Transformation of Electronics Taking Local Effects into Account

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Abstract

For a rigorous calculation of the static and dynamic characteristics of a p-n junction, the use of Extended Phenomenology is necessary. Moreover, both the design and selection of the operating point of electronic elements must be carried out taking into account the Thermal Force. This will improve the performance of both traditional elements and allow the creation of fundamentally new ones.

Keywords: Phenomenology, P-n Junction, Volt-Watt Characteristic.

Thermodynamic Phenomenology

Boltzmann gave his students no more than a C in Thermodynamics, saying that "Only God knows Thermodynamics perfectly." He added, "I know Thermodynamics only at a B, so a student with better than a C cannot know it." This demonstrates the complexity of even Boltzmann's Thermodynamics, i.e., Historically, non-orthogonal, interdependent Thermodynamic Forces were chosen to describe it, rather than an Orthogonal Frame. Moreover, as will be shown below, a Linear Approximation to Thermostatics was actually chosen in the Boltzmann equation. However, Ilya Prigogine demonstrated that there is another aspect, not considered in principle by Thermostatics, which allows us to expand the Domain of Understanding and approach the "divine." Therefore, taking this into account, Thermodynamics must be both Refinement and Correction from its BASE – General Phenomenology.

Phenomenology is, in principle, a Description of an Effect, a specific one. But since Effects are varied and numerous, their Descriptions tend to be reduced to a General, in particular, a Thermodynamic Description [1]. The necessary mathematization of the Thermodynamic Description is carried out in the first approximation, i.e., at the level of linear equations, which strictly correspond to the consideration of diffusion processes [2]. But also, for more complex, nonlinear processes, correct Linear Phenomenology specifies the correct choice of the Orthogonal Reference Frame, and, thus, the correct and complete description of the initial sections [3].

Moreover, traditionally, such Thermodynamics (Boltzmann) is constructed using the Absolute THERMOSTAT – any processes in it are considered as striving towards the Absolute Thermostat [4]. But in modern Thermodynamics, numerous Particular Phenomenologies are compiled, containing both internal contradictions and contradictions in the Description of even associated Effects. Taking into account Prigogine's Production of Local Entropy, as shown in my works, made it possible to unravel Thermodynamic compilations [5-8]. This led not only to a deeper understanding of other Fundamental Theories, in particular Quantum Mechanics and the Theory of Relativity, but also to the understanding that traditional Thermodynamics (Boltzmann) contains fundamental contradictions with Reality [9,10]. Thus, it predicts the Heat Death of the Universe and prohibits the Existence of LIFE [11]. So, it is not surprising

that Cosmological Theories, and even pure Mathematics, while formally using its mathematical developments (Grisha Perelman, for example, used Ricci Flows), essentially simply ignore Thermostatics. Meanwhile, Ilya Prigogine's Thermodynamic Discovery suggests that the reference point should not be the Absolute Thermostat, but rather the Flows in Chaos, which form Observable Structures at different Scales.

Local Thermo-Electronic Effects

That a surface (phase boundary) reflects not only photons but also phonons is well known, both from the physics of phonon formation and from specialized precision experiments on lanthanum hexaaluminate and higher manganese silicide quasicrystals [12-15].

So, it's not particularly surprising that when heat flows through a crystal interface, such as an p-n junction, a discontinuity—a temperature drop—occurs at the boundary of the asymptotic curves of the temperature dependences (Figure 1).
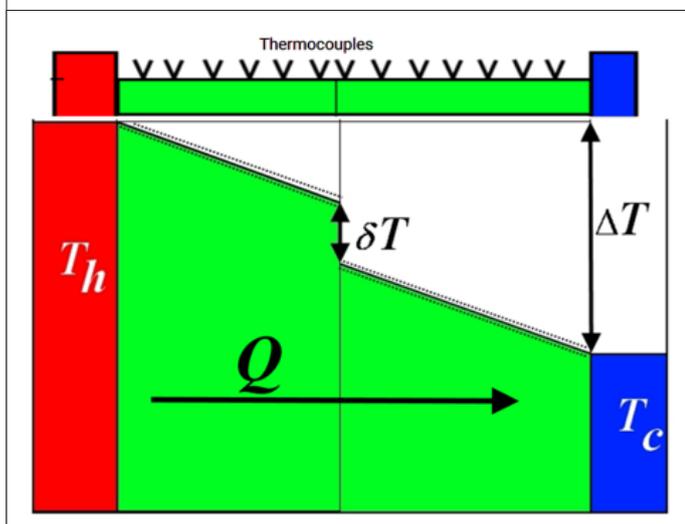

Figure 1: Discontinuity of thermocouple asymptotic curves at the crystal interface.

The temperature jumps at the crystal interface shown in Figure 1 due to phonon reflection is precisely what determines the decrease in thermal conductivity of polycrystals and the anisotropy of thermal conductivity in layered crystals.

Also, given Prigogine's Local Entropy Production at the potential barrier of the p-n junction, the occurrence of thermoelectronic effects in it is not particularly surprising [16, 17].

