Quantum Vacuum Zero Point and Negative Energy: Theory and Applications

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The quantum vacuum with filled negative energy states presents an unlimited source of potential energy. The well known built-in voltage potential for some select semiconductor p-n junctions and various rectifying devices is proposed to be favorable for generating DC electricity at “zero bias” (with no DC bias voltage applied) in the presence of Johnson noise or 1/f noise which originates from negative energy in the quantum vacuum (Koch, 1982). The 1982 Koch discovery that certain solid state devices exhibit measurable quantum noise has also recently been labeled a finding of dark energy in the lab (Beck, 2004). Tunnel diodes are a class of rectifiers that are qualified and some have been credited with conducting only because of quantum fluctuations. Microwave diodes are also good choices since many are designed for zero bias operation. A completely passive, unamplified zero bias diode converter/detector for millimeter (GHz) waves was developed by HRL Labs in 2006 under a DARPA contract, utilizing a Sb-based "backward tunnel diode" (BTD). It is reported to be a "true zero-bias diode". It was developed for a "field radiometer" to "collect thermally radiated power" (in other words, 'night vision'). The diode array mounting allows a feed from horn antenna, which functions as a passive concentrating amplifier. An important clue is the "noise equivalent power" of 1.1 pW per root hertz and the "noise equivalent temperature difference" of 10°K, which indicate sensitivity to Johnson noise (Lynch, et al., 2006). There also have been other inventions such as "single electron transistors" that also have "the highest signal to noise ratio" near zero bias. Furthermore, "ultrasensitive" devices that convert radio frequencies have been invented that operate at outer space temperatures (3 degrees above zero point: 3°K). These devices are tiny nanotech devices which are suitable for assembly in parallel circuits (such as a 2-D array) to possibly produce zero point energy (ZPE) direct current electricity with significant power density (Brenning et al., 2006). Photovoltaic p-n junction cells are also considered for possible higher frequency ZPE transduction. Diode arrays of self-assembled molecular rectifiers or preferably, nano-sized cylindrical diodes are shown to reasonably provide for rectification of electron fluctuations from thermal and non-thermal ZPE sources to create an alternative energy DC electrical generator in the picowatt per diode range.

1. Introduction

The US currently spends between 5 and 10 cents per kilowatt-hour (kWh) depending upon whether we are a residential or commercial customer. Furthermore, the US Electric Power Industry generates approximately 4,000 billion kWh on an annual basis (www.eia.doe.gov). These Fig.s indicate that electricity consumption is about a $300 billion market commanded by the public utilities. It is proposed that distributed single cubic-meter electricity generating units may become a reality in the near future with the emergence of zero point energy (ZPE) rectifiers deployed in the form of three-dimensional arrays. This event is predicted to create a disruptive effect on the public utilities, while it empowers ordinary individuals from all walks of life including third world countries, opening up vast areas of the world that are presently uninhabitable due to the lack of on-site energy generation capability.

The built-in voltage potential across the ends of semiconductor *p-n* junctions, caused by the charge q difference between the positive *p*-doped and negative *n*-doped material, is about 0.6 volts for silicon diodes and normally depends primarily upon kT/q and the ratio of charge carrier concentrations (about 0.026 eV for silicon at room temperature) where k is the Boltzmann constant and T is the absolute temperature. Furthermore, it requires an equivalent voltage bias to overcome the potential barrier and create electronic conduction through the diode rectifier. However, there are other forms of rectifying devices suitable for generating DC electricity with much lower bias voltage requirements. The class of rectifiers that are compatible with ZPE levels of energy are those that operate at “zero bias” (with no bias DC voltage applied whatsoever). Tunnel diodes are one class of rectifiers that are qualified. Microwave rectenna diodes are also good choices since many are designed for zero bias operation. Reference articles are attached showing the use of “broadband spiral antennas” and phase conjugate mirrors for amplifying electromagnetic frequencies that make up quantum noise. The tunneling current in the diodes can also be influenced by the use of magnetic fields as low as 10 gauss as well.

With the numerous discoveries of the various energetic features of the quantum vacuum, as devices get smaller and smaller, it is a predictable certainty that more and more nanotechnology devices will begin exhibiting chaotic zero point energy. It is also noted that developments in molecular nanoelectronics have presented a wide range of molecular and nano-crystal diode options, including Schottky photodiodes based on organic molecules (Reed, 2003). There are many features of Casimir effect and other

ZPE-related phenomena which lend themselves to possible generation of electricity (Valone, 2003). One example is the dramatic change of dielectric constant of a cantilever cavity by illumination with a microlaser in order to increase the Casimir force as Pinto proposes and generate 0.5 nW (nW = nanowatt = 10-9 W) of electricity with a 100 micron device (Pinto, 1999). Presently, the Casimir force is becoming more commonplace since it is a frequent hazard in the nanotechnology field for the Casimir effect to literally destroy a nano-cantilever when the spacing drops below one micron.

