Dependence of pyroelectric response on inter-electrode capacitance for integrated-optical circuits utilizing *x*-cut $LiNbO_3$ chips

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The pyroelectric response of integrated-optical circuits (IOC) has been studied for IOCs utilizing *x*-cut $LiNbO_3$ chips with different topologies of electrodes. The schematic sketch of the IOC chip is given in Fig. 1. Each IOC contains the coplanar Au/Cr electrodes, consisting of an electro-optic modulator on main –x surface (placed near center of bottom part of chip). The pyroelectric response was measured by the method which had been described in previous paper [1], i.e. the pyroelectric voltage U_{in} was directly recorded while changing the temperature T of the sample in the range from 295 to 380 K. The range of temperature scanning rate $V = dT/dt$ covered the interval from ≤ 0.1 to 1.5 K/min. A measuring resistor (R_m = 1.06 GΩ) was wired in parallel to the one of modulator electrodes and amplifier input, thus U_{in} appeared on this electrode and amplified by factor of 5 was measured with an electrometer. Two extra In-Ga electrodes were deposited on +z and –z surfaces of chip's lateral edges and one extra electrode was grounded. According to the previous finding [2], such a conductive coating must decrease the pyroelectric response, that is undesirable phenomenon at practical application of IOC [2, 3].

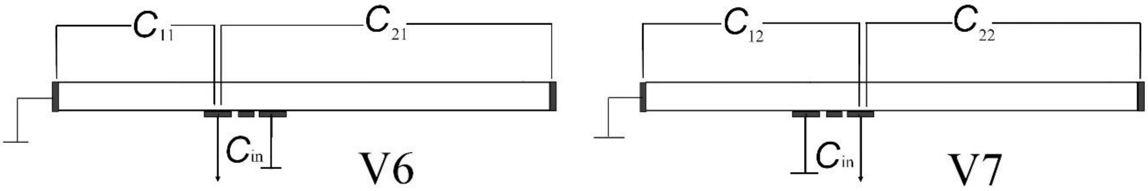

Figure 1. Schematic diagrams of the different topologies for IOC electrical connection. C_{in} is input integral capacitance of modulator and amplifier for measuring circuit, C_{ij} are capacitances of different parts of IOC chip. One of modulator electrodes is connected with C_{in}.

It has been experimentally established, that pyroelectric voltage U_{in} is proportional to the temperature scanning rate V (Fig. 2), and a magnitude of U_{in} depends on electrodes connection topology (Figs. 1,2).

A physical model is proposed in Figure 1. Here the intent is to choose the simplest model possible that will adequately describe the transient effect. The pyroelectric crystal (in conjunction with the electrodes) acts as a capacitor. When the crystal experiences a change in

