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Design and Fabrication of Dual Mode Pyroelectric Sensor: High Sensitive Energymeter for Nd: YAG Laser and Detector for Chopped He-Ne Laser

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Abstract: Pyroelectric sensor using TGS has been designed and fabricated which can be operated in laser energy meter mode as well as pyroelectric detector mode. The amplifying circuit configuration has very good signal to noise ratio, very high input impedance and low drift. The pyroelectric sensor has been tested using Q-switched Nd: YAG laser and chopped He-Ne laser. The sensitivity of pyroelectric sensor in energymeter mode is 421.7V/J and the voltage responsivity of the pyroelectric sensor is 3.27 V/W in detector mode. *Copyright © 2008 IFSA.*

Keywords: Pyroelectric, Laser energy meter, Pyroelectric detector, Thermal time constant

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1. Introduction

Pyroelectric sensors are used in three ways: (a) to detect a signal modulated at a constant frequency; (b) to detect signal and reproduce the transient signals at output and (c) to measure the total energy of the input laser pulse (Laser energy meter) [1]. The principle of heat conduction and basic principle of pyroelectric detector was described by J. Cooper et al. [2]. The noise analysis of single element pyroelectric detector was described by E. H. Putley et al. [3]. The design and fabrication of laser energy meter using TGS was described by S. Satapathy et al. [4]. In this report we have described the design of pyroelectric sensor which can be operated in both laser energymeter and detector mode simultaneously.

2. Theory

2.1. Pyroelectric Sensor as a Detector

If pyroelectric sensor plate is exposed to beam of radiation containing a component modulated at angular frequency ω, the incident power of the beam can be written

$$W = W_0 + W_\omega e^{j\omega t}, \tag{1}$$

where $W_\omega \le W_0$.

The temperature of the plate is found by solving the equation

$$\eta W = H(dT/dt) + G\,T \tag{2}$$

Solving for the amplitude of the component T_ω at angular frequency ω of the excess temperature gives

$$T_\omega = \eta W_\omega (G^2 + \omega^2 H^2)^{-1/2} \tag{3}$$

and $\phi = \tan^{-1}(\omega H/G)$ is the phase difference between the radiation and temperature oscillation. H is thermal capacity of sensor plate and G is thermal conductance of the sensor element. Thermal time constant of sensor element is $\tau_T = H/G$.

Having calculated T_ω, the corresponding pyroelectric charge appearing on the surface of the element can be obtained at once and the output voltage produced calculated by considering the electrical circuit of the element.

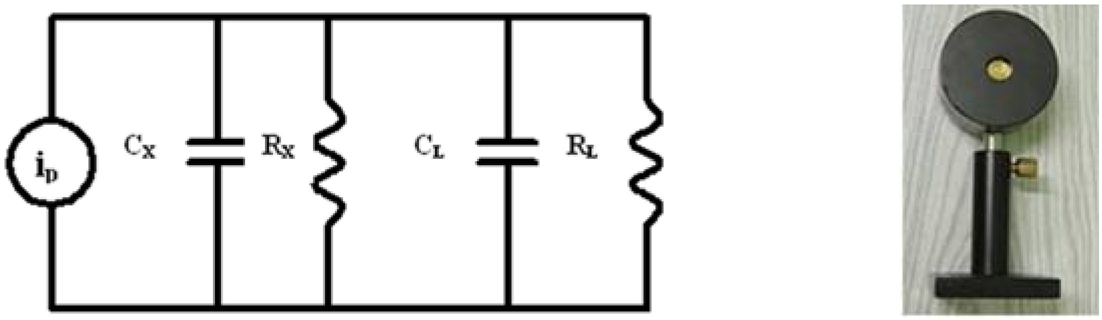
The equivalent electrical circuit of pyroelectric detector is shown in Fig. 1(a). If we represent the element as C_x in parallel with a resistance R_x, the alternating charge on the electrodes is equivalent to a current generator in parallel with the capacity. If the element is connected across the input of an amplifier whose input impedance can also be represented by a capacity and a parallel resistance, the voltage applied to the amplifier is found by calculating the voltage across the equivalent circuit for the combined impedances.