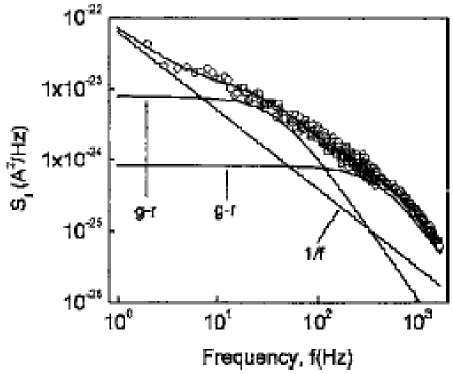


Fig. 1. Example of 1/f noise in the picoampere current range from a diode rectifier, along with contributed noise (g-r lines) from two quantum dot devices (Tsormpatzoglou, 2005).

2. Laboratory Measurement of Non-Thermal Noise Current

Considering electronic circuits, it is important to note that $1/f$ noise (noise that decreases with frequency) in carbon shunt resistors and electronic components is also very commonplace (Fig. 1). One textbook estimates a noisy operational transresistor circuit used to condition small currents, using parameters for an AD549 electrometer op amp (Analog Devices, Norwood, MA) to have the dominant term coming from Johnson noise (often regarded only as thermal noise) and a minimum noise current of about 0.12 microamps DC (Northrop, 1997). In tunnel junction diodes, thermal fluctuations will lead to a voltage difference across the junction and stimulate tunneling electrons (Sheng, 1978). Furthermore, the electronic fluctuations of ZPE have been measured in the laboratory as some university researchers have been careful to isolate the thermal component of noise (Eq. (3)) in order to evaluate the *non-thermal, broad spectrum noise* more closely. In a resistively shunted Josephson junction (RSJ), which normally operates at liquid helium temperatures, the non-thermal portion of noise has been unequivocally been measured. With good agreement with the quantum correction to the Nyquist noise generated in the shunt resistor, the spectral density of noise in the resistor, including zero-point and negative energy fluctuations is found to be (Koch, 1980):

$$S(f) = \frac{hf}{\pi R}\coth\frac{hf}{2kT} \qquad (1)$$

Koch (1982) notes that in the extreme quantum limit $eV \gg kT$, the observed noise is generated solely by zero-point fluctuations in the shunt resistor R, which has a current spectral density of hf/pR where h is Planck's constant and f is the frequency. However, treating the electron as a quantum mechanical wave packet, which has some probability of penetrating the barrier by macroscopic quantum tunneling (MQT), a need for a quantitative theory that deals with both zero-point fluctuations and MQT is needed. Koch (1982) measured about a 10% contribution of $1/f$ noise to the white noise spectral density and focused on the noise generated solely at the junction, taking into account all extraneous sources of noise. For frequencies ν up to 500 GHz, Koch (1982) verified that the spectral density of the Josephson junction was in excellent agreement with the prediction of Eq. (2). Furthermore, the presence of the zero-point energy coefficient term $2hf/R$ was demonstrated at frequencies of $hf > kT$.

$$S_J(f) = \frac{2hf}{R}\coth\frac{hf}{2kT} \qquad (2)$$

In Fig. 2, the spectral density of the measured noise is plotted as compared to the dashed lines, which show what the data would look like *without* a ZPE fluctuation term contribution. The graph also clearly shows the upper frequency limit of ZPE fluctuations that Koch measured for the noise spectrum. This work sets the stage for further investigation of other circuit elements and devices that may also exhibit similar behavior of a broadband white noise spectral density due to ZPE that may be buried in thermal Johnson noise as well.

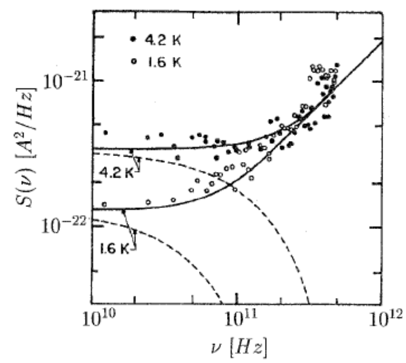


Fig. 2. Measured spectral density of current noise in the shunt resistor of Josephson junction at 4.2K (solid circles) and 1.6K (open circles) up to 500 GHz. Solid lines are the prediction of Equation 2 while the dashed lines represent the theoretical prediction in the absence of the zero-point energy term and fall far below the data at the higher frequencies (Koch, 1982).

Further considering resistor-based noise from the quantum vacuum, Blanco et al. (2001) have proposed a method for enhancing the ZPE-induced voltage fluctuations in circuits. Treating a coil of wire theoretically as an antenna, they argue that the antenna-like radiation resistance of the coil should be included in the total resistance of the circuit, and they suggest that it is this total resistance that should be used in the theoretical computation of the ZPE-induced voltage fluctuations. Because of the strong dependence of the radiation resistance on the number of coil turns (scaling quadratically), coil radius (quartic scaling), and frequency (quartic scaling), these enhanced ZPE-induced voltage fluctuations should be measurable in the laboratory at quite accessible frequencies in the 100 MHz range (Davis, 2006). To clarify, Koch (1982) emphasized the existence of ZPE fluctuation broadband white noise which is found in the semiconductor junction and more prominently in the shunt resistor. However, as Eq. (1) and Eq. (2) demonstrate, the resistance R is found in the denominator and so it is unlikely that high resistance is an advantage when attempting to transducer ZPE fluctuation noise in a circuit.

