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FEASIBILITY OF ONE-CRYSTAL GaAs ARTIFICIAL PYROELECTRIC ARRAY

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Multifunction properties of GaAs and other III-V semi-insulating crystals could be expanded by the artificial decreasing of their electric response symmetry that could be transformed from piezo- into a pyroelectric class. Artificial pyroelectricity of III-V type semiconductors forms a basis for one-crystal pyroelectric sensor. The voltage sensitivity of GaAs (111)-cut is the similar to PZT pyroelectric ceramics, so GaAs wafer could be used as a thermal-to-electric transducer in a new microelectronic device named ***pyrotransistor****. The last is uncooling far infrared (IR) detector based on MESFET technology.*

Current tendency of modern night vision system development is the increase of sensor elements number in the receiving matrix (focal plane array). This permits to get rid of optic-mechanical scanning unit and reduces requirements to sensor element sensitivity because the response is accumulated at all frame duration. Essential feature of such elements must be quite **uniformity**: sensitivity of each separate element should differ no more than 0.1%. Such uniformity is possible to realize only by application of modern microelectronics processing of semiconductors. But the lasts use far infrared photoconductivity and, therefore, need deep cooling.

Modern uncooling IR-sensors are based on pyroelectric effect in some polar dielectrics. Pyroelectric ceramics is possible to integrate with semiconductor by hybrid microelectronic technology [1]. But the main problem of pyroelectric integrated sensor is to provide a negligible thermal contact between pyroelectric transducer and high thermoconductive silicon wafer. So such arrays need a very complicated system of packaging. Moreover, the rigid bound of several materials with a sharp distinction between their chemical and thermal properties poses problems for technology. For example, as water-soluble pyroelectric-champion TGS so crystals of $LiTaO_3$ -type are difficult to integrate with semiconductor matrix processor. Moreover, each pyroelectric cell of such hybrid-type "pyroprocessor" have different sensitivity, so the effect from the matrix fall short of its ideal.

We propose to use the artificial pyroelectricity in the III-V polar semiconductors in order to apply the potentialities of microelectronics for one-crystal thermal imaging. It is well known that only 10 from 20 piezoelectric classes of crystals allow pyroelectricity and, as a rule, only these crystals are operable as pyrotransducers. However, GaAs type of crystals belongs to the other 10 classes which are nothing more than piezoelectrics but show a "latent" polar structure (being perfectly self-compensated if the crystal is a stress-free). Recently it was shown how this self-compensation could be artificially broken by partial limitation of strains under the special boundary conditions [2]. So it is possible to transform the passive *i*-GaAs wafer into an active *thermal-to-electric* energy transducer. It was obtained that GaAs "pyrocoefficient" is ~1.5 $\mu C/m^2K$ with the voltage sensitivity $S_V = 0.02\ m^2C^{-1}$. Some other of III-V semiconductors have these parameters 10 times more and, above all, they are much closer to dielectrics than semi-insulating GaAs.

Fig.1 shows how artificial decrease of symmetry could transform usual piezoelectric into pyroelectric. Finned structure produced by special etching provides planar strains limitation: only thermally induced thickness strain should be permitted and just in the direction of [111] type polar axis. In the proposed case the GaAs-type wafer is "pyroelectric" transducer itself while amplifiers and other microelectronics are no more than very thin epitaxial layers with an ultra low thermal mass. Wafer-"pyrotransducer" integrated with FET amplifier can be basis of new microelectronics device named **pyrotransistor**. The last consists of MESFET with a submicron channel and realized in the thin high-level doped epitaxial layer deposited onto (111)-cut wafer operating as "pyrogate".

