{\text{diode}}=600\mu\text{m} \times 200\mu\text{m}$)

Figure 8. Quasistatic CV measurement of an integrated capacitance on foil
($A=2\text{mm} \times 2\text{mm}$, $d_{\text{parylene}}=350\text{nm}$)

The reverse leakage of the diode on foil is higher than the leakage of the discrete diodes and the worse heat conductivity of plastic substrate compared to glass or Si reduces the forward bias that can be applied before irreversible damage occurs. Current densities of 3 A/cm^2 through the diode are nevertheless possible.

The dc output of the integrated rectifier was measured as a function of the ac frequency of the applied input, for an ac voltage with amplitude of 15 V and a load of 1 MOhm. In Fig. 9, the measurement results have been plotted as circles. The rectified dc voltage at 869 MHz is 4.5 V.

Figure 9. Frequency vs. rectified dc voltage.

Lines : calculated achievable rectified voltage with plastic diodes in a rectifier configuration as a function of the frequency of the base carrier for various charge carrier mobilities, mentioned in the insert, assuming 160nm pentacene film thickness;

Symbols : measured performance of our rectifiers: closed diamonds: rectifier with discrete pentacene diode on glass; open circles: integrated rectifier on plastic substrate.

Further increases of the voltage level is expected to be possible using more complex rectifier schemes, such as with the double half-wave rectifier presented recently for HF frequency (5).

Conclusion

We successfully demonstrated UHF rectification using a rectifier comprising an organic Schottky diode and an integrated capacitor on foil. The rectified voltage was 4.5 V at 869 MHz, for an ac input voltage with 15 V amplitude. The operation of this organic device at UHF frequency opens the pathway for plastic UHF RFID tags.

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References

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