Hence

$$V = \omega p A T_\omega R (1+\omega^2\tau_e^2)^{-1/2} \tag{4}$$

$$R_v \text{ (Voltage responsivity)} = V/W_\omega = \eta(\omega p A R/G)\,(1+\omega^2\tau_e^2)^{-1/2}(1+\omega^2\tau_T^2)^{-1/2}\,, \tag{5}$$

where τ_e is RC time constant of circuit including sensor material capacitance and resistance. The ‘p’ is the pyoelectric coefficient of the material and A is the active area of the sensor.



(a) (b)

Fig. 1. (a). Schematic diagram of pyroelectric sensor. (b). Picture of pyroelectric sensor.

For $\tau_e << 2\pi/\omega << \tau_T$, the heat wave does not travel to rear face of the crystal. Before reaching the rear face of the crystal the heat released from the front surface.

$$V_0(t) = \left(\frac{p}{c^{/}d}\right)(R)W_\omega \tag{6}$$

If pyroelectric detector satisfies $\tau_e << 2\pi/\omega << \tau_T$ condition then the exact replication of input signal was produced at output.

2.2. Pyroelectric Sensor as a Laser Energy Meter

For energy meter application, the condition pulse width of laser (w) << thermal time constant of sensor must be satisfied. This indicates that the thickness of sensor is much greater than the diffusion depth so that during the radiation pulse little heat will flow out of the rear surface of the ferroelectric. Then the output voltage of sensor can be expressed as

$$V_0(t) = \left(\frac{Ap}{c'd}\right)\left(\frac{1}{C}\right) \exp\left(\frac{-t}{\tau_e}\right) \int_0^\omega \exp\left(\frac{t}{\tau_e}\right) F(t)\, dt\ , \tag{7}$$

where, τ_e = RC, the electrical time constant of the circuit and w is the pulse width of the source. Similarly, F(t) is the space-averaged energy flux per unit area absorbed by the detector. The ‘p’ is the pyoelectric coefficient of the material and A is the active area of the sensor.

If the electrical time constant is long compared with the duration of incident signal, and $\tau_e >> w$ then eq^n. 25 simplifies to

$$V_0(t) = \left(\frac{p}{c^{/}d}\right)\left(\frac{1}{C}\right)e^{-t/\tau_r}\left(A\int_0^w F(t)dt\right), \tag{8}$$

where $\left(A\int_0^w F(t)dt\right)$ = E (total energy of the pulse fall on the detector).

So out put voltage at any time for the condition $w << \tau_e << \tau_T$ is

$$V_0(t)=\left(\frac{p}{c^{/}d}\right)\left(\frac{1}{C}\right)e^{-t/\tau_r}E \tag{9}$$

On the other hand, if the electrical time constant is short compared to the duration of the pulse ($\tau_e << w << \tau_T$), then

$$V_0(t)=\left(\frac{Ap}{c^{/}d}\right)(R)F(t) \tag{10}$$

The output voltage is now independent of input capacitance. Here the output is proportional to the instantaneous flux incident on the slab, rather than the total integrated flux, and thus reproduces the transient wave shape of the pulse.

From above analysis it is clear that the equation 6 and equation 10 are equal. So if we choose proper width of laser pulse and frequency of chopped continuous light, then the pyroelectric sensor can be operated in both laser energymeter and as well as detector mode.

3. Experiment

Fig. 1(b) shows the pyroelectric sensor fabricated using TGS crystal. The construction parameters are specified in the Table1.

Table 1. Main features of constructed dual mode pyroelectric sensor.