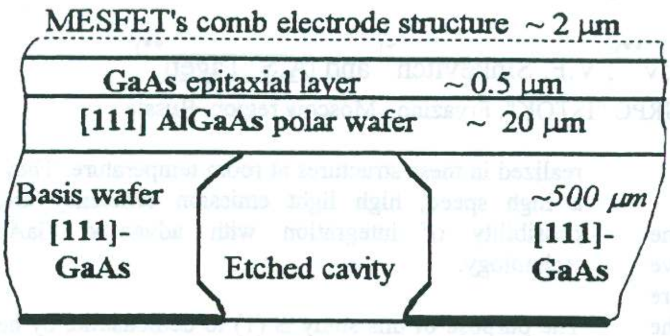

Fig.1. One of possible designs of "pyroelectric" one-crystal array (under-MESFET cell with cavity ~ 100x100 μm^2)

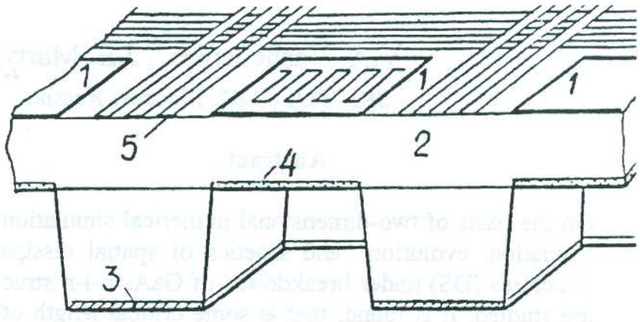

Fig.2. Sketchy picture of array: 1 - MESFET; 2 - polar wafer-transducer; 3 - metalized ridges; 4 - absorbent & electrode layer, 5 - readout circuits.

Produced by etching, a stepwise back-face of wafer is required for partial clamping realization (each cavity is located under MESFET "pyroelectric" region). In addition, to provide planar strains limitation full the [111]-GaAs wafer would be compressed in its plane, bounded by the rigid ring.

The modulation frequency of IR-radiation in the III-V crystal "pyrodetector" depends on the equilibrium concentration of charge carries. In the standard ~ 10^{-9} $Ohm^{-1}m^{-1}$ semi-insulating GaAs the screening of dynamic pyroelectric field is overlooked at the modulation frequency ~1 KHz. However, in some GaAs - III-V solid solutions this frequency would be reduced to 20 Hz. Infrared radiation could be absorbed as by special IR-absorbent layer covering the back side of AlGaAs polar wafer so due to internal IR absorption immediately in this wafer.

In the former case, thermal diffusion from IR-absorbent to wafer limits the operation speed. The finned design provides IR reflection from metalized ridges and practically full absorption in cavities. As applied to semi-insulating GaAs, a modulating frequency ~1 KHz is required at which the temperature wave length in GaAs wafer is about 100 μm. The more thick wafer could not essentially increase the "pyroelectric" response.

The letter case, that is for internal absorption, seems to be more interesting because it is inherent to the III-V type crystals only (which are semitransparent for infrared radiation). Thermal-to-electric response could be got directly in the crystal lattice without any delay, while MESFET also is capable to rapid operation (with a pulses rise up to 10^{-11}s). So the inertless is one of the advantages of new device, moreover, thin-wafer detector would distinguish "IR colors".

Planar strain limitation in the [111]-cut of III-V semi-insulating crystals opens up the possibilities for new type of microelectronic sensors that are uncooling and one-crystal array. The last has advantages as over semiconductor photonic arrays which need cooling so over pyroelectric ones produced by hybrid processing. Hundreds of pyrotransistors on the same wafer would form matrix thermal image processor which sensitivity increases as square root from cells number. The current status of microelectronics can guarantee the identity of each cell in this one-crystal array.

References

[1] R.Watton. Ferroelectric materials and IR bolometer arrays: from hybrid arrays towards integration, *Integrated Ferroelectrics*, Vol.4, pp.175-186, 1994.

[2] Y.M.Poplavko and L.Pereverzeva. "Artificial pyroelectricity in GaAs", *Journ. Technic. Fiziki (Russian)*, Vol.62, pp.93-98, 1992.