What is surprising is something else. The photoelectric effect has long been described and has long been actively used, whereas the thermionic effect (Figure 2a), comparable in magnitude but out of phase with it in p-n junctions, which leads not to blocking currents but to blocking voltages (Figure 2b), has been ignored. They ignored the p-n transition theory built on the basis of Thermostatics because they limited themselves to Particular Phenomenology, which does not take into account the Thermal Force [18]. Moreover, they also relied on the non-rigorous Richardson-Demscher formula obtained for Macroscopics [19].
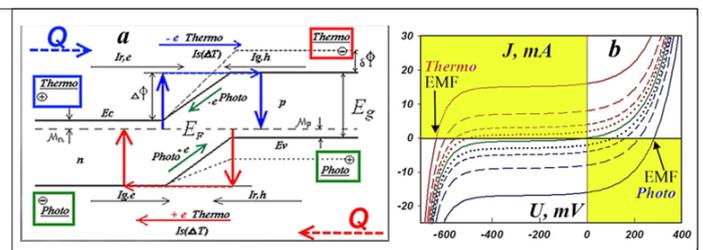

Figure 2: Formation of the Thermionic and Photoelectric Effects in an n-n Junction (a) and their antiphase Current-Voltage Characteristics (b): yellow segments represent absorption regions of the corresponding fluxes with the generation of electrical power.

Thermionic effects were also ignored in Ioffe's Theory of Thermoelectricity, based on the macroscopic diffusion theory, because they limited themselves to Particular Phenomenology, which disregarded the Concentration Force, and, using the same Richardson formula, they completely prohibited Ballistic Effects in n-n junctions [20].

However, having encountered a lack of understanding (and long-term refusals to publish my articles) of the Local (NANO) Thermo-EMFs I discovered, I became convinced that, in a period of stagnation for Fundamental Science, the discovery of something fundamentally new is met with rejection by the scientific community. For my thoroughly substantiated invention, I immediately received the USSR Inventor's Medal (thanks to the clever Academician San Sanych Kaplyansky, who gave a positive review of my "anomalous" invention).

But there is also a fundamental difference between the thermionic and photoelectric effects. The photon momentum is very small, and therefore the photoelectric effect is, in principle, isotropic—independent of the direction of light propagation in the p-n junction. Meanwhile, the phonon momentum is large and makes a certain contribution to the local thermo-EMF of the p-n junction. Although their polarity is always determined by the polarity of the p-n junction, their magnitude for heat flow propagation along the p-n junction (perpendicular to the plane in Figure 1a and Figure 3) is also, in principle, independent of the heat flow direction. However, for the heat flows shown in Figure. 1a, their absolute value can change when the flow direction is inverted.
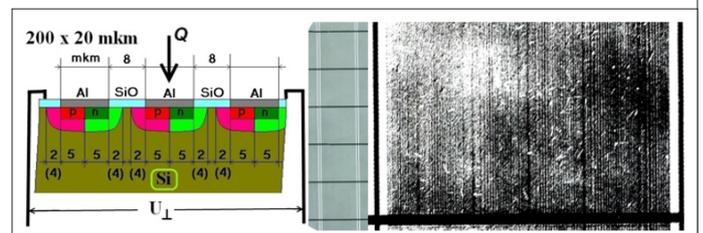
Figure 3: Schematic of the measured p-n junction structure (left), photograph of several measured chips (center), and a high-magnification photograph of one chip (right).

However, when the heat flow propagates along the interface between the p- and n-junction regions (Figure 3), high values of local thermoelectric power are observed both for the heat flow direction shown in Fig. 3a and for the inverse direction

shown in Fig. 4. For the inverse heat flow direction, due to the thermal inertia of the silicon substrate, the thermoelectric power measured on the modulated heat flow was conducted at a low frequency of 33 Hz (Figure 4).
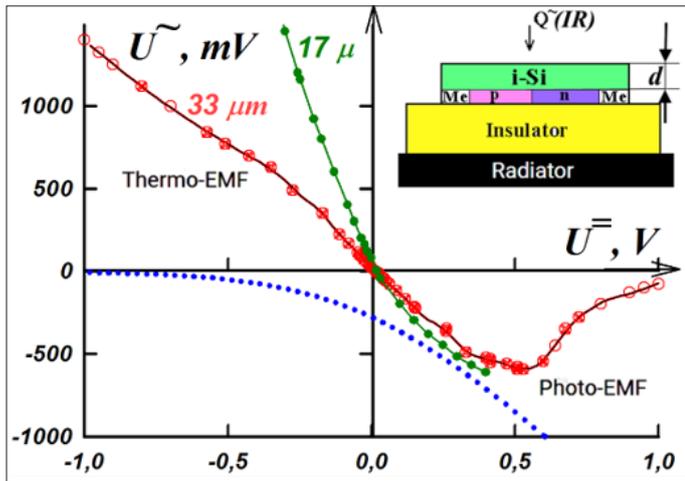
Figure 4: Dependence of the amplitude of the transverse EMF of the p-n junction structure (volt-watt sensitivity taking into account the phase-sign), irradiated through silicon (red and green curves) and the Pho-EMF of the standard (blue dotted curve) of the p-n junction on the constant bias voltage per p-n junction . Measurements were carried out with modulation of the heat flux with a frequency.

