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Rectenna materials improving low scale RF power harvesting for embedded miniature sensors

Samir Mekid

Mechanical Engineering Department, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

Abstract

The paper reviews suitable innovative materials used to improve harvesting power through ambient Radio Frequency (RF) needed for standalone embedded sensors. The Rectenna (a combination of a rectifier and antenna) material is one of the main three key elements constituting the scavenging system including the resonator based on the material, the number of multiplier stages and the low pass filter. The system uses electromagnetic waves travelling in ambient air captured through an antenna to an electronic unit and will excite a subsystem to harvest energy. This subsystem is the heart of the concept of power scavenging and is material based concept in most of the cases treated in this paper.

Keywords: Power harvesting, RF, resonator, rectenna, batteryless

1. Introduction

Permanent energy supply is highly needed for battery-less standalone electronic devices. The daily and continuous use of these devices exhibit a real issue with batteries and their fast recharging. Methods for extracting or harvesting energy from the surrounding environment are of great importance because it reduces the maintenance scheduling, transportation, weight and cost of energy needed by the standalone devices. The energy sources of interest are the largely untapped sources of ambient energy resulting from human activity and environmental energy flows in the form of waste heat, movement and vibration.

It is important to remind that power transmission dates back in early work of Hertz who has shown the propagation of electromagnetic waves in air. Tesla followed by transmitting power from one side to another wireless in 1899.

A couple of innovative techniques have already shown a possibility of improvement of scavenged power through RF waves in ambient air. The known three parameters governing the power scavenging are the resonator, the number of multiplier stages and the low pass filter. The resonator or the rectenna shows better performance if specific promising micro-scale energy harvesting standard materials are used e.g. ceramics, single crystals, polymers and composites, and also new engineered materials currently being developed. Resonator can provide increased voltage level with single stage voltage multiplier. Further improvement with this scheme can be obtained by multiple stages. It is also demonstrated that the use of LPF provides the output voltage with little amount of harmonics. Since RF to DC conversion efficiency has emerged as challenging issue, so band pass filter can be used to complete this objective by removing the second and third harmonic at antenna [1].

Our current interest is material. The energy sources of interest to this paper is in the Low power requirements (μW to mW) – for example heat and movement lost from portable electronics and mobile communications. The aim is not to generate large-scale power, but to capture small amounts of ‘energy’ that is ‘wasted’ during industrial and everyday processes. There is currently a great commercial potential for energy harvesting technologies, hence many projects are supported by European companies, from

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Corresponding author. *E-mail address*: smekid@kfupm.edu.sa.
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automotive to electronics manufacturers as well as European framework 7 programmer [2], [3]. It important to note the amount of harvested power has very low density power ranging from 0.1 μW/cm3 to 0.001 mW/cm3. Fig. 1 shows measured GSM-900 power density levels.

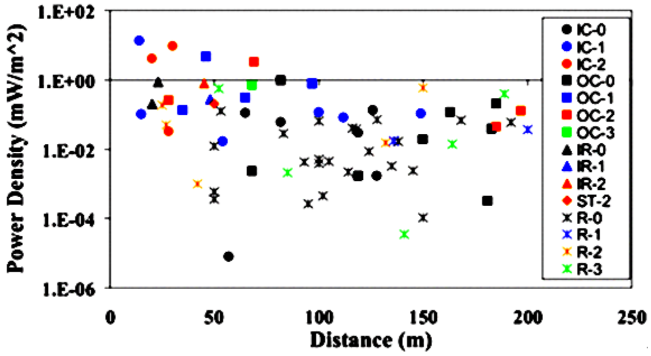
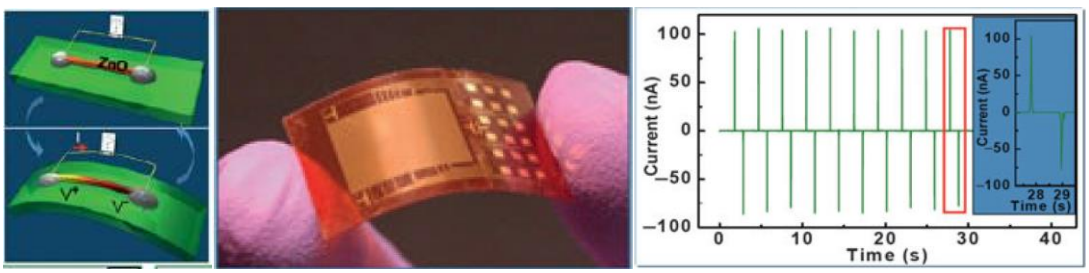


