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Noninteger coding of biological origin for information storage and processing

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Abstract
A pair of two polynucleotide sequences wound around the carbon nanotube serves the basis for noninteger (the base of natural logarithm, *e*) coding. The device description is proposed. New concepts of *e*-bit and *e*-byte are introduced. The device is operating with spin phases that are read out with a laser beam. The basis of the device is the Spin Hall Effect that stems from large spin-orbit coupling and hyperfine coupling. Together these couplings split the Fermi level into a number of sublevels which finally produce a conductive zone. Decoherence is excluded thanks to selection rules. The device may operate at 100 GHz or higher that is a revolutionary breakthrough in constructing super fast computers of new generations.

1. Introduction

Over evolution the genetics has developed the unique code[1,2] that is still shrouded in mystery until now. According to many views,[2] this code is perfect and might serve the basis for constructing a new generation of computers.[3]

Any computer initially suggests its numeral basis or a minimal digit system it operates with.[4] Today we know two integer digital systems that generate many others (a decimal e.g.) – a two-digit system (a binary code) and a thee-digit system (a ternary code).

A two-digit system dominates now on the computer market. Every notebook or smartphone operates with two digits – “1” and “0”. Widespread use of the two-digit system is obvious as the current electronic materials[5] employ the simplest “1” and “0” signals to construct bytes.

However, there is a three-digit computer (ternary computers) that operates with trits (“0”, “1” and “2” or “-1”, “0”, “1”) and trytes (analogue to bytes in the two-digital system). Electronically based ternary series of computers under the name *Setun* (after the name of the river that flows into the Moscow river nearby the place where the Moscow University is located) was originally manufactured in the laboratory of N. Brusnetsov in Moscow State University (1958).[6-8] In the U.S. the ternary computer *Ternac* was developed in 1973. The ternary computer has an advantage over the binary computer in a number of factors (this is not surprising because the binary constructed manifold is a subspace of the ternary manifold[8]), among which are speedier computer performance, higher image resolution, extensive logic, and code information density/storage (*d*) that obeys a simple relation (1)

$$d = \ln\varepsilon/\varepsilon \quad (1)$$

Here ε is a base of a numeral system. From (1), *d* reaches its maximum at ε = *e* (the base of natural logarithm).

The binary and ternary information coding are integer. We know, however, that the most efficient system pertaining to signal acquisition, storage, and representation assumes the number *e* which is noninteger. The noninteger digit system operating with the number *e* is only starts paving its way. This way, however, is highly promising that makes computations highly productive.

Like each computer, the noninteger computer operates with its specific bytes (in the binary system this is byte, in the ternary computer this is tryte, in the noninteger computer this is e-byte, or Berry's byte).

$$e\text{-bit is } e = 2.71828$$

$$e\text{-byte (Berry's byte) is } e^{\pi} = 23.10$$

Where does π come from? This is Berry's phase arising from a signal circling around a closed curved loop.[9] Mathematically, the curve is understood as a projection on the Poincare sphere.

The noninteger algebra is not properly developed; mostly, it is classified.[10] However, the noninteger mathematics exists and stands in the wings.[10]

2. Aim of the Paper

The paper aims to develop a new computer device that operates on a noninteger base. The base is the number *e*. The device assumes higher speed, compact information storage, and better image clarity than commonly used computers. The device is operating on the Spin Hall Effect that is applicable to a paired trinucleotide sequence wound around the carbon nanotube.

The paper is a revolutionary breakthrough into creation of noninteger chips of biological origin, possessing reproduction and obtaining stable signals. The device is based on reading out spin phases arising upon the electron motion along a curved trinucleotide (*e*-bit) sequences. The phase is detected through a rotating spin laser beam.

The phase energy accumulation results from large spin-orbit (SO) and hyperfine coupling (HFC).[11] The latter occurs thanks to repeatedly embedded spin active ^{31}P (phosphorus) atoms in the polynucleotide backbones. The phase is non-dissipative, as is the case in quantum computers, and changes its value upon the transfer from one ^{31}P to another. The total turn over the closed loop on the Riemann manifold (this is just a paired polynucleotide chain) returns the phase π (Berry's phase).

The device is not a quantum computer, but exploits the elements of quantum computing, including electron and nuclear spin.

Below we give brief information about the effects used in the device construction.

