Smoke detection by the reduction of corona discharge threshold

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Abstract—**This paper presents an ionic smoke sensor working without a radioactive ionization source. The presence of smoke particles reduces significantly the effective corona discharge threshold of air by a factor greater than 5. The smoke sensor consists of a wire under an intermediate continuous voltage which generates a current only in presence of smoke. The sensor electric consumption is therefore very low and can operate for a long time. Results of a prototype operating under 600 V with a 25-μm-diameter wire are shown.**

I. Introduction

Smoke is one of the first indications of a fire therefore its detection is a good way to trigger an alarm in order to put out the fire or to evacuate inhabitants in time. Although smoke sensors were invented in the 40's, only major companies could afford them because of their rather high price and installation constraints. The first truly affordable home smoke sensor was developed by Duane D. Pearsall in 1965 and came to market in 1969 [1]. Today there are different kinds of smoke sensors depending on their detection principle, mainly those using light beams and those using charged particles.

In the case of smoke sensors using light beams, two operating modes are currently implemented. In the first operating mode, a photoreceptor receives the light from a laser source. In presence of smoke, the laser beam is attenuated and less light reaches the photoreceptor as illustrated in Figure 1a. The subsequent reduction of light triggers the alarm. This type of sensors is usually installed in large areas because the larger the distance between the laser source and the photoreceptor, the better the sensitivity. In the second operating mode, the photoreceptor is mounted in such a way that it does not receive any direct light from the source. In presence of smoke, one part of the light is scattered and reaches the photoreceptor as illustrated in Figure 1b. The increase of light at the photoreceptor triggers the alarm. That later operating mode is the one used for most of all optical punctual smoke sensors, and is then particularly well suited for domestic applications.

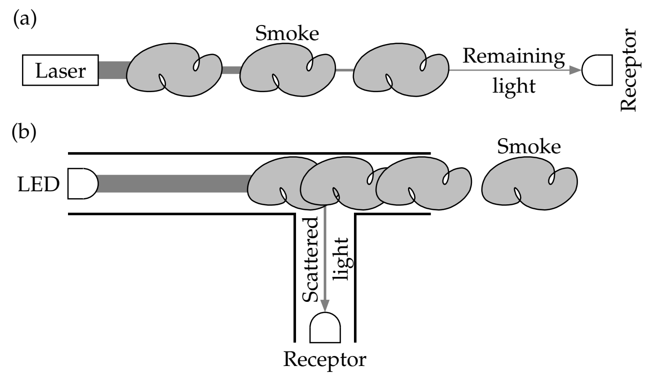

Figure 1. Principle of optical smoke sensors. (a) Operating mode for a detection over large areas. (b) Operating mode for a punctual detection. The source is often a light emitting diode (LED).

In the case of smoke sensors using charged particles, a ionization source generates charged particles which then drift slowly in a low electric field imposed by nearby electrodes submitted to a low voltage. That is illustrated in Figure 2 where a minute quantity of the radioelement americium-241 releases continuously energetic α particles that ionize surrounding air. The charge drift generates a measurable continuous electric current. When smoke particles enter the drift chamber, they interact with the charged particles and reduce their speed, which increases the probability of their neutralization or dispersion. The resulting large current drop measured from the electrodes triggers the alarm.

Ionization smoke sensors have very good performances, responding to smaller particles and with less smoke amount than optical sensors [2]. However according to new standards in some countries such as France [3], commercialization of such sensors is no longer accepted because of the presence of the radioactive source for the generation of the charged particles. Nevertheless, they are still widely in use in many countries, for instance they represent 80% to 90% of all installed smoke sensors in American homes [4].

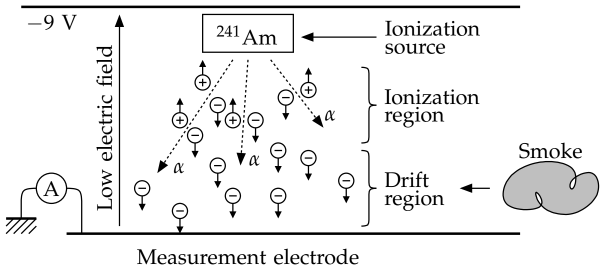

Figure 2. Principle of an ionic smoke sensor. In presence of smoke, much less charged particles reach the measurement electrode.

In this paper, a new approach is proposed for detecting smoke with charged particles without using any radioactive source. This approach uses the reduction of the corona discharge threshold of air due to the presence of smoke particles. In the first section, the experimental set-up and the measurement procedure are described. In the second section, results are presented taking into account the effect of temperature and moisture.

II. Experimental set-up

A. Prototype description

A 25-μm-diameter gold-coated tungsten wire is centered in a 36-mm-diameter cylindrical stainless-steel electrode. The wire is stretched tightly by a spring and held to a positive voltage. The cylindrical electrode is grounded via an electrometer for measuring the drift current. We have used a Keithley 600B electrometer to measure current down to 0.1 pA. A computer regularly acquires the signal measured by the electrometer. In order to reduce electromagnetic noise, the sensor and the electrometer are placed in a Faraday shielding box as shown in Figure 3.