As we look at the dominant contribution to electronic noise, thermal voltage fluctuations are proportional to the resistance as seen in Eq. (3). Therefore, high resistance may be recommended for rectifying thermal fluctuations.

$$V_N = 4kTRF_{BW} \tag{3}$$

Voltage noise V_N from thermal fluctuations has the form of Eq. (3) and depends upon the Boltzmann constant *k* (1.38 x 10-23), absolute temperature *T* (Kelvin), the resistance *R* of the circuit, and the frequency bandwidth F_{BW} in Hertz. It may be emphasized that ZPE fluctuation circuits working at room temperature will automatically include thermal fluctuations and perhaps should be designed to maximize both contributions. Furthermore, optimizing a resistance circuit for thermal fluctuation rectification should also include zero bias diodes for high efficiency, which will also therefore, absorb heat from the environment. The recent discovery of a Brownian refrigerator also called "the world's smallest fridge" accentuates the availability of additional spinoffs from the development of a molecular diode rectifier array for noise transduction (Van den Broeck, 2006).

3. Argument for the Use of Certain Devices for ZPE Conversion

Regarding the existence of substantive experiments showing extraction of negative energy from the quantum vacuum, a summary of the most robust examples has been published (Valone, 2007). It also includes the discovery that there exists a class of diodes (rectifiers) that operate at "zero-bias" (no voltage applied to make them work) and well into microwave frequency bands, that are suitable for generating trickle currents from the zero point energy quantum vacuum because of natural nonthermal electrical ZPE fluctuations (1/*f* or Johnson noise), in addition to a serendipitous "piggy back" inclusion of electrical noise from thermal fluctuations, as well as any and all ambient electromagnetic field (EMF) radiation that happens to impinge on the diode generators. In effect, such zero bias diode arrays are predicted to act as broadband *energy harvesters* for a vast range of wasted electromagnetic interference which, especially in urban environments, can have a reasonably valuable power amplitude from radio, cellular, television, radar, satellite, short-wave, ELF, VLF, Schumann and other EMF transmissions.

Furthermore, there are patents and published studies that review tunneling semiconductor devices at zero voltage (zero bias). Several microwave diodes also exhibit this feature. However, it is important to appreciate that looking in the noise level (1/*f* noise or Johnson noise) is where ZPE manifests (Valone, 2004). Nature has also been helpful since broadband white, 1/*f* and thermal noise in the diode is also generated at the junction itself and therefore, requires no minimum signal to initiate the conduction in one direction.

It should also be noted that the work of Yasutomi (2004) with peptide molecular photodiodes just 1 nm across is advantageous for possible 2-D parallel arrays of diodes. Many of these molecular diode rectifiers are also self-assembling, which facilitates fabrication techniques (Dhirani, 1997). However, most organic molecular diodes exhibit high resistance and fairly large junction bias voltage. Even single-electron transistors (SET), which can be viewed as back-to-back diodes (*p-n-p* or *n-p-n*) display a spectral noise density similar to a black body radiation curve (Fig. 3). SET's sometimes have "the highest signal to noise ratio" near zero bias. Furthermore, these "ultrasensitive" devices that convert radio frequencies have been invented that operate at outer space temperatures (3 degrees above zero point: 3°K). These devices are tiny nanotech devices so it is possible that lots of them could be assembled in parallel (such as an array) to produce ZPE electricity with significant power density (Brenning et al., 2006).

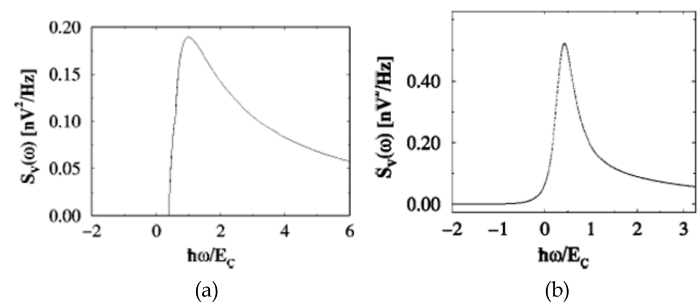
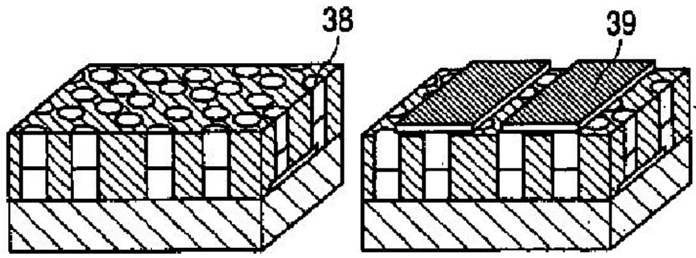