3. The Background of the Spin-Orbit and Hyperfine Coupling

a) *Spin-orbit coupling (SOC).* Unlike the Zeeman effect, which suggests the external magnetic field, the SOC is an external property of any atom, molecule, nanoscale cluster, or semiconductor, including quantum wires and dots.[12] The SOC is a relativistic effect. It results from interaction of the electron magnetic moments with the magnetic field generated by their own orbital motion. The SOC splits energies of the molecular cluster that initially possesses equal energies (a Femi energy level, ε_F, or the highest occupied energy level). The most important thing of the SOC is that it could change the spin phase. Depending on the structure, the SOC energy varies in the region 0.02 – 20 cm^{-1} that is detectable by modern optical techniques.

b) *Hyperfine coupling (HFC).* The HFC is the interaction of a nuclear spin with the electron spin.[13] The effect is much weaker than the SOC – two-five times in energy. Not every atom possesses the nuclear spin. Nature, however, offers this atom, ^{31}P (phosphorus), that shows a 100% abundance of nuclear spin. ^{31}P atoms are the integrable part of any polynucleotide backbone.[1,2]

The Spin Hall Effect (SHE) is a transport phenomenon predicted by M. Dyakonov and V. Perel in 1971.[12,14] It consists of spin accumulation on the lateral surfaces of an electric-carrying sample; the sign of spin directions is normally opposite on the opposite boundaries. In a cylindrical wire, the current-induced surface spins wind around the wire. When the opposite current occurs, spins gain reversal. The SHE needs no external magnetic field. The spin accumulation induces circular polarization of the emitted light as well as the Faraday (or Kerr) polarization rotation of the transmitted (or reflected) light, which allows researchers to monitor the SHE by optical means. Fig.1 shows the SHE for two arbitrary electrons treated as classical rotating balls. It is necessary to emphasize that the electrical current might be replaced by any laser impact or heat.

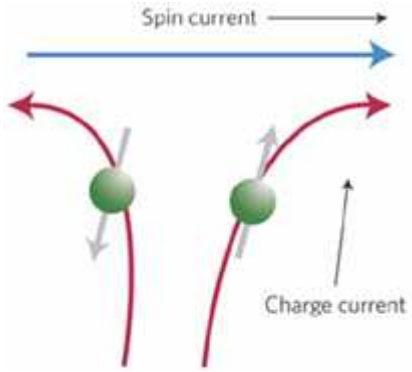

Fig. 1*. The SHE on a semiconductor surface in the vicinity of the Fermi energy level. Green balls are hypothetical electrons.*

The Berry phase is the geometric phase that arises on a

curved space (the Poincare sphere, e.g.).[9] In electrodynamics, the Berry phase φ_B is a 1-form of the vector potential **A**

$$A_i = i\left\langle \psi \left| \frac{\partial}{\partial \lambda_i} \right| \psi \right\rangle$$

$$\varphi_B = \oint_C A = \int_{S_C} F, \quad F = dA \qquad (2)$$

λ_i is a number of parameters (normally these are coordinate displacements from point to point on the manifold); C is a closed loop, and F is a differential of **A**; normally $\varphi_B = \pi(1-\cos\theta_i/2)$.[9] The full turn over the loop returns $\varphi_B = \pi$ that corresponds to a spin reversal.

The Berry phase allows us to create a number of states differing in the angle of polarization. This comes from the ability of the vector potential undergoes a gauge transformation when **A** is identical to $\boldsymbol{A}+\nabla\gamma$.

$$\mathbf{A} \rightarrow \mathbf{A} + \nabla\gamma \qquad (3)$$

$\nabla\gamma$ is a gauge; in traditional electrodynamics γ is the electrostatic potential that differs from point to point.

In agreement with electrodynamics, the vector **A** is associated with the appearance of magnetic field $\mathbf{B} = \nabla\times\mathbf{A}$. This B affects the strength of SOC and HFC.

4. The Device Description

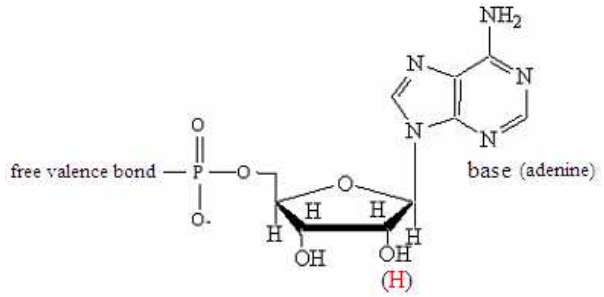

Fig. 2. *Adenosine monophosphate (ribonucleotide; RNA molecules). Deoxyribonucleotide (DNA) differs from the shown structure by replacing the right OH group by the H atom (shown in red). The sequence appears through adding nucleotides (the nature offers only four nucleotides differing by their bases: adenine, guanine, thymine (uracil in RNA), and cytosine) to a free valence bond (left) of the P atom. The sequence is normally twisted. The P atom creates the hyperfine interaction, see the text.*

