Developing optoelectronic devices based on AFV properties to control the physical and chemical parameters of oil products

N Rakhimov, V Sh Mukhametshin and K T Tyncherov

Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation

E-mail: nemrah@mail.ru, info@of.ugntu.ru

Abstract. This article deals with the development of optical devices based on anomalous photovoltage films. We propose technology for the manufacturing of the optical radiation receiver based on anomalous photovoltage films and optoelectronic sensors to control the physical and chemical parameters of substances and materials. The photoreceiver is a semiconductor device that registers optical radiation and transforms the input optical signal into the output electrical signal of the photodetector. The goal of this work is to facilitate automation and improve labor productivity, as well as miniaturize and improve the quality of oil product analysis and develop a new type of telemetric sensors. The use of generator photoreceivers based on multilayer composition (MLC) as sensors facilitates the fast and accurate oil product measuring and monitoring without contact even for their significant quantities.

1. Introduction

The efficiency improvement for the development of oil reserves that are difficult to recover largely depends on the parameter control for the processes in oil beds and the changes in properties of produced fluids [1–8]. It is also crucial to increase the quality of oil product analysis using telemetric sensors.

2. Materials and Methods

The development of metering and monitoring using optics in the oil and gas industry is fraught with the emergence of various optoelectronic devices. These optoelectronic devices have various functions in nondestructive inspection systems. The generic photoreceivers (photodiodes, photoconductors, phototransistors, etc) in the optocouplers are used to control just one parameter of the object. If a generator MLC photoreceiver is used, the metering circuit becomes versatile [9, 10].

Anomalous photovoltage (APV) films are basically special converters that transform the light input into the anomalously high photovoltage [11]. This fact and the study of external impacts on the properties of films became the basis for the development of a range of optoelectronic devices.

The APV films were examined using a powdered cadmium telluride in vacuum with the substrate temperature of 200–250 °C. The film thickness was between 0.7 and 1.5 um.

The reverse side of the APV film was exposed to an artificial lighting source with the intensity of \(~8\times10^{-2}\) W/cm² and the power of 300 V/cm². During the experiment, we established that the reflection of light leads to the anomalous photovoltage effect. We assumed that if the reverse side of the glass or
quartz substrate was treated with Ag reflecting coating, the value of the APV effect shall change. The application of the silver reflecting coating on the reverse side of the glass substrate was done under the pressure of $10^{-4}$ mm Hg and the temperature of 250–600°C. These conditions were created to reduce the possible oxidation of the silver reflecting coating.

It is known [1] that the matrix APV receiver transforms the distributed radiation flux (optical image) into an electrical potential relief, creating on a glass-metal plate with discrete anisotropic conductivity, consisting of a glass base and thin covar wires piercing it. On one side of such a glass-metal plate, a thin layer of platinum is applied by cathodic sputtering, after which special holes are created with the help of a covar etchant.

A photosensitive semiconductor film is applied to the surface of the plate prepared in this way by thermal evaporation in a vacuum. This film generates APV under illumination. The deposition is carried out at an angle to the normal, as a result of which a discrete photovoltaic element in the form of an APV film is formed on the lateral surface of each hole, contacting one end with a covar fiber (output of an elementary photocell) and the other end contacting with a common platinum electrode on the surface of the plate. The system of such microphotocells forms a photodetector matrix, which is an autonomous sensor of multielement optical information.

With this in mind, the film production process was carried out as follows:

1. On one side of the glass substrate positioned at 45° to the molecular beam direction, a 0.2 um thick layer of cadmium telluride (CdTe) was applied under the temperature of 420-600 °C and the pressure of $10^{-5}$ mm Hg.

2. On the reverse side of the glass substrate, a 1 um thick reflecting layer of silver was applied using the thermal evaporation method under the substrate temperature of 250–300°C and the pressure of $10^{-4}$ mm Hg.

3. Results

Example 1. The photosensitive layer was applied by the thermal evaporation of crystalline cadmium telluride under the temperature of 400 °C in vacuum and the pressure of $10^{-4}$ mm Hg on the glass substrate. The substrate was positioned at 45° to the direction of the molecular beam. The thickness of the film was 0.2 um. Then the reverse side of the glass substrate was coated with a reflecting layer of silver using the thermal evaporation method under the substrate temperature of 250°C and the pressure of $10^{-4}$ mm Hg. The film thickness varied within 1 um. The value of anomalous photovoltage under the luminance of $10^4$ lx, in this case, was about 210–215 V.

The operating principle of any optron is based on the transformation of the electric signal into optical radiation [9, 10]. Thus, the photon acts as the information medium and facilitates a rather high optoisolation of the optron input and output.

This led us to formulate the main problem, i.e. the development of an APV film-based optron. This device must have the same properties as the emitter-photodiode, emitter-photocell, and other similar optrons.

We must provide that the developed APV-film optron can amplify even very low signals. During the experiments conducted, we found out that optrons with direct optical coupling based on the APV effect facilitated a steady signal amplification in the optical radiation receiver (ORR). Such optrons are optoelectronic voltage transformers with electromagnetic coupling.

In general, depending on the functional capabilities of the ORRs, they are divided into amplitude (integral) ones, which respond only to the average illumination value of their photosensitive surface, and coordinate-sensitive (informational) ones, which respond to the spatial distribution of the optical signal. Coordinate-sensitive ORRs, in turn, are subdivided into selective transformational, position-sensitive and two-dimensional coordinate-sensitive ones.

