Investigation of the sensitivity of MIS-sensor to thermal decomposition products of cables insulation

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Abstract. Sensitivity of the MIS-sensor to products of thermal decomposition of insulation and jacket of the most common types of cables is investigated. It is shown that hydrogen is evolved under heating the insulation to temperatures not exceeding 250 °C. Registration of the evolved hydrogen by the MIS-sensor can be used for detection of fires at an early stage.

1. Introduction

The problem of fires in Russia and around the world is very acute. More than 35 thousand incidents of ignition have occurred in Russia only during the first quarter of 2014, and more than 3 thousands of people have been perished. According to the official statistics of the Ministry of Emergency Situations, almost 30% of the total number of fires for the above period occurred due to damage of insulation and jacket of cables, which led to a short circuit and a further ignition of the insulation [1]. To ensure the safety of both people’s lives and property, we must detect fires at an early stage. Not one of the modern fire detectors can cope with this task, since they react to an already existing fire. Therefore development of a device which can detect fires at an early stage is an actual task.

A MIS-sensor can be used as a sensitive element of such a device since it exhibits a very high (at ppm level) sensitivity to hydrogen [2] which, as a rule, is evolved during the thermal decomposition of the cable insulation. Detecting hydrogen appearance the MIS-sensor can warn about an imminent threat of fire. More details on the thermal decomposition of insulation materials used in this work are available in [3,4].

A fire detector based on a MIS-sensor can be used in places of large people accumulation, such as concert halls and shopping centers. Also, this device can be used in works with a high danger.

2. MIS-sensor scheme

Sketch of the MIS-sensor is shown in Figure 1. A silicon (4) plate of KEF-15 with thickness of 0.4 mm is used as a basis for the structure. One surface of the plate is coated with SiO₂ film (3) obtained by oxidizing in dry oxygen. A Ta₂O₅ film (2) of about 100 nm thickness covers the SiO₂ layer and a catalytic metal film (palladium) of about 30 nm thickness is deposited from above. The MIS structure is operated at a constant temperature of 100 °C. The temperature is measured by the thermistor (10) and stabilized by the electronic circuit of the gas analyzer.

The MIS structure represents a capacitor whose capacitance depends on the applied voltage (bias voltage). This dependence is called the volt-farad (C-U) characteristic. When hydrogen appears over
the palladium film, the C-U characteristic shifts to the left along the voltage axis (Figure 2) and a change of the MIS-sensor capacitance is registered when a bias voltage is fixed.

![Figure 1](image1.png)

**Figure 1.** MIS-sensor sketch: 1 – Pd film; 2 – Ta₂O₅ film; 3 – SiO₂ layer; 4 – silicone wafer; 5 – metal electrode; 6 – insulating layer; 7 – heater; 8 – electric contacts of heater; 9,11 – electric contacts of MIS-structure; 10 – thermistor.

**Figure 2.** C-U characteristic of the MIS-sensor. The dashed line shows the shift of the volt-farad characteristic under hydrogen influence.

### 3. Experimental

The experimental setup shown in Figure 3 was assembled to perform experiments on thermal decomposition of cables.

![Figure 3](image2.png)

**Figure 3.** Sketch of experimental setup: 1 – air pump, 2 - heat reactor with a sample of cable insulation, 3 – carbon filter, 4 – vessel with MIS-sensor inside, 5 – rotameter, 6 – chip, 7 – PC.

The experimental setup works as follows. The pump (1) supplies air to the reactor (2) made of quartz tube on which a nichrome-wire heater was wound. Thermal insulation of the reactor was provided with glass wool and asbestos cloth. Sample of the cable inside the reactor was heated to the initial temperature of 100 °C and then temperature was raised in steps of 10 °C up to a value at which hydrogen evolution from the cable insulation begins. The air flow supplies all products of the thermal decomposition to the MIS-sensor (4) while only hydrogen detection is the aim of our work. Since the MIS-sensor can be sensitive also to other gases produced under the thermal decomposition they were delayed by two carbon filters situated in front of the sensor housing (3) and directly in the housing. The signal from the MIS-sensor was processed using an electronic recorder and PC (7). The recorder
detected capacitance of the MIS-sensor in picofarads. Change of the capacitance with time was measured. Sensitivity of the MIS-sensor to hydrogen (Figure 4) was calibrated before the measurements.

Experiments were carried out for KSPVG and MKESH cables widely used in household and industrial equipment, communication systems. Insulation of the KSPVG cable is made of polyethylene and its jacket is made of polyvinyl chloride. Both insulation and jacket of the MKESH cable are made of polyvinyl chloride. There are also some impurities intended improve mechanical and heat characteristics of the cable isolation [5].

**Figure 4.** Calibration curve of MIS-sensor.

### 4. Results and discussion
Response of the MIS-sensor to thermal treatment of the insulation and jacket of the KSPVG and MKESH cables are presented in Figures 5 and 6.

**Figure 5.** MIS-sensor response under heating KSPVG insulation and jacket.
In the experiment with KSPVG cable (Figure 5) of the MIS-sensor response was not found at room temperature. A small increase of the sensor readings was observed in the range from 170 to 235 °C of temperature inside the reactor. At temperature of 235 °C the response began sharply increase and the signal raised during 10 minutes. As known, capacitance of the MIS-sensor increases with increase of hydrogen concentration (see Figure 2). Such a sharp increase of the signal may mean that at 235 °C, an intensive evolution of hydrogen from the insulation and jacket of the cable begins. Appearance of small peaks (small jumps of capacitance) on the response curve can be caused by the evolution of hydrogen from impurities in the cable’s insulation and jacket at high temperature.

Increase of temperature to 238 °C leaded to partial relaxation of the MIS-sensor response, however the signal began to grow again when temperature was rised to 240 °C. After 15 minutes the reactor heater was switched off and the capacitance of the MIS-sensor began to decrease: the relaxation process began. According to calibration of the sensor (see Figure 2) the overall increase of the capacitance obtained in this experiment, which is equal to 75 pF, correspond to hydrogen concentration of 3 ppm.

![Figure 6. MIS-sensor response under heating MKESh insulation and jacket.](image)

In the experiment with the MKES cable (Figure 6) no response of the MIS-sensor was also found at room temperature. A small increase of the sensor readings was observed in the range from 150 to 200 °C of temperature inside the reactor. Above 200 °C the response sharply increased and the signal raising lasted for half an hour until temperature inside the reactor reached 215 °C and the output signal of the sensor was over loaded. After that the reactor heating was switched off. This experiment has also revealed that the capacity of the MIS-sensor increases with increasing reactor temperature and thermal decomposition of cable’s insulation and jacket leads to hydrogen evolution. Increase of the MIS-sensor capacitance by 120 pF observed in this experiment corresponds to hydrogen concentration of 7 ppm.

We should note in addition that in both experiments the sharp increase in the MIS-sensor response began at temperatures not exceeding 250 °C. Such low temperatures are typical for the early stages of a fire.

5. Conclusion

Our experiments have revealed that hydrogen evolution caused by thermal decomposition of isolation and jacket of KSPVG and MKES cable begins at temperatures typical for early stages of a fire.
Amount of the evolved hydrogen is enough to safely detect it by the MIS sensor. We concluded that a MIS-sensor can be used as a sensitive element for detection of fires at early stages.

Acknowledgments
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