Parameters	
Material	TGS (Triglycine Sulphate)
Aperture (Diameter)	20 mm
Area	3.14 cm^2
Thickness of material	0.5 mm
Sensor configuration	Flat
Coating material	Gold
Voltage sensitivity(Energymeter mode)	421.7 V/J
Minimum measurable energy	10 μJ
Voltage responsivity (same sensor in detector mode) at 13 Hz	3.27 V/W at 10 MΩ resistor in amplifying circuit

4. Results and Discussion

According to the parameter specified in the table 1 the thermal time constant of pyroelectric sensor is ≈ 870 ms. When there is no external amplifying circuit, then the RC time constant of the crystal through 1 MΩ resistor is 4 ms. Fig. 2 shows the out put of sensor exposed to pulsed Nd: YAG laser of pulse width 17 ns. In this case the pulse width much less than the thermal time constant and electrical time constant of the sensor. So the pyroelectric sensor acts as a laser energy meter. The fall time of the output signal of the energy meter depends on the electrical time constant of the laser (RC time constant of the sensor). The noise level of the energy-meter is 2 mV (Fig. 2(g)). When Nd: YAG laser pulse of energy 1.22 mJ falls on the energy-meter the out signal of 40.7 mV generated (Fig. 2a). As the input energy of laser pulse decreases to 80 μJ the out put signal also decreases to 2.56 mV. But for further decrease of input laser energy, the out put signal was not detectable due to noise level of the sensor. The sensitivity of the laser- energy meter has been shown in Fig. 2(h). The sensitivity of the pyroelectric sensor in laser-energy meter mode without any external amplifier circuit is 33.7 V/J.

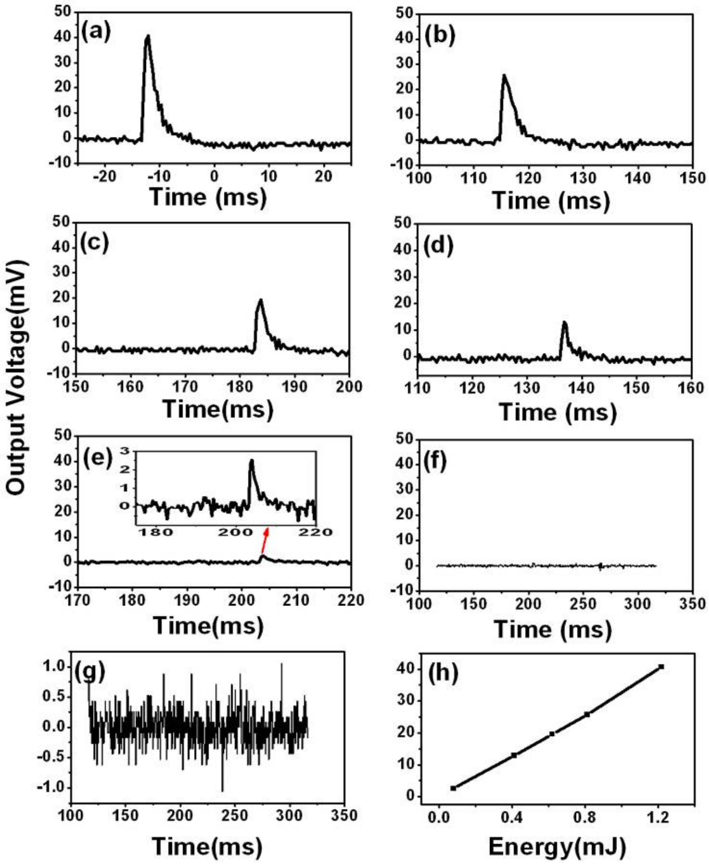


Fig. 2. (a-g). Out put voltage response of pyroelectric energy meter without amplifier to Nd: YAG laser pulses of 17 ns width. (h). Sensitive curve of energymeter.

The same pyroelectric sensor (without amplifier) was used as a pyroelectric detector for chopped continuous He-Ne laser. But due to large noise to signal ratio, the output signal was not observed when chopped He-Ne laser radiation fall on the detector. For energymeter mode operation the condition laser pulse width << electrical time constant << thermal time constant must be satisfied. But for detector mode operation the exact shape of the chopped input signal should be reproduced at output. In this case the condition electrical time constant << 1/ chopped frequency << thermal time constant must be satisfied.

