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RADIATION CHEMISTRY

Processes Induced in DLC/Polyimide Structures by Irradiation with ^{60}Co γ-Rays

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Abstract—The DLC/Kapton structures irradiated with ^{60}Co γ-rays at doses to 1 MGy have been studied by measuring transmission and attenuated total reflection (ATR) spectra. It has been shown that there are significant changes in the spectra in the ranges of vibrations of O–H, CH_2, and CH_3 bonds due to radiation-induced processes in the byproducts of polyimide synthesis and residual solvents. Significant differences were found in the radiation-induced processes occurring in the bulk and near-surface region of a polyimide film and DLC/polyimide structures. After irradiation, the bulk of polyimide exhibited bands due to asymmetric and symmetric vibrations of the CH_3 group. Bands associated with the vibrations of the CH_2 group were additionally observed in the near-surface region. The formation of CH_2 groups in the near-surface layer under irradiation was more pronounced in DLC/polyimide structures than in polyimide films; this was due to the additional supply of hydrogen from the DLC film.

Keywords: polyimide, diamond-like coatings, attenuated total reflection spectrum, absorption spectrum, γ-irradiation

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INTRODUCTION

Gas electron multiplier (GEM) is a gas detector consisting of two metal layers separated by a thin dielectric with a regular matrix of open (gas) channels in the dielectric between electrodes. Such detectors detect X-rays and charged particles with good spatial resolution. The advantages of GEMs are lower cost compared to that of a semiconductor detector of the same size and better resolution than that in scintillation detectors [1]. At present, GEMs are widely used in elementary particle physics, nuclear physics, and radiology and in nondestructive testing devices [1–3].

A polyimide (Kapton) substrate, in which a number of through holes with a diameter of 70 μm are etched with a step of 140 μm, is used as a dielectric for GEM detectors [1]. The main advantage of the Kapton substrate is its good radiation resistance [4, 5]. However, a high potential difference required to achieve high gain ratios can lead to irreversible damage to the polyimide substrate by an electric discharge due to breakdown in the gain region; this leads to deterioration in performance, up to a complete failure of the device, and to contact bridging. A promising approach to solve this problem is the use of GEM with resistive electrodes (RE-GEM) [3], which prevent the development of a self-sustaining discharge in a gas. Nanosized diamond-like carbon (DLC) coatings are the most suitable material for creating resistive electrodes for GEMs [6].

The GEM is exposed to radiation in the course of operation. This circumstance causes interest in studying the radiation resistance of DLC/polyimide structures. The aim of this work was to study the effect of gamma-radiation on the DLC/polyimide structure.

EXPERIMENTAL

The DLC layers to 400 nm thick were deposited onto a polyimide Kapton film (thickness, 200 μm) by high-current pulsed magnetron sputtering of GL-1 graphite with the following magnetron discharge parameters: discharge voltage, 900 V; pulse frequency,