Fig. 1. Measured GSM-900 peak power density levels as a function of distance to the nearest base station. IC=Inner City, OC=Outer Country, IR=IndustRial area, ST=Small Town, R=Rural or country-side are. a: 0=outdoor on the ground, I=outdoors on roof, terrace or balcony, 2=indoors, close to windows, 1.5m or less, 3=indoors, not close to windows [4].

2. Types Materials Used in RF-Based Energy Harvesting

Several promising micro-scale energy harvesting standard materials are used e.g. ceramics, single crystals, polymers and composites, and also new engineered materials currently being developed. Micro- and nano-scale Metal Insulator-Metal (MIM) tunnel diodes are being developed [5] to provide half-wave rectification as part of a "rectenna" energy harvesting system, which includes a radiation-collecting antenna, a rectifying MIM tunnel diode, and a storage capacitor. High-frequency MIM tunnel diodes for power rectification were designed, fabricated and characterized. Planar Pt/TiO_2/Ti stacks are being fabricated to create a diode with highly asymmetric I-V characteristics that has a very low threshold voltage. A MIM tunnel diode is composed of two conductive metal layers separated by a very thin dielectric, and operates on the principles of thermionic emission and quantum tunneling Preliminary results exhibit asymmetric I-V characteristics with threshold voltages of less than 700 mV. Initially this MIM was a poor resistive element because of fabrication issues.

Single and multi-walled carbon nanotube-based technology for radio frequency [6] switch working in the range of 40–60 GHz and fulfilling the specifications were exploited. The first processed component had an operating voltage of 14 V for an ohmic contact in a Nano-Electro Mechanical System (NEMS) tweezer design. High Frequency Simulation Software (HFSS) RF-simulation on an innovative NEMS geometry shows encouraging results with transmission ratios between "on" state and "off" state up to 34% for ohmic-contact switch and 25% for a capacitive-contact switch.



a) b) c)

Fig. 2. a) principle of ZnO with two metal electrode in equilibrium and stretched, b) high output nanogenerator using integration of millions of nanowires transferred to polymer substrate. c) output of 2V and 100 nA are obtained.

Piezoelectric cantilever [7], [8] is used to induce strain via RF signal propagation. Hence, when a piezoelectric cantilever is subjected to RF propagation field, an alternating current is induced in the piezoelectric cantilever causing mechanical movement. Hence, maximum effect is achieved when RF frequency matches the resonant frequency of the cantilever. When a voltage signal of 10 Vpp propagates in the line it sets an alternating current in the actuator electrodes. The effect of piezoelectric material was also exploited in ZnO nanowires laterally bonded on a flexible substrate (Fig. 2). One of the unique advantages of ZnO is that all of the nanowires grow along the *c* -axis (i.e., in the polar direction) and are uni-axially aligned. Once the wires are strained, a macroscopic piezo-potential is created, which can drive a flow of electrons, thus converting mechanical energy into electricity.

On another application [9], RF waves are received from a mobile phone and rectified to generate a DC voltage by a rectenna (a rectifying circuit with an antenna). The layered rectenna is photo-etched from copper-clad FR4 material [10], which allowed for a fast realization of the product. To model the dc output voltage, the incident power received by the patch antenna is measured for a fixed transmit-receive setup. This data is used in the model to predict the dc output voltage of the rectenna. The dc output voltage is predicted and measured in Fig. 3. The system was fabricated with 0.6 _m-CMOS technology, and can supply well-regulated 4.0 V/1mA DC power to the load for 10 ms periodically.

