ELTEC INSTRUMENTS, INC.

# ELTECdata #114

# Flame Detection/Study/Monitoring with Lithium Tantalate Pyroelectric Detectors

Of nature's many phenomena, the flame is by no means the simplest. The typical hydrocarbon flame is a mixture of molecules – some being created and some being destroyed. It's an aerodynamic event with regions of laminar and/or turbulent flow. To say that a flame is "generally exothermic" is the supreme understatement. A flame is truly energized matter.

Since the energy of the flame is not contained as in controlled fusion, the direction of the energy is outward to equilibrium. The energy is moving by conduction, convection, and radiation. Radiation results from the making and breaking of molecular bonds and requires that atoms be energized to the extent that electrons jump orbits – and thus emit photons, in the visible and ultraviolet region of the spectrum.

Combustion is rarely complete, and minute agglomerates of solid carbon are formed, heated to a glowing red or even white heat. These particles have a very high emissivity and behave as miniature black bodies radiating a planckian spectral distribution of photons, many of which are in the infrared.

One very useful phenomena in the hydrocarbon flame is very strong infrared emission at 4.3 micrometers – a consequence of the almost violent molecular agitation of carbon dioxide.

Normally, at ambient temperatures, 4.3 micrometers is an absorption band for carbon dioxide. In fact, the carbon dioxide in the atmosphere is enough to absorb the 4.3 micrometer energy from the sun.

We live in a sea of electromagnetic waves: radio, visible light, earth-temperature infrared distributions, a few gamma rays, etc. However, there is not much 4.3 micrometer radiation in our environment. The filament of an incandescent bulb, glowing white hot is certainly emitting 4.3 infrared. Nevertheless, the filament is in a glass envelope – and most glasses have little or no transmission at 4.3 micrometers.

To detect/study/monitor any phenomena, it is best to restrict the view to some aspect that is peculiar to that phenomena, in this case the 4.3 micrometer emission of a hydrocarbon flame. The "peculiar aspect" must be practically instrumental to be useful. And fortunately, such a device is at hand.

The device is a lithium tantalate pyroelectric detector. The lithium tantalate is a single-crystal material, like quartz or diamond, so it doesn't age. Technically, lithium tantalate is a noncentrosymmetrical crystal. There is one axis along which a temperature change will produce not only a lattice stress, but also an electric dipole moment – generation of charge. By properly cutting the crystal into a wafer and electroding the surfaces, the charge can be collected and used as a signal. Since the bulk resistivity is above 10 teraohms cm, the electrodes make the crystal sandwich behave like a capacitor. Thus, the detector can be viewed as an "active capacitor." A high megohm resistor is put across the detector so the generated charge becomes a voltage potential. One terminal of the resistor is presented to the gate of a field effect transistor and the other terminal to ground. Placing from +3 to +15 volts on the drain of the transistor and a resistor from the source to ground completes a source-follower circuit and the device now has low impedance (usable) output.

Alternately, one side of the lithium tantalate crystal can be presented to the negative input of a transimpedance amplifier and the other side of the crystal to ground. A high megohm resistor connected to the input and output of the amplifier becomes the gain-controlling feedback loop and the device functions as a very high-gain current to voltage converter.

Eltec Instruments makes both types of devices described above and many variations as well – using standard TO-5, TO-18, and TO-8 transistor housings.

The pyroelectric detector is a "thermal" detector. Thus photons are absorbed by the electrode and crystal as heat – and the heat stresses the lattice to produce the charge. The crystal doesn't care what kind of photons it absorbs. The photons can be ultraviolet, visible, near infrared, and far infrared to 1,000 micrometers in wavelengths. So to make it a dedicated flame detector, a narrow bandpass interference optical filter/window is placed over the crystal. The window, as you would expect by now has its transmission centered at 4.3 micrometers.

The pyroelectric detector is an AC device. It has to see a change to respond. No change, no output.

When dealing with an "unfriendly" flame, as might break out in a chemical plant, the detector is looking at an area with no flame (no 4.3 micrometer radiation) and then, an instant later, at a flame. There's a change in 4.3 micrometer radiation (from none to lots) and there's a healthy change in the detector output to trigger an alarm or automatic foam generating equipment. If only a smoke detector had been relied upon, everyone would have been killed and the plant destroyed by the time the smoke was sufficient to trigger the device.

However, there are other possible sources of 4.3 micrometer radiation other than a hydrocarbon flame to consider. A very hot object, as Planck has shown, emits 4.3 infrared.

But an uninsulated steam pipe in the field of view will emit either a constant stream of 4.3 infrared (no change, no output), or a change in 4.3 (as the pipe heats up or cools down) at a rate well below the thermal time constant of the detector (again, no change). But if some object, such as a forklift was to pass between the uninsulated steam pipe and the detector, the detector will respond if the rate is within the frequency response of the detector.

Also, say the detector is in a steel mill and hot beams are moved past the detector by rail. The detector will indeed respond!

Now, go back to the physical flame. The flame exhibits a phenomena known as "flicker." The flicker is a bulk phenomena exhibiting an alternate increase-decrease in radiated energy at the rate of about from 5 to 15 Hz. If a narrow bandpass electrical filter is added prior to the alarm comparator, an alarm is seen only if the "source" is emitting 4.3 infrared and only within the electrical passband (perhaps taking more than one sample for good measure).

The electrical filtering and sampling may give a response time of 1 second. If that's too slow, there is another approach.

The other approach is to use two detectors. One detector has a 4.3 micrometer window and the other detector has a reference window. Some use 3.8 micrometers as a reference and some use 5 micrometers as a reference. Now, if a hot object passes in front of both detectors they will give similar (but not identical) output magnitudes. But if there is a hydrocarbon fire, the detector with a 4.3 infrared window will give a substantially greater output. And the alarm will be sounded!

Thus the usefulness of the pyroelectric detector as a sensor in a fire alarm.

If you are dealing with a "friendly" flame, as in a boiler, you always have the flicker output. No output, no flame. Shut off the gas to the boiler.

The detector can also be used to study flames. Namely, does the flicker frequency relate to efficient operation of a flame? Does the behavior of the flame in other regions of the spectrum relate to efficiency or some other parameter (the detector can be fitted with any optical bandpass window with a linear response throughout the spectrum)? Additionally, the radiation to the detector can be modulated (chopped) giving a drift-free AC signal proportional to the input radiation (as from the hot carbon particles referred to earlier) to actually monitor the temperature of the flame (with an appropriate window).

In summary, lithium tantalate pyroelectric detectors are yet another tool in making the ancient quest to tame, use and understand fire.



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