Moreover, the signal amplitude (volt-watt sensitivity) naturally increased with decreasing shielding substrate thickness. However, biasing the p-n junction with a constant voltage shows that at zero bias, we have a differential voltage between the thermo-EMF and photo-EMF of the structure. Whereas at a non-zero bias, in full accordance with the I-V characteristics shown in Fig. 2b, we have electrical power generation either due predominantly to local thermo-EMF or photo-EMF.

Figure 4 shows the dependences of the thermo-electronic effects, which occur perpendicular to the direction of heat flow and, according to the traditional thermoelectric definition, are called transverse, on the bias voltage of the p-n junction.

These dependences indicate that the maximum power extracted from the p-n junction (50%) is achieved with the corresponding optimal bias, which is automatically obtained if the load resistance is equal to the internal resistance of the p-n junction. When the heat flow propagates perpendicularly across the p-n junction, a thermionic voltage arises in it along the direction of the heat flow, which, in traditional thermoelectric terminology, is called longitudinal.

Moreover, depending on the flow direction (blue and red dotted arrows in Figure 2a), while maintaining the polarity of the Local Thermo-EMF, determined by the polarity of the p-n junction, and the current-voltage characteristic shown in Figure 2b, the flux bias is, in principle, different, and the total voltage across the p-n junction may differ [21]. For similar p-n junctions, but with inverted polarity (formed on H-type and P-type substrates), these dependences of the total longitudinal voltage on the total drop across the silicon substrate with the p-n junction above,

on which the measuring thermocouple was placed, are shown in Figure 5.
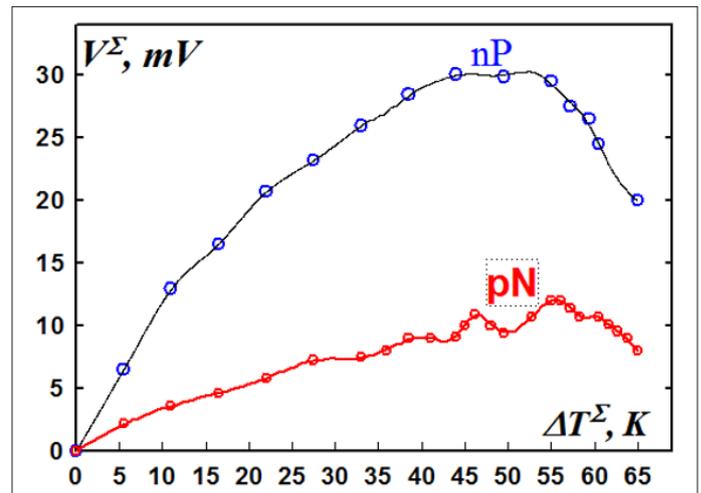
Figure 5: Dependences of the longitudinal thermionic emf arising at inverse n-n junctions on the total temperature difference across the n-n junction and the substrate.

The total temperature difference directly across the n-n junction, for the reason shown in Figure 1, is difficult to determine. However, given that the substrate is approximately 100 times thicker than the n-n junction, its thermoelectric power is formally in the tens of mV/K range, which is two orders of magnitude higher than that of traditional thermoelectric materials [22-24].

The longitudinal thermionic emf of the n-n junction also depends on its bias voltage/current. However, the volt-watt dependence similar to that shown in Figure 4 also exhibits thermionic resonance (Figure 6).
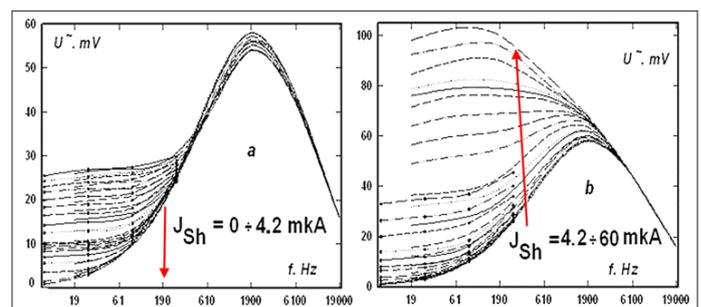
Figure 6: Frequency dependences of the volt-watt dependence of the thermoelectric power of the p-n junction at different bias currents.

Conclusions

Thus, phenomenologically accounting for the thermal force in the p-n junction not only allows, as demonstrated in previous studies, to rigorously determine its equilibrium state, but also reveals its fundamentally new dynamic characteristics. Theoretically, taking into account the extended characteristics of the p-n junction is essential for both the design and operation of all electronic components. Practically, thermionic EMFs can be used in both generators and refrigerators. In particular, they can be used to create low-temperature high-voltage generators and, conversely, processor coolers, both external and integrated.

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