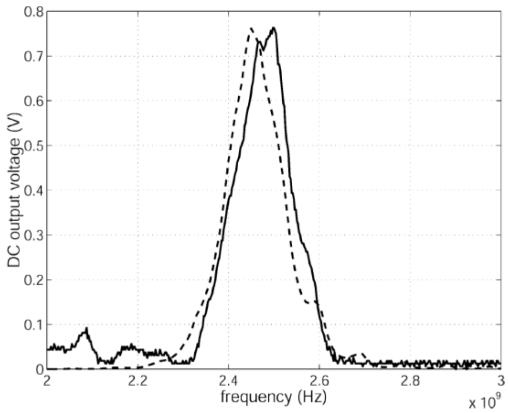
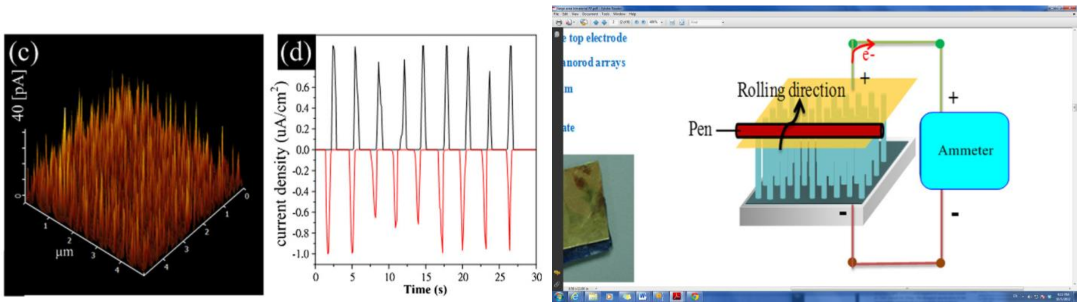


Fig. 3. DC output voltage of the stacked rectenna. Measurement (solid) and model (dash).



a) b) c)

Fig. 4. a) Nanorods grown on, b) current received from 2x2 cm^2 based on concept in c).

ZnO is also used to generated power as follows [11]. An optimal Radio Frequency (RF) sputtering process (sputtering power, sputtering time, and target type) to grow a ZnO seed layer on an Indium Tin Oxide (ITO) glass followed by the hydrothermal growth of a well-aligned perpendicular ZnO nanorod array for the fabrication of a piezoelectric nanogenerator Fig. 3. The change in nanorod morphology, crystallinity, orientation, growth rate, diameter, length, and number density of ZnO nanorods were controlled by modifying various processing parameters. A prior seeding of ZnO nanoparticle with good wurtzite structure and with preferred orientation along the (002) direction of the crystal is critical for the subsequent growth of well-aligned vertically oriented ZnO nanorods on ITO substrates. A large area (2_2cm^2) of the piezoelectric nanogenerator bimaterial sheet was fabricated by combining the vertically grown ZnO nanorod array electrode with an Au-coated polyurethane (PU) film as the other electrode. By rubbing the two electrodes together, the nanodevice generates an optimal output current density of about 1μA/cm^2 in Fig. 4c).

3. Conclusion

A couple of innovative techniques have already shown a possibility of improvement of scavenged power. The known three parameters governing the power are the resonator, the number of multiplier stages and the low pass filter. The resonator or the rectenna has shown better performance if specific promising micro-scale energy harvesting standard materials are used e.g. ceramics, single crystals, polymers, composites, and new-engineered materials currently under development.

Piezoelectric nanogenerators have been developed that can serve as self-sufficient power sources formicro-/nanosystems. For wurtzite structures that have non-central symmetry, such as ZnO, GaN, and InN, a piezoelectric potential (piezopotential) is created by applying a strain.

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