Fig. 3. Spectral density of voltage noise in a single-electron transistor (a) in the off-state as compared to the (b) normal run mode at 1.5 nA and E_c = 2.5 K (Kach, 2003)

Beginning with the patent literature, the following US patents are perhaps the most significant for indicating ZPE research in this area. "Diode Array" by Charles Brown #3,890,161 and "Type II Heterostructure Device" by Capasso #4,704,622 actually acknowledge ZPE for their functional nature (Note: www.google.com/patents is a good source of printable, pdf-format patents). Capasso, an IBM engineer, indicates that his tunneling device only works if ZPE is present, analogous to what Planck discovered a century ago with his well-known second radiation law that matched the black body curve for the first time. Brown suggests that metal-metal diodes probably will be a popular brand for ZPE usage with millipore sheet assembly. While Brown patented his invention back in 1975, his idea has been revived and rejuvenated by Kuriyama's "Method for Manufacturing a Semiconductor Device" US Patent #7,183,127 which cites Brown's patent and others with similar cylindrically shaped pores for p-n junction design. It is encouraging to note that Kuriyama's preferred range of diameter for each cylindrical diode is not smaller than 1 nanometer (nm) and not larger than 10 nm. In addition, several references are cited for nano-hole and nanowire construction techniques, especially with regard to *p-n* or *p-i-n* junctions. A typical example of aluminum-silicon nanostructures has achieved an average diameter of 3 nm per cylinder with a 7 nm spacing between them, with a length of 200 nm per cylinder. Kuriyama also notes that these dimensions also hold if germanium is substituted for silicon. He also includes the important option of an electrode plate on the top and bottom of the diode array, or an electro-conductive substrate for the bottom common conductor. The smallest diameter that Kuriyama cites as a practical example has a 1 nm cylinder width with a 3 nm spacing between the diodes in 1000 nm square semiconductor dies, as seen in Fig. 4. This creates a diode density of approximately 10^{12} diodes per cm^2 which is on the order of self-assembled quantum dot GaAs Schottky diodes grown by atomic layer molecular beam epitaxy (ALMBE) with InAs dots which have a diode density of 10^{11} per cm^2 (Hastas, 2003).



(a) (b)

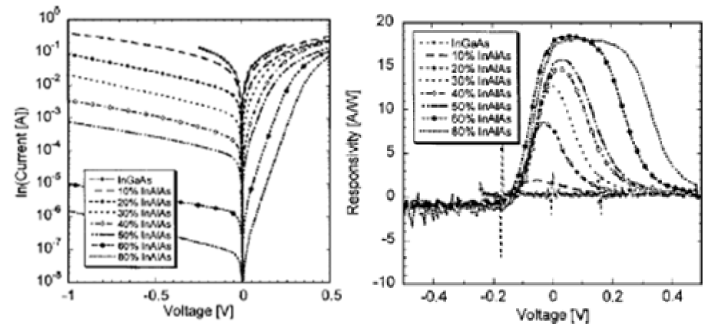
Fig. 4. Updated version of a Brown's p-n junction (a) diode array (38) and (b) with parallel conductors (39) added (Kuriyama, A., Miyata, H., Otto, A., Ogawa, M., Okura, H., Fukutani, K., and Den, T., "Method for Manufacturing a Semiconductor Device", U.S. Patent 7,183,127, Feb. 27, 2007, Fig. 4D and 4E).

To summarize this section, the diodes reviewed provide the ability for greater than uncertainty generation of energy from ZPE and can be enhanced with resistance in the circuit for thermal noise rectification as well (Davis, 2006). Davis cites the multiple papers that Koch published decades ago. Davis presented this interest at the 2006 STAIF conference and has approached Lockheed Martin to fund a replication of Koch's work. Dr. Christian Beck, who also cites Koch's paper, uses the Koch experiment to argue that dark energy is measurable in the laboratory (Beck, 2005). The next section contains specific detail that further helps to explain zero bias diodes (Valone, 2007).

4. Examples of Zero Bias Diodes Useful for Energy Generation

An invention developed in 2005 by the University of California Santa Barbara is the "semimetal-semiconductor rectifier" for similar applications, to rival the metal-semiconductor (Schottky) diodes that are more commonly known for microwave detection. Fig. 5 shows the zero-bias rectifier that is capable of high "RF-to-DC current responsivity" 20 A/W which operates at room temperature with a noise equivalent power (NEP) of 8.9 x 10-13 W/Hz½. Most importantly, the inventors claim that the new diodes are about 20 dB more sensitive than the best available zero-bias diodes from Hewlett-Packard (Young et al., 2005).

Solid-state diodes which exhibit the ability to rectify EMF energy include the class of "backward diodes" which operate with zero bias (no external power supply input). This includes US patent #6,635,907 "Type II Interband Heterostructure Backward Diodes" and also US patent 6,870,417 "Circuit for Loss-Less Diode Equivalent". These devices have been used in microwave detection for decades but have apparently never been tested for nonthermal zero point energy fluctuation conversion. There is every reason to presume they include such ZPE radiation conversion in their everyday operation but it is unnoticed with other EMF energy being so much larger in amplitude. US Patent #6,635,907 from HRL Laboratories describes a diode with a very desirable, "highly nonlinear portion of the *I-V* curve near zero bias."