To operate the pyroelectric sensor in both modes following electronic circuit was designed (Fig. 3). OPA129 is wired in TI amplifier mode with the transimpedance of 10 MΩ. Bias current is in the range of famp. The input pins are guarded and guard ring is connected to lowest circuit potential to remove the effect of leakage current. Signal line is perfectly shielded using RG178 coaxial cable to reduce the effect of external noise. For the same purpose whole circuit is also shielded. Gain picking is avoided by using 220 pF capacitor across feedback resistor. This circuit configuration has very good signal to noise ratio, very high input impedance and low drift.

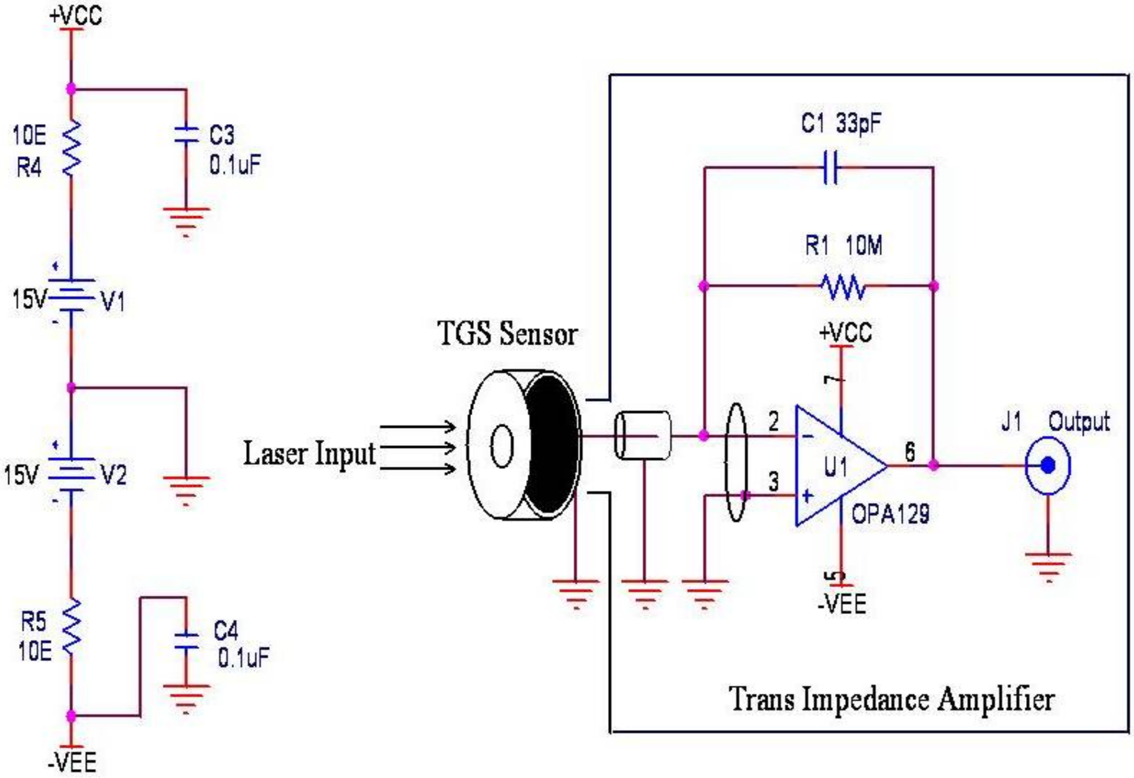


Fig. 3. A scheme of amplifier of pyroelectric sensor output signal.

Using above amplifying circuit the pyroelectric sensor was tested in both pulsed Nd: YAG laser and also in chopped He-Ne laser. The RC time constant of pyroelectric sensor after amplification circuit is 3.5 ms.