The device is composed of two hydrogen (H-) bond paired nucleotide sequences – codons and anticodons (each of three nucleotides, Fig.2-4), totally 23 (this is *e*-byte), – wound around a carbon nanotube of 2nm thickness (this is close to that in a living cell).[3] The carbon nanotube (CN) is an excellent support for nucleotide sequences thanks to stacking interactions between the nucleotide bases and carbon rings (CNs have very small energies, E_{SOC} and E_{HFC}, compared to those in polynucleotides 5 cm^{-1} (E_{SOC}) and 0.05 cm^{-1} (E_{HFC})). Fig.5 shows a polynucleotide chain wound around the CN (physically, this is a topological insulator;[15] 2,2 nm long). H-bonding arises automatically between two correctly aligned (base-to-base correspondence) polynucleotide chains. Polynucleotide chains of desired sequence are now routinely synthesized in chemical laboratories through the world. CN supports and polynucleotide winding around them is now created in many chemical laboratories, like ours, using standard protocols and tunneling microscope technique.

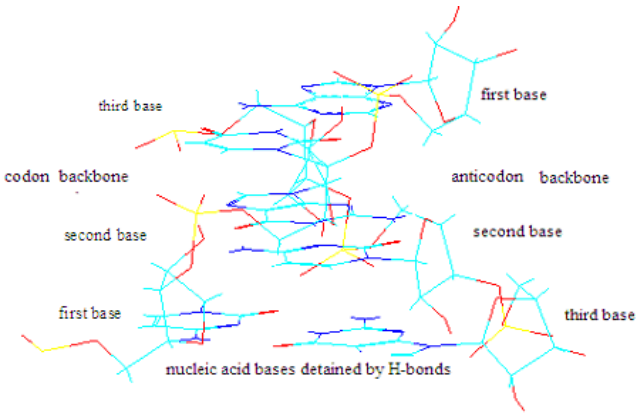

Fig. 3. *A realistic codon{rC-rG-rA)-anticodon(rG-rC-rU) sequence comprising three nucleotides from both sides (traditionally the numbering of bases on both backbones is opposite). Hydrogen bonds, H-bonds, (see the text) detain both sequences together; they are not displayed and could be found in each manual on biology or on the Internet. Yellow are ^{31}P (100% spin abundance) atoms; blue are carbon atoms, dark blue are nitrogen atoms; Hydrogen bonds between bases are not displayed. A sequence of three bases (they are paired with those of the codon) form the noninteger computer base.*

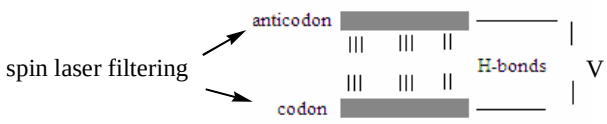

Fig. 4. *A simplified picture of that shown in Fig.2. Gray thick lines indicate the backbones of the codon and anticodon (the twist is not shown). Thin vertical lines stand for hydrogen bonds (H-bonds) – three lines for rC-rG and rG-rC and two lines for rA-rU (the Watson-Crick pairing rules). The V is the electrostatic potential that keeps the layers together.*

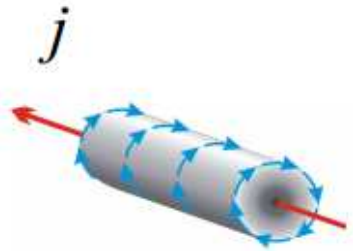

Fig. 5. *A polynucleotide chain winded around the carbon nanotube. **j** means the direction of the laser beam or charge current.*

A distinctive feature of the device is the energy equality of two highly occupied electrons, which fill the Femi level (see above). The equality is reached by varying a distance (tunneling microscope) between the codon and anticodon triplets, Fig.4. Compared with the classical Watson-Crick pairs, our distances are longer by 0.17 Å (DFT:B3LYP, 6-31G** basis set, quantum chemistry computations[16]).