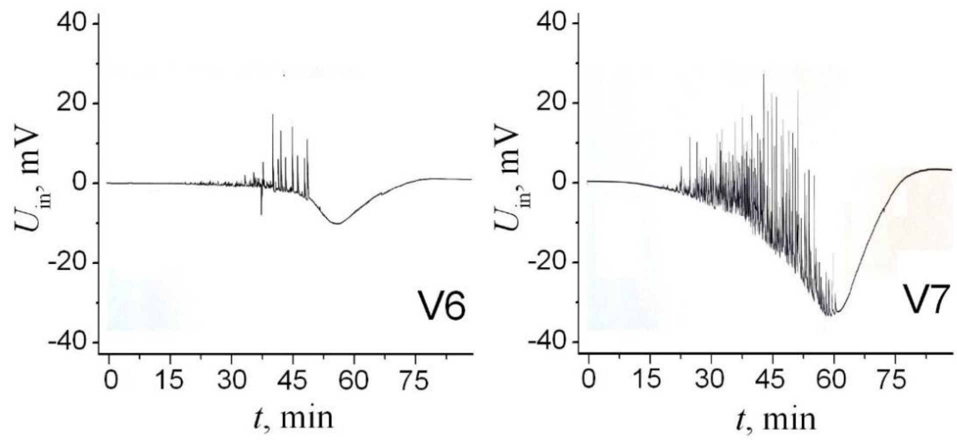

Figure 2. Pyroelectric voltage U_{in} measured for the two different electrodes connection topologies (see Fig. 1) as functions of scanning time t during heat-up of IOC. Rate $V = dT/dt$ of temperature change was gradually increased from $V \leq 0.1$ K/min (at $t \leq 5$ min) to the maximum value of 1.5 K/min at $53 \leq t \leq 62$ min, after V decreased and $V = 0$ at $t \geq 84$ min. Sharp pulses in the electrometer output are related to electric discharges over the IOC's surface.

temperature, it frees electric charges that appear on the extra electrodes deposited on the polar surfaces of lateral edges of IOC chip. The pyroelectric $LiNbO_3$ crystal is oxide, and it has very high resistance [1-3]. Thus, these accumulated charges cannot leak through the material. Thus, under homogeneous change in temperature, the pyroelectric $LiNbO_3$ crystal acts as a charge generating capacitor [4].

A simple circuit composed of capacitances is chosen to model how the charge distribution, and thus the electric field, may depend on the electrode connection topology. The scheme given in Fig. 1 divides the IOC capacitance into different contributions. Direct measurement of the capacitances of different parts of IOC chip gave the following results: $C_{11} \cong 5.1$ pF, $C_{22} \cong 2.6$ pF, $C_{21} \cong 4.1$ pF, and $C^*_{21} \cong 1.9$ pF. C_{21} and C^*_{21} are capacitances measured, when a second modulator electrode is ungrounded and grounded, respectively. The ratio of the capacitances for the different-length inter-electrode gaps scales roughly with the gaps length ratio. Note, that a simple evaluation of C^*_{21} and C_{21} capacitances ratio cannot be directly made because the shape of the field lines should be substantially different in these cases. Thus, the pyroelectric voltage U_{in} depends on capacitance C_{ij} of a chip part between the modulator electrode, which is connected to measuring circuit, and ungrounded extra electrode deposited on right edge of IOC (Fig. 1).

To estimate quantitatively a ratio between U_{in} magnitudes at the different electrodes connection topologies, we consider that during the temperature increase at a rate V the change of the charge q at an effective capacitor C_{ij} in the time is given by the difference of the charge released due to pyroelectric effect and the charge transferred through the measuring circuit. The voltage U_{in} across C_{in} equals to the voltage across the corresponding capacitor of the IOC chip:

$$U_{in} \sim R_{in} C^*_{21} \frac{dq}{dt}, \text{ and } U_{in} \sim R_{in} C_{22} \frac{dq}{dt},$$

for V6 and V7 electrodes connection topologies (Fig. 1), respectively. $dq/dt \sim \gamma \times V$, where γ is pyroelectric coefficient [1].

In fact, the experimental results obtained (Fig. 2) is consistent with our simple model of the IOC as the charge generating capacitor divided into the different contributions, according to the electrodes topology. Besides, these results show that a further suppression of undesirable pyroelectric response is possible by decrease of appropriate contributions in IOC capacitance, that may be achieved by increase of the inter-electrode gap or/and IOC chip width. Moreover, some additional suppression would be possible by decrease of a chip thickness and optimization of electrodes configuration [5].

At the other hand, we can apply the two-component model [3] for qualitative explanation of the pyroelectric response of IOC. The two components are: (1) pyroelectric: unscreened bound charge buildup occurs on *z* surfaces of lateral edges, and (2) electrostatic: capacitive loading of modulator electrodes causes the potential of these electrodes to change much less than the potential of the rest of the -*x* surface, leading to a large potential difference between the modulator electrodes. Considering the close proximity of electrodes to bound charges, very large field may be generated between electrodes.

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