Selective transformational ORRs are used for image analysis and scanning, which converts a spatially distributed optical signal into a temporal distribution of an electrical video signal. Scanning can be based on a wide variety of physical phenomena using, as a rule, linear-progressive scanning of the image.
The authors investigated the possibility of applying the technology developed to control the physical and chemical parameters of various substances and materials using the APV effect. To this end, high-quality APV films were produced based on CdTe admixed with In, Cu, Al, and Se. The operating principle of the APV film is shown in the figure.

The authors also studied the operating principles of the optical radiation receiver. It was synthesized from thin semiconductor materials and shaped like a wedge. Its spectral range turned out to be pretty wide: from UV to IR.

**Figure 1.** The operating principle of the anomalous photovoltage film

The number of anomalous photovoltage films in the photoreceiver was calculated. Varying the layer production technologies, we could change the structure of transmission electrons to obtain, for instance, the heterojunction, for which the offset of continuity band was equal to the difference between the electron affinities of two materials.

The produced optical radiation devices based on the APV effect have very high photoconductivity. The spectral range of photosensitivity indeed covered the range from the UV to IR regions [11, 12].

We also studied the sensitivity of the devices to the magnetic fields. In multiple layer elements, anomalously high photomagnetic effects were observed.

As we established, the optoelectronic devices with MLC elements can be used to meter and research the topology of magnetic fields and objects. Generic photoreceivers need a power supply in their circuits to operate, and MLC photoreceivers with the APV effect do not require a power supply. Such photoreceivers become voltage sources when exposed to light.

4. Conclusion
The optical radiation elements in optoelectronic devices become autonomous photoreceivers with light excitation. Using such devices in nondestructive inspection and oil product analysis systems, it is possible to measure mechanical geometrical parameters of various objects and to identify the composition and structure of materials.
The multilayer photoreceiver reacts to light polarization. This property can be used to identify defects, evaluate surface roughness, and measure the thickness of complex structure objects. Besides, the exposure to light creates internal fields in MLCs, which gives them new photoelectronic properties.

Using MLC as the basis, it is possible to develop a matrix photoreceiver without any external power supplies working as an image converter (for various objects and items) into the electric potential pattern. In this case, the MLC-based optoelectronic device will operate as a control device for the product's appearance.

As it turned out, one of the most promising optical methods for non-destructive testing is an optoelectronic method based on an emitter and an APV receiver, which eliminates an external power source for an ORR, reduces weight and dimensions, and provides complete electrical isolation between the "light-emitting diode - ORR" circuits.

The optoelectronic primary converters using APV receivers as autonomous ORR open extensive opportunities in the development of controlling and metering devices for physical and chemical parameters of compounds and materials, which is completely confirmed by the existing extensive experience of using APV receivers.

References
[1] Miller G A 2007 Some Perspectives on Various Methods of Oil Shale Extraction, Piceance Basin, Colorado 27th Oil Shale Symp. Colorado School of Mines Golden (Colorado, 15-19 October 2007) p 14
[2] Akhmetov R T, Mukhametshin V V, Andreev A V and Sultanov Sh Kh 2017 Some Testing Results of Productive Strata Wettability Index Forecasting Technique SOCAR Proceedings 4 83–87. DOI: 10.5510/OGP20170400334
[3] Mukhametshin V V 2017 Eliminating uncertainties in solving bottom hole zone stimulation tasks Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering 328(7) 40–50
[4] Akhmetov R T and Mukhametshin V V 2018 Estimation of displacement coefficient with due account for hydrophobization of reservoir using geophysical data of wells IOP Conf. Ser.: Earth Env. 194(6) 062001. DOI: 10.1088/1755-1315/194/6/062001
[5] Kimos A 2011 Engineering Natural Gas from U.S. Shale Deposits. Retrieved from: http://buildipedia.com/aec-pros/engineering-news/extracting-natural-gas-from-shale
[6] Batalov D A, Mukhametshin V V, Dubinskiy G S and Andreev V E 2018 Laboratory grounding of waterproofing sealant based on acrylic polymers IOP Conf. Ser.: Earth Env. 194(4) 042003. DOI: 10.1088/1755-1315/194/4/042003
[7] Rogachev M K, Mukhametshin V V and Kuleshova L S 2019 Improving the efficiency of using resource base of liquid hydrocarbons in Jurassic deposits of Western Siberia J. of Mining Institute 240 711-715. DOI: 10.31897/PMI.2019.6.711
[8] Akhmetov R T, Kuleshova L S and Mukhametshin V V 2019 Application of the Brooks-Corey model in the conditions of lower cretaceous deposits in terrigenous reservoirs of Western Siberia IOP Conf. Ser.: Mater. Sci. Eng. 560(1) 012004. DOI: 10.1088/1757-899X/560/1/012004
[9] Grundmann M 2020 Nano-optoelectronics – concepts, physics, and devices (Berlin)
[10] Sakai K 2005 Terahertz optoelectronics (Berlin)
[11] Rakhimov N R and Seryoznov A N 2005 Coordinate-sensing optical receiver Patent RF № 2246779 bul no 5
[12] Rakhimov N R, Umarova G A and Zakirova K D 2019 Studying optoelectronic detectors for fatigue parameters control on machine-building metal surfaces J. of Phys.: Conf. Ser. 1333(6)