Initially, the electron spins on the E_c and E_{ac} (lower

indexes indicate the codon and anticodon, respectively) levels have the opposite directions. Upon laser excitation two electrons become distributed over three states – two excited states, indicated with red arrows, and the conductivity level, Fig.6; the amount of each nucleotide contribution is of no significance because three nucleotides are required together. The SOC splits the energy of each electron (left or right, Fig.6) into the oppositely directed combination (not shown).

The HFC, in turn, splits the energy of the SOC sublevels. The HFC split could leave a spin unchanged or reverse it. Everything depends on the strength of the interaction between the active ^{31}P nuclei and the electron. If the strength is not enough, the spin remains unchanged, if yes – the spin alters its orientation. In our case ($E^1_{HFC} > E^3_{HFC}$), we have the energy diagram shown in Fig.6 where the excited state is singlet (two dashed red arrows).[13] The excited state on the right is practically equal to the energy of the conductivity zone (the red dashed line).

Any computer operates with bytes. To make *e*-byte from *e*-bits it is not enough to raise the *e*-bit to π power, see introduction. We have to learn the device to read out spin phases from *e*-bits, which constitute the *e*-byte. This is carried out with a spin laser using two beams, passing through two ferromagnet nanometer filters, Fig.4(left), aligning the electrons in opposite directions (this leads to appearance of the red arrows, Fig.6). The presence of the conductivity zone allows the electron on the right to move along the *e*-byte (the paired polynucleotide chain). This electron motion changes the electron polarization (eq.(3)) when passing each *e*-bit through the HFC.

The read/out process occurs on the x-y plane (Berry's plane). This is possible thanks to a famous formulae,[10] (4)

$$e^{\pi} = \pi\, e^2 \qquad (4)$$

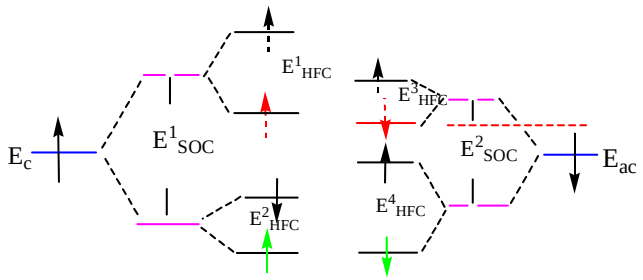

Fig. 6. *The energy diagram of the two highly occupied electrons in the vicinity of the Fermi level. The energy of the codon is equal to the energy of the anticodon: $E_c = E_{ac} = \varepsilon_F$. E_{SOC} and E_{HFC} stand for the energy of SOC and HFC. Solid arrows (long initial, shorter are those on the split sublevels) indicate the spins in low-energy states; green arrows indicate the spins in the ground state. Dashed arrows indicate spins in excited states. Red dashed line indicates the conductivity zone on the polynucleotide spiral.*

The right part of (4) is a mantissa of a spared circle. Finally, instead of the *e*-byte (an upward cylinder with unknown technical approach of how to read out spin polarizations) we deal with a simple rotation of the polarization angle along a two- nanometer circle, see above. Simplistically, this is shown in Fig.7. The circle is divided into 23 sectors corresponding to *e*-bits. The laser beam from the transmitter with the fixed orientation (Fig.6, left energy level) rotates along the circle filled out with changing orientations of each sector. This is possible because the transmitter velocity is 23 times higher than that on the *e*-byte.[10]

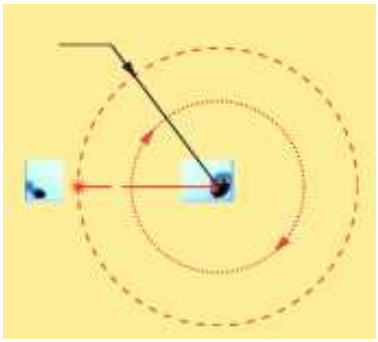

Fig. 7. *Schematic picture of the signal read-out processing. The inner circle depicts the rotating read-out beam, the outer circle depicts "frozen" phases; for details see the text.*

Signal reading out comes from comparing the phases. The phase change upon laser excitation occurs at 100 GHz and higher. This is great technical breakthrough in computer operation power.

What we have outlined before is the spin laser technique. Practically, the complex of the laser source (femtosecond laser at 265 nm) and two filters demand a very low energy and might be highly compact.

The number of *e*-bytes might be numerous. First, this is achieved through changing nucleotide positions in trinucleotide sequences and, second, through changing spin orientation angles on the filters. Both approaches are mostly identical.

The reliability of the device preventing decoherence is achieved through selection rules.

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