(a) (b)

Fig. 5. Example of a modified Schottky diode (semimetal-semiconductor) InGaAs rectifier for sensitive room-temperature microwave detection that operates well at zero bias voltage, where (a) shows increasing current levels in amperes with lower InAlAs percentage and (b) shows increased responsivity in A/W at zero bias voltage and higher InAlAs levels (Young, 2005).

These diodes produce a significant current of electrons when microwaves in the gigahertz range are present. Another example (Fig. 6) is Morizuka's Patent #5,930,133 from Toshiba entitled, "Rectifying device for achieving a high power efficiency." They use a tunnel diode in the backward mode so that "the turn-on voltage is zero." Could there be a better device for small voltage ZPE fluctuations that don't like to jump big barriers?

In 1994, Smoliner reported, for the first time, resonant tunneling while applying no voltage at all to the one-dimensional quantum wells that his team had created. They used "anharmonic oscillation" to substitute for zero point energy, which they ignored "for simplicity" though it was powering the tunneling of their electrons in each well, where the electrons prefer a zero voltage bias for the best results (Smoliner, 1994). In Fig. 7, Smoliner reports wave function calculations for quantum dot tunneling diodes that show a maximum at zero bias voltage (Smoliner, 1996). Such work with quantum dots also cite the "zero-bias voltage anomaly" which displays a Kondo resonance and coherent coupling that enhances transport at zero bias and low temperatures (Schmid, 1997).

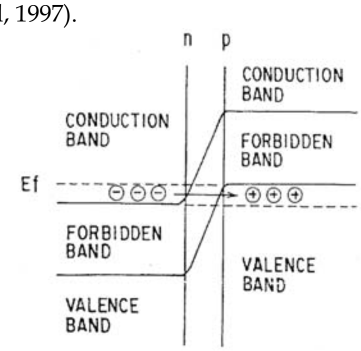


Fig. 6. Tunneling current in a reverse-bias, backward tunnel diode used as a rectifying device at zero bias (Morizuka, K., "Rectifying device for achieving high power efficiency," U.S. Patent 5,930,122, July 27, 1999, Fig. 5)

A completely passive, unamplified zero bias diode converter/detector for millimeter (GHz) waves was developed by HRL Labs in 2006 under a DARPA contract, utilizing a Sb-based "backward tunnel diode" (BTD). It is reported to be a "true zero-bias diode" that does not have significant $1/f$ noise when it is unamplified. It was developed for a "field radiometer" to "collect thermally radiated power" (in other words, 'night vision'). The diode array mounting allows a feed from horn antenna, which functions as a passive concentrating amplifier. The important clue is the "noise equivalent power" of 1.1 pW per root hertz (picowatts or a trillionth of a watt) and the "noise equivalent temperature difference" of 10K, which indicate sensitivity to Johnson noise which includes ZPE. Perhaps HRL Labs has one of the recommended devices for passive thermal and non-thermal electric energy generation (Lynch, et al., 2006).

Dr. Peter Hagelstein from Eneco, Inc. was thinking along the same lines when in 2002 he patented his "Thermal Diode for Energy Conversion" (US Patent #6,396,191) which uses a thermopile bank of thermionic diodes. These are slightly different, more like thermocouples, than the diodes that are advocated in this article. However, Hagelstein's diodes are so efficient that he predicts that, with only a 10°C temperature difference, a water pool of six meters on a side could supply the electricity for a house. He also suggests their use as "efficiency boosters" for augmenting the performance of electric or hybrid cars.

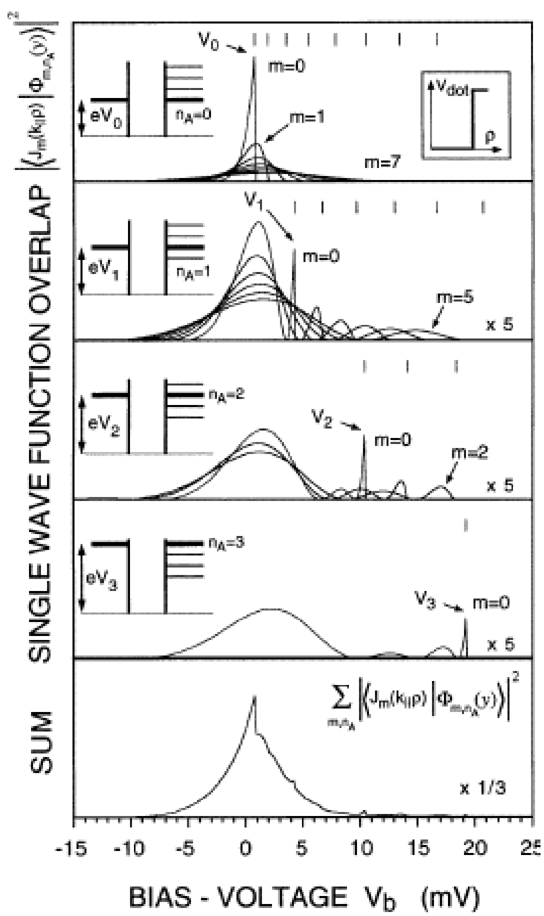


Fig. 7. Calculated wave function overlap between the 2D state and the lowest three 0D states for a quantum dot with a rectangular potential of finite height (for example, an ultra-small, pillar-shaped double-barrier resonant tunneling diode), including the sum over all 0D subbands showing a maximum at zero bias voltage (Smoliner, 1996).