Fig. 4 shows the out put signal from sensor (which acts as energymeter) for different input energy of Nd: YAG pulses. The amplification circuit was designed in such a way that the noise level was still 2 mV. Due to amplification the out put signal increases 12 times compared to the sensor output without amplification circuit. For 1.22 mJ input energy of Nd: YAG laser pulse (17 ns pulse width), the output signal is 507 mV (Fig. 4(a)). Similarly an out put signal of 7.11 mV generated for an input energy of Nd: YAG laser pulse of 24 μJ (Fig. 4(g)). Since the noise level of sensor is 2 mV one can measure laser energy below 24 μJ up to 10 μJ. Using amplification circuit mentioned in Fig. 3, the sensitivity of pyroelectric sensor in energymeter mode increases from 33.7 V/J to 421.7 V/J. The high sensitive energymeter can measure energy of input laser pulse up to 10 μJ. The sensitivity curve of high sensitive energymeter is shown in Fig. 4(h).

The pyroelctric sensor can also be used as detector if $1/\tau_E >> \nu$ (frequency of chopper) $>> 1/\tau_T$. The thermal time constant and RC time constant of pyroelectric sensor with amplification circuit are 870 ms and 3.5 ms respectively. So this sensor should act as detector when chopper frequency lies between 10 Hz to 250 Hz. The fabricated detector with amplification circuit has been exposed to chopped continuous He-Ne laser (2 mW). The output signals of detector at different chopped frequency are shown in Fig. 5.

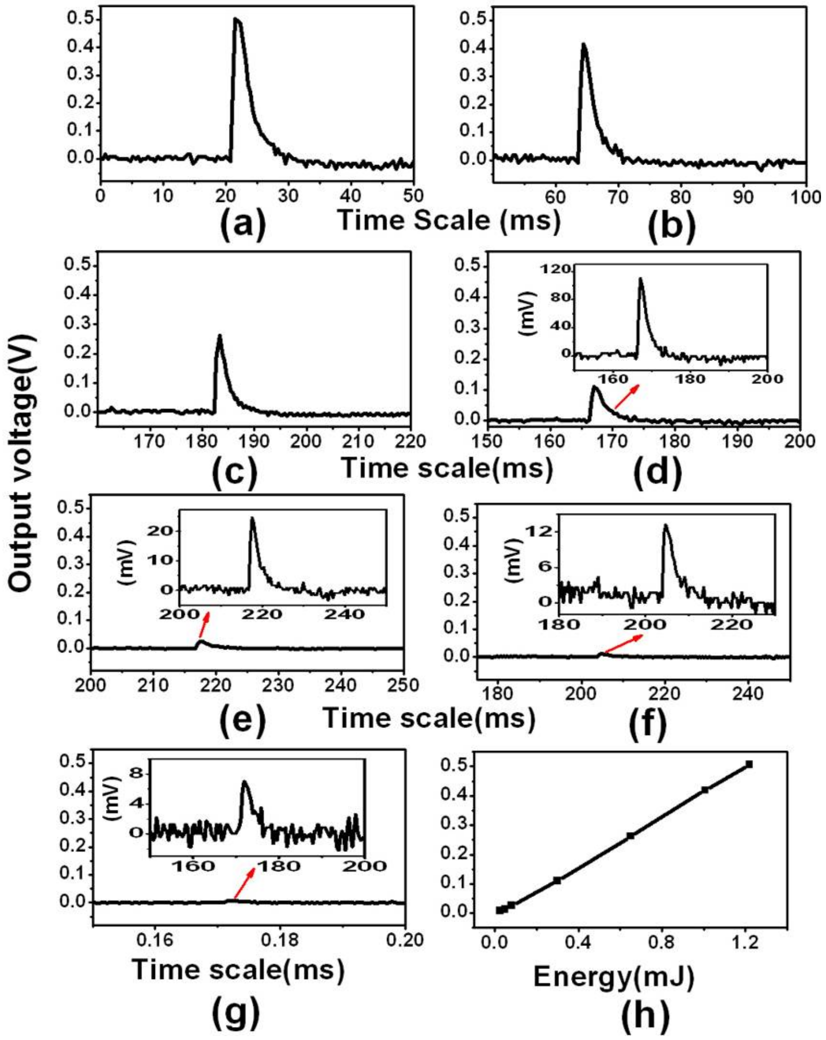


Fig. 4. (a-g). Out put voltage response of pyroelectric energy meter with amplifier to Nd: YAG laser pulses of 17 ns width. (h) Sensitive curve of energy meter with amplifier.