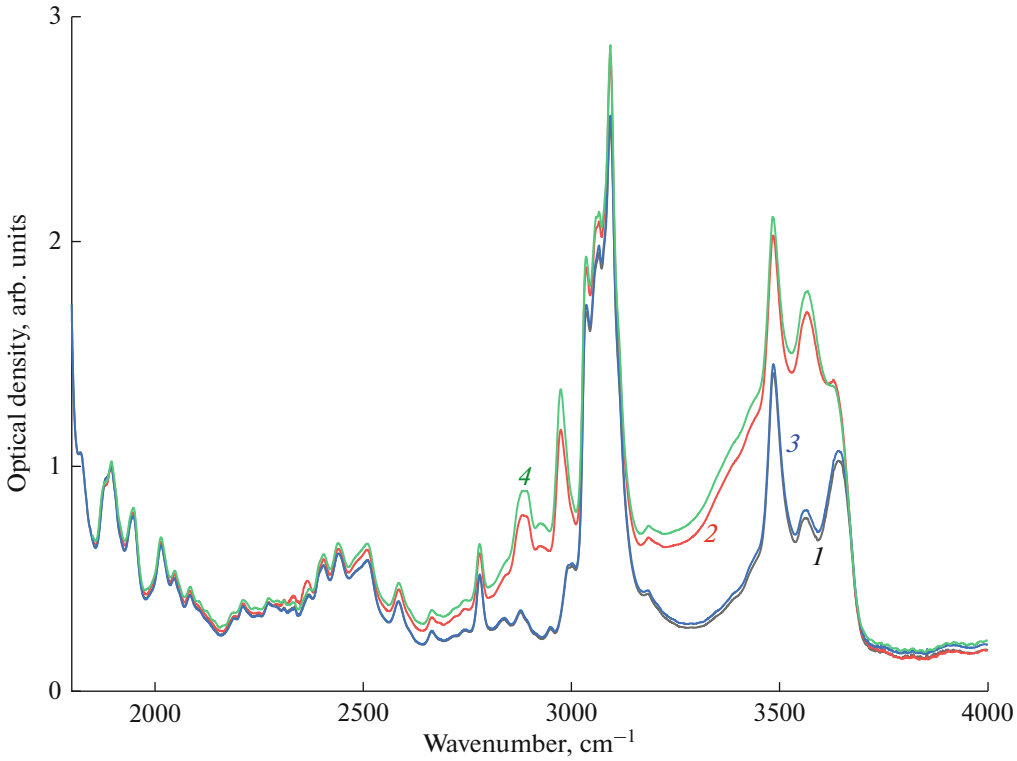

Fig. 1. Optical density spectra of (*1, 3*) initial and (*2, 4*) γ-irradiated (dose, 1 MGy) (*1, 2*) polyimide films and (*3, 4*) DLC/polyimide structures.

3 kHz; pulse duration, 50 μs; working gas, argon; working pressure, 2.7×10^{-3} Torr; and bias, floating potential. The deposition was carried out without sample heating. The coating thickness was set by the deposition time based on a deposition rate of 5 nm/min. Before sputtering, the substrates were cleaned in isopropyl alcohol using an ultrasonic bath for 15 min. Immediately before the deposition, the substrate was cleaned with a stream of argon ions (Ar^+) at an accelerating voltage of 3.5 kV for 30 min.

IR spectroscopy was carried out in two modes: transmission through the entire sample and measurements of attenuated total reflection (ATR) spectra. Measurements in the transmission mode were recorded as optical density spectra on a Vertex 70 spectrometer (Bruker Optik GmbH) in a range from 4000 to 400 cm^{-1}; the resolution was less than 0.06 cm^{-1}. It should be noted that, due to the high absorption intensity of polyimide in a wavenumber range of 400–1800 cm^{-1}, an analysis of the optical density spectra in this region is difficult to perform. The ATR spectra were measured at room temperature using an ALPHA spectrophotometer (Bruker Optik GmbH) in a range from 4000 to 1000 cm^{-1} with a resolution of 2 cm^{-1}; the number of scans was 24. Note that in the measurement of ATR spectra, the depth of penetration d_{eff} of a light beam into the sample depends on the wavelength λ; the refractive indices n_2 and n_1 of the prism and the sample, respectively; and the angle of incidence α; under the conditions of our experiment, d_{eff} was ~0.5λ [7]. For the used range of wavenumbers, d_{eff} varied from 1 to 5 μm. Thus, a comparison of the optical density and ATR spectra makes it possible to analyze radiation-induced processes both in the bulk and in the near-surface layers.

Photoresistive films were irradiated with γ-rays at doses to 1 MGy using an MRKh-γ-25M unit with a ^{60}Co γ-radiation source at room temperature and atmospheric pressure. The absorbed dose rate was 0.12 ± 0.003 Gy/s.

RESULTS AND DISCUSSION

The optical density spectra of unirradiated polyimide and DLC/polyimide structures almost coincided. The only difference was that the intensities of peaks at 3560 and 3640 cm^{-1} in the DLC/polyimide structures was slightly higher than in the polyimide (Fig. 1, curves *1*, *3*). However, the presence of the DLC film led to an increase in the background absorption of the ATR spectrum, which increased with the DLC film thickness. In this case, the shape of the spectrum (the position and intensity of the bands) did not change significantly (Fig. 2, curves *1*, *3*).

The optical density spectra (Fig. 1 and Table 1) exhibited a number of bands in a wavenumber range of