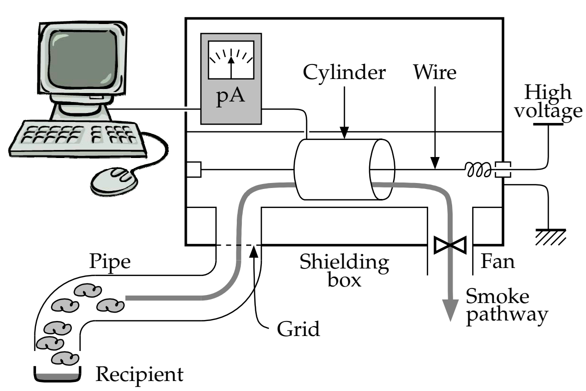

Figure 3. Experimental set-up. The sensor prototype is placed in a Faraday shielding box. It is fed with smoke driven by a fan from a pipe.

Smoke is driven to the sensor by a guiding pipe and is extracted from the sensor by a fan. Smoke particles are generated by burning a combustible in a recipient. The combustible contains essentially 5 to 10 g of a mixture of incense, lavender straw and a special mushroom named Amadou which is well known for generating a lot of smoke during its combustion. By the action of the fan, smoke rises through the pipe then crosses the sensor along its axis. A 72-μm-pitch grounded grid is inserted at the entrance of the sensor in order to remove most of the ions generated during the combustion.

B. Corona discharge

The 25-μm-diameter sensor wire can ionize surrounding air when held to a sufficient high voltage. The electric field generated by the wire being very divergent, there is a range of applied voltage for which ionization occurs without producing an electrical breakdown. The voltage needed to ionize the molecules of air between the electrodes depends on different parameters such as the ionization energy, the presence of other particles, the gas pressure, the distance between the electrodes and their shape [5], [6], [7]. In a cylindrical geometry, the voltage threshold depends drastically on the wire diameter [8]. The corona threshold in our geometry is about 2.3 kV in air as shown in Figure 4.

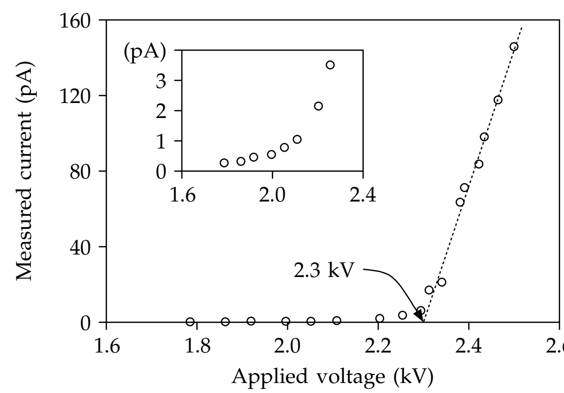

Figure 4. Measured current with the electrometer as a function of the applied voltage to the wire.

All experiments are carried out by applying less than 1 kV to the wire. Therefore no corona discharge is expected in absence of smoke.

C. Measurement protocol

Each experiment contains four steps. First, the power supply is switched on as well as the electrometer and the fan. Second, the acquisition program is run to receive data from the electrometer. Third, the combustible is lit in the recipient and then is put at the end of the pipe. Fourth, the recipient is taken away after few minutes and smoke is gently removed from the measurement system by the fan.

III. Results and discussion

We have shown [9] that under an intermediate voltage, a current is detected in presence of smoke as shown in Figure 5a.

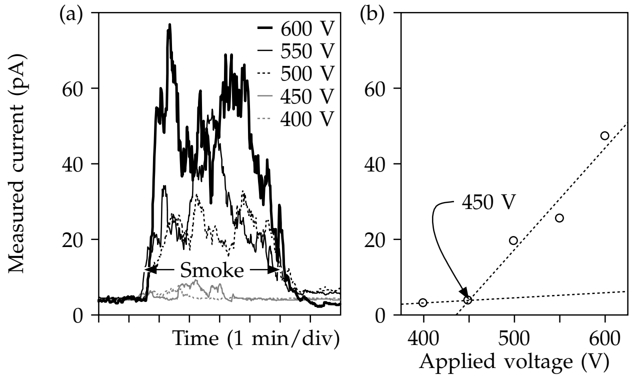

Figure 5. (a) Signals obtained at different applied voltage as a function of time when smoke enters the sensor. (b) Signal mean amplitude as a function of the applied voltage in presence of smoke.

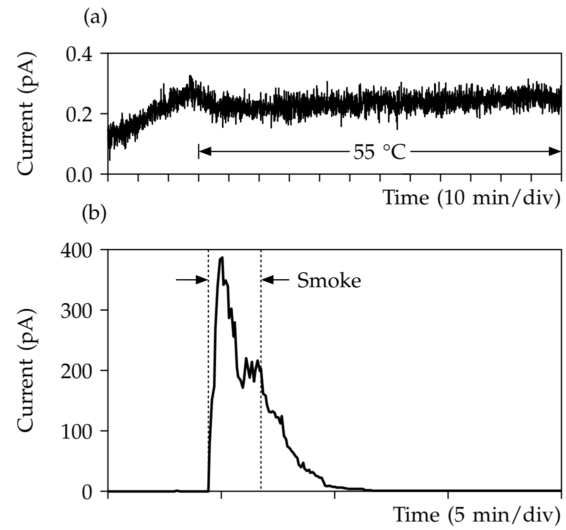

Figure 6. (a) Evolution of the signal at 55°C without smoke under 600 V. (b) Signal produced by smoke at 55°C under 600 V.