The output signal tries to replicate input chopped signal at 13 Hz. When frequency of input signal increased to 100 Hz the detector shows integrating output according to input signal. The responsivity of detector is shown in Fig. 5(f). At 13 Hz the voltage responsivity of detector is 3.27 V/W, which decreased to 1.84 V/W at 109 Hz. In amplification circuit 10 MΩ feed back resistor was used. If 100 Giga Ohm feed back resistor will be used as generally used in detector circuit, the responsivity will be increased.

5. Conclusions

This manuscript described the fabrication of dual mode pyroelectric sensor. The sensor can be used to measure the energy of the pulse of Q switched Nd: YAG laser. The sensitivity of the sensor in laser energy meter mode is 421.7 V/J. So energy up to 10 μJ can be measured using this pyroelectric sensor. The pyroelectric sensor can also be used as detector for continuous laser i.e. He-Ne laser and solid state diode laser. This report also described the detection of chopped continuous wave of He-Ne laser. In detection mode the responsivity of the pyroelectric sensor is 3.27 V/W with 10 MΩ resistor in amplifying circuit.

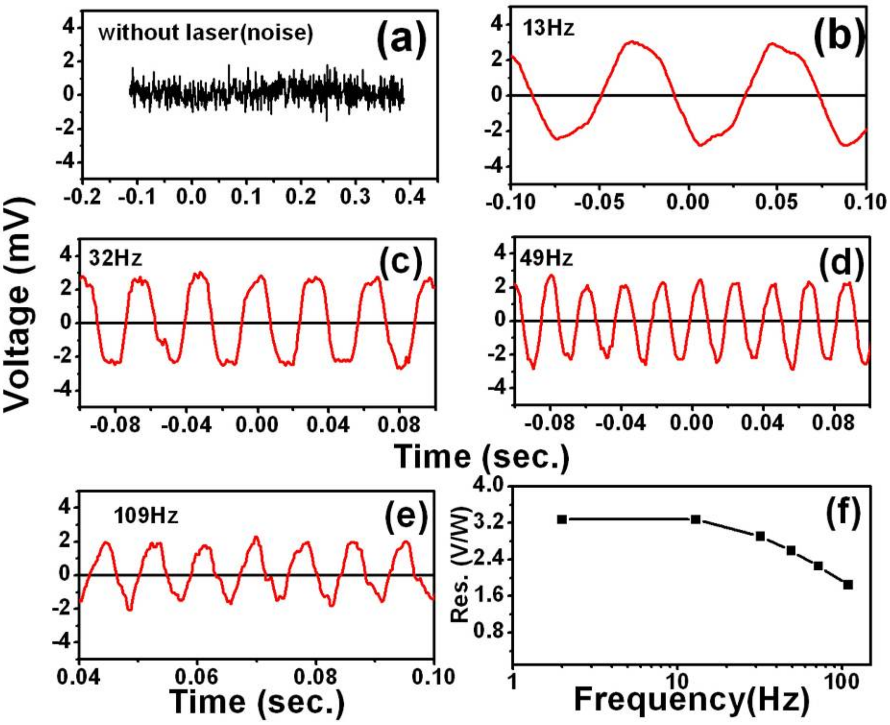


Fig. 5. (a - e) Out put voltage response of pyroelectric detector to He-Ne Laser (2 mW). (f). Responsivity curve of detector.

[*] All measurements were taken using 1 GHz LeCroy digital Oscilloscope and input laser energy was calibrated using Ophir laser energy meter.

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