Other devices which also will provide the fuelless electrical energy cars, planes and homes need simply use zinc oxide or titanium oxide films that can convert ambient heat into electricity, as used in photovoltaic panels. A few reports indicate that these work reliably for years. Such solid-state diode converters will also grab the nonthermal ZPE in the process and therefore can work in outer space, even without solar exposure.

5. Theoretical Energy Density Considerations

Since the ZPE spectral density depends upon the third power of the frequency, which is inversely proportional to the wavelength, an interesting exercise is to see how much energy is available from the quantum vacuum or the DEAC is to calculate the ZPE spectral density for various frequency ranges. This can also be regarded, using $c = \lambda f$, to correspond to certain minimum volumes based on an assumption of a resonant cavity, such as with the physics approach to scattering problems or electromagnetic radiation. Both models apply to treatments of virtual particle radiation. A more in depth treatment of this topic is found in my book on the subject (Valone, 2004). Integrating over the frequency range of interest produces a higher, fourth power dependence of the ZPE spectral density on frequency *f*, where the angular frequency $\omega = 2\pi f$ (Milonni, 1994).

$$\int_{\omega_1}^{\omega_2} \rho(\omega)\, d\omega = \frac{\hbar}{8\pi^2 c^3}\left(\omega_2^4 - \omega_1^4\right) \quad \text{eV/m}^3 \qquad (4)$$

Initially we assume that a resonant frequency of 10^{17} Hz will correspond to a wavelength on the order of the junction size. Roughly estimating a typical nano-sized diode junction to be on the order of a cubic nanometer (1 nm^3) for the Kuriyama nano-size cylinder-shaped diode, the spectral energy density of the zero point field in that volume would possibly suggest what the maximum energy is theoretically available in that small volume from the quantum vacuum. A preliminary estimate of the photon energy at the frequency of interest using the Einstein Eq. $E = hf$ yields a keV range of energy or by conversion, radiation energy in the femtojoule (10^{-15} J) range. Therefore, it is expected that the ZPE spectral density will also be of the same order of magnitude. Substituting a resonant frequency of 10^{17} Hz into Eq. (4) yields about 390 eV/nm^3 which when converted tells us that an energy density of about a terajoule per cubic meter (10^{12} J/m^3) is available from the quantum vacuum up to that frequency but only about a femtojoule of energy in a cubic nanometer (10^{-15} J/nm^3) which is about the same as the simple photon energy calculation.

However, in order to justify a power level of a picowatt per diode, it would be advantageous to show that at least a picojoule per diode is available theoretically from the zero point field, since watts equal joules per second. Therefore, two considerations usually are introduced at this point. One is that the maximum accessible frequency must be higher than 10^{17} Hz and secondly, perhaps the resonant cavity or scattering volume size needs to be correspondingly reduced. The second consideration, to quantum vacuum engineers and physicists, is easy to justify since the Zitterbewegung or quantum fluctuations affects individual atoms and electrons directly, more than atomic clusters of crystal lattices in a semiconductor junction. The volume of an atom (picosphere = 10^{-12} m^3 = 1 pm^3) or electron (femtosphere = 10^{-15} m^3 = 1 fm^3) would then be more appropriate for resonant frequency considerations of the influence of ZPE-induced noise. (The classical electron radius e^2/mc^2 is about 2.8 fm.) Respectively, Eq. (4) yields about 390 keV/pm^3 and about 390 MeV/fm^3 due to the X-ray (10^{20} Hz) and gamma ray (10^{23} Hz) ranges of the corresponding resonant frequencies. *The latter spectral energy density is therefore at least 62 pJ per electron.* Thus exceeding the desired order of one picojoule, it would then be multiplied by the number of electrons expected to be present in the *1) the Hastas self-assembled GaAs Schottky diodes* or *2) the Kuriyama high density nano-size cylinder-shaped diodes*, since the non-thermal random activity of electron noise is the essence of Johnson noise and the focus of attention for a ZPE converter.

6. Power Estimates for Diode Array Energy Converter

Energy generation solutions for deep space travel where solar energy is minimal and the temperature hovers near absolute zero may not emerge for several years besides nuclear power which has a limited life span. However, power estimates for the diode array energy converter (DAEC) at room temperature on earth will normally be swamped by thermal noise. Therefore, designing the ideal ZPE diode power capability specifications to encompass both environments seems to be an expedient answer, with a bandwidth range of frequencies to include at least 1 to 10^{12} Hz as suggested from Fig. 2 and Fig. 8.