At low voltage, that is to say below 450 V in our geometry, the small detected current is due to an electrochemical effect between smoke and the measurement electrode. The amplitude of the signal does not much depend on the electric field in the sensor but it drastically depends on the nature of the smoke and of the electrodes. The signal amplitude is indeed completely different with a copper electrode if smoke is composed exclusively of incense or of Amadou mushroom. Therefore the electrochemical effect is not good for detecting all kinds of smoke.

At larger but still intermediate voltage, that is to say between 450 V and the corona discharge threshold of air, a clear current is detected in presence of smoke. That current has been identified as a corona discharge [9] as if the corona discharge threshold in air had been reduced by the presence of smoke. The nature of smoke does not much modify the results.

The voltage threshold between these two behaviors is of the order of 450 V as can be seen in Figure 5b. The sensor could operate with voltages as low as 500 V. In the following subsections the effect of temperature and moisture on the sensor are tested.

A. Effect of temperature

Smoke sensors must work under extreme environmental conditions such as temperature as high as 55°C. Although sensors are not required to detect smoke at such extreme conditions, they are required to not trigger false alarms.

During the temperature increase up to 55°C, which corresponds to the first 30 minutes of the signal in Figure 6a, the measured signal presents little variations, rising from 0.1 pA to 0.3 pA. When temperature stabilizes, the current also stabilizes at 0.25 pA approximately. It is worth noting that it corresponds to an electric consumption of only 150 pW. All these variations can be considered as negligible since the signal variation is very large in presence of smoke at a voltage of 600 V as shown in Figure 6b.

It can be concluded that temperature is not a significant parameter for our smoke sensor.

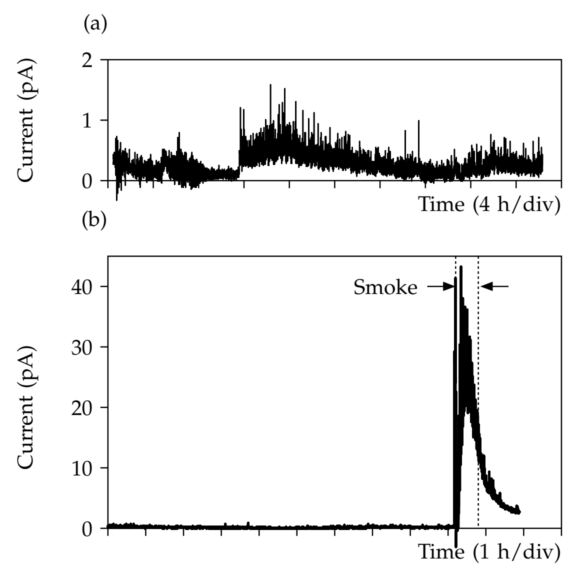

Figure 7. (a) Evolution of the signal at 40°C and 90% moisture without smoke under 600 V. (b) Signal produced by smoke at 40°C and 90% moisture under 600 V.

B. Effect of moisture

Moisture is usually seen as the most impacting parameter for ionic smoke sensors because it modifies ionization thresholds and charge mobilities. Moisture can therefore triggers false alarms. Tests have been made in a climatic chamber BINDER APT Line KMF (E5.2).

The evolution of the signal without smoke at 40°C and under 90% moisture is presented in Figure 7a. Moisture acts more strongly than temperature on the signal, but the variations remain relatively small, within the pico-amp, even over very long periods of time. Indeed these variations are completely negligible compared to the signal variation due to the entrance of smoke into the sensor as shown in Figure 7b. It can be noticed however that the smoke induced signal is smaller under moisture conditions than under dry conditions. Without smoke, the sensor electric consumption slightly increase to 300 pW. But the signal remains relatively small, in fact much less than the signal in presence of smoke (Figure 7). It can be concluded that even in very heavy moiture, our smoke sensor continue to work efficiently.

IV. Conclusion

In this paper we have shown that smoke can be detected by a corona discharge. The detection is based on the reduction of the effective corona electric field threshold due to smoke. In absence of smoke, there is no discharge while in presence of smoke the corona discharge is triggered providing a large detectable current. In our geometry, the sensor can work under voltage as low as 500 V and the nominal current without smoke is less than a pico-amp. Therefore the consumption of the sensor is very small allowing long-lasting operation.

The effect of temperature and moisture is completely negligible on the sensor operation which can still detect smoke at 55°C or at 90% moisture. That kind of sensor could replace ionization smoke sensors, giving a good detection to smoke without requiring a radioactive source.

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