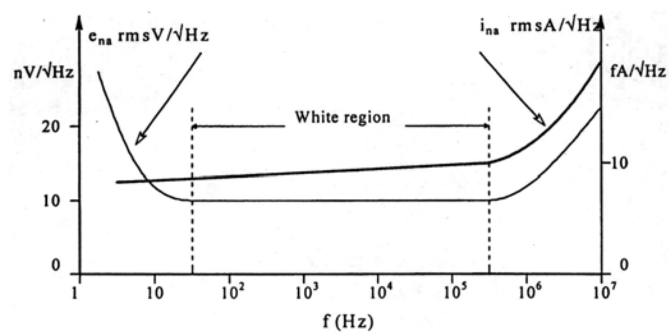


Fig. 8. Plots of typical input noise root power spectrums for an FET input amplifier (Northrop, 1997).

To initiate power estimates for the DEAC, it is helpful to compare with the textbook order of magnitude estimates for broadband noise in solid state circuit components, whose range from the previous discussion also apply to the DEAC. Fig. 8 displays the $1/f$ noise region for an FET input amp in the 1 to 10 Hz range, with white noise extending from 10 to 10^5 Hz, above which the estimated noise becomes proportional to f (Northrop, 1997). The important observation for this section is that thermal and nonthermal sources produce voltage fluctuation noise in the nanovolt (nV) range per root hertz and current fluctuation noise in the femtoampere (fA) range per root hertz. Therefore, a rough power estimate over our ideal bandwidth would be to multiply them both for a power calculation with $P = IV$, using the lowest common amplitude of $\left(10 \text{ nV}/\text{Hz}^{1/2}\right)\left(10 \text{ fA}/\text{Hz}^{1/2}\right)\left(10^{12} \text{ Hz}\right) =$ 0.1 nW per device. This estimate is also of the same order of magnitude as the Pinto Casimir electrical generator mentioned earlier. Pinto among others like the Brown patent, make reasonable calculations of the energy density of arrays of vacuum engines similar to ZPE diodes, which conservatively reach estimates of hundreds of kilowatts/cubic meter (kW/m^3) according to Pinto (1999). Converting 0.1 nW to the equivalent 100 pW = 100 x 10^{-12} Watt and conservatively taking into account unseen conversion losses, frequency limits, etc., it can be further trimmed by estimating this calculation as a range of 1 pW at the lowest to 10 pW as a maximum power per diode, thus factoring in a 1/100 loss factor as a buffer against overestimates.

The most interesting arrangement of diodes and resistors may be a convenient 10 cm^3 (10 cc) box but could be larger if the diode packing density requires it. The proposed DEAC box will perhaps involve a choice of *1) the Hastas self-assembled GaAs Schottky diodes* or *2) the Kuriyama high density nano-size cylinder-shaped diodes*, both estimated to be in the range of 10^{11} per cm^2 diode density. Using a conservative packing density of 2 mm per layer (with 1.1 mm substrates), we can pack 5 diode array layers in 1 cc and therefore, 5000 diode layers in 10 cc. This raises the diode density to 5 x 10^{14} diodes (*500 trillion diodes*) in a 10 cc box. This is a favorable quantity for the estimated picowatt (1 to 10 pW) power level per diode, which yields a minimum of a 500 Watt DC generator from thermal and non-thermal noise combined, for the lowest estimate of 1 pW per diode. It is worthwhile noting that an array of a trillion molecular switches has been proposed using less than 100 zJ (100 x 10^{-21} joules) per switch based on direct experimental measurement of a single molecule (Loppacher, 2003). Loppacher et al. also note that it requires "less than a femtojoule of energy" to switch a solid state transistor, which may be useful in an advanced design of a switching DEAC for AC output.

Surprisingly, the DEAC may reach into the optimal region of 5 kW if 10 pW per diode is possible, though this may only be possible with the additional input of thermal and ambient EMF *energy harvesting*. Note that the increase above 10 nV and 10 fA in voltage and current noise levels clearly produced at the low frequencies and most importantly, at the higher frequencies, in Fig. 8, as well as any ambient electromagnetic smog, have been ignored for convenience. Of course, this estimate translates to hundreds of kilowatts/cubic meter (kW/m^3) if such arrays were manufactured in larger sizes of a cubic meter.

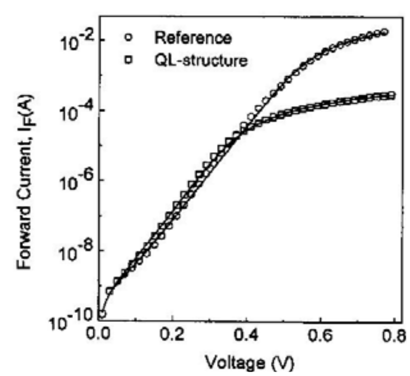


Fig. 9. Experimental forward current-voltage characteristic of a typical Au/n-GaAs Schottky diode for a reference GaAs sample

and the GaAs with InAs QL structure sample showing 10-10A current conduction at zero bias voltage (Hastas, 2003).

Looked at another way, Fig. 9 shows that Hastas measured a forward current of 10^{-10} A or 100 picoamperes experimentally for a typical self-assembled ALMBE GaAs Schottky diode at zero bias voltage. With 500 trillion diodes in the 10 cc box example, this equates to 50 kA of current at 10 millivolts (10 mV) generated for a 500 W estimated output. In such a case, assembling a certain number of the diodes *in series* to create a convenient voltage for power conversion would be an obvious method for electrical energy utilization and ultracapacitor storage.

A third perspective is offered with the Diode Array US patent #3,890,161 of Charles Brown mentioned previously. Brown suggested arrays of diode cylinders 25 nm in diameter for thermal and non-thermal electric noise conversion. With an estimated frequency bandwidth of 10^{10} Hz and a 50% loss factor, his power estimate is 10^{-5} Watts for a million diodes or equivalently, 5000 W for 500 trillion diodes, which is in the middle of the range estimated by two other approaches. It is also noted that the 25 nm diameter of the Brown diode can be reduced to a limit of 1 nm that is achievable today, as suggested above in Kuriyama's manufacturing patent, with Hastas' Schottky diodes or other molecular diodes.

It is also worth noting that the perspective offered above is consonant with the present industrial effort to accomplish energy harvesting and electromagnetic reception on a small scale today. A tunneling nanotube radio, using a single tunable nanotube for example, has been proposed and simulated (Dragoman, 2008). Therefore, it is important to emphasize that on the ground, especially near urban environments, a large amount of broadband EMF noise is available for energy harvesting with DEACs, that will conceivably overwhelm the small amount of energy available from thermal and non-thermal noise sources by several orders of magnitude. As such, the proposed DEAC operating as a broadband radiation scavenger would be more suitably labeled an "electromagnetic field energy harvesting urban generator of electricity" (EMFEHUGE) for commercial marketing purposes. An example of such a concept is the integrated environmental energy extractor that has been developed by General Electric, with supporting electronics such as diodes, to rectify and extract energy from movement of a capacitor or of a dielectric material (Ghezzo, Mario et al., "Integrated Environmental Energy Extractor", U.S. Patent 6,127,812, Oct. 3, 2000). A microscopic antenna system for focusing ZPE and amplifying its resonant frequencies for electricity generation has been patented by the U.S. Air Force (Mead, Franklin B. and Nachamkin, Jack, "System for Converting Electromagnetic Radiation Energy to Electrical Energy", U.S. Patent 5,590,031, Dec. 31, 1996). The Air Force approach to including a hemisphere collector or preferably a parabolic collector may also be advantageous with the proposed DEAC as well as other electromagnetic wave amplification techniques. It is also noted that "sub-picowatt signal level" detection is has already been accomplished with only a 120-element microbolometer diode array, designed for *low noise* performance by NIST, where random noise is systematically filtered out (Luukanen, 2004).

7. Practical Considerations

Diode arrays of self-assembled molecular rectifiers or nanosized cylindrical diodes have been shown to reasonably provide for rectification of electron fluctuations from thermal and nonthermal ZPE and negative energy sources to create an alternative energy DC electrical generator. Any additional noise perhaps contributed by a series carbon resistor will also increase these estimates for the thermal noise though at the same time is expected to reduce the power output (Northrop, 1997). Since these calculations have been done at room temperature, it should be noted that if solar heat or any other heat source is added, such estimates will also increase proportionally, such as with the Schottky photodiodes mentioned earlier. However, every DEAC is designed to rectify thermal noise and therefore cause refrigeration instead of the typical semiconductor heat generation, which serendipitously helps in a time of increasing global warming. In the expected near future scenario of climate change, thousands of people in temperate zones are at risk during the summer for heat stroke (over 2000 people died in France during a heat wave that lasted two weeks). Therefore, having a solid-state, square meter sealed cube that generates electricity and cools the building will serve both vital purposes. Ideally, it will also make rural areas and third world countries habitable while lessening developed countries' dependence on centralized grid power.

A practical consideration is the fact that the thermal conversion to electricity causing refrigeration is expected to occur at the junction of each diode, while possible heat generation could be expected from the rest of the circuitry and wiring leading the electrical current out of the DEAC. Therefore, typical silicon carbide heat conductors, which are also electrical insulators, can be used advantageously in this situation to manage thermal dissipation and heat exchange.

Though today's trend toward energy harvesting is cited as supportive of this article's thesis, it should be noted that the proposed DEAC is novel and untested, apart from the diodes and devices referenced. With the entire electronics industry focused solely on *noise reduction*, it is no surprise that no one has built a practical DEAC prototype so far. Proving that broadband electrical noise exists is easy. Designing the best zero bias diode array for the job of harvesting it is another engineering effort worthy of a future article. Certainly, a new research direction is warranted in order to reverse the present noise reduction trend in zero bias diodes in favor of noise amplification, noise equivalent power increase, and high noise to signal ratios suitable for energy harvesting rectifiers. Such a research effort is found in the literature with the investigation of the necessary conditions for enhancement of shot noise and that it results in charge accumulation rather than system instability (Song, 2003).

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