The dielectric properties of the diamond-like films grown by ion-plasma method

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Abstract: Diamond-like films was deposited by ion-plasma method in impulse mode. The dielectric properties of the diamond-like films in the frequency of $10^{-1} – 10^6$ Hz at room temperature were studied. The dispersion of the dielectric parameters indicates the existence of non-Debye relaxation mechanism correlates with structural changes. The charge transfer is temperature activated hopping process.

1. Introduction

Diamond-like thick films are one of the first coating used for hardening the cutting tool runs at high speed without forced. Also the mechanical properties are of interest structural, optical and electrical characteristics of diamond-like films on various substrates. In connection with the possible practical application of the grown layers is especially important to study their dielectric properties. The aim of this study was to determine the characteristics of the dielectric relaxation processes in the diamond-like films by dielectric spectroscopy. This method allows us to investigate not only the dielectric properties, but their relationship with the structure of the systems [1].

Diamond-like films was deposited by ion-plasma method on device UVNIPA-1-001 in impulse mode. The substrate was a tantalum foil with a thickness of 0.5 mm. The thickness of the film was $d \sim$ 3.7 µm [2]. The samples in the deposition chamber are rotated, the resulting films are deposited evenly and repeat the relief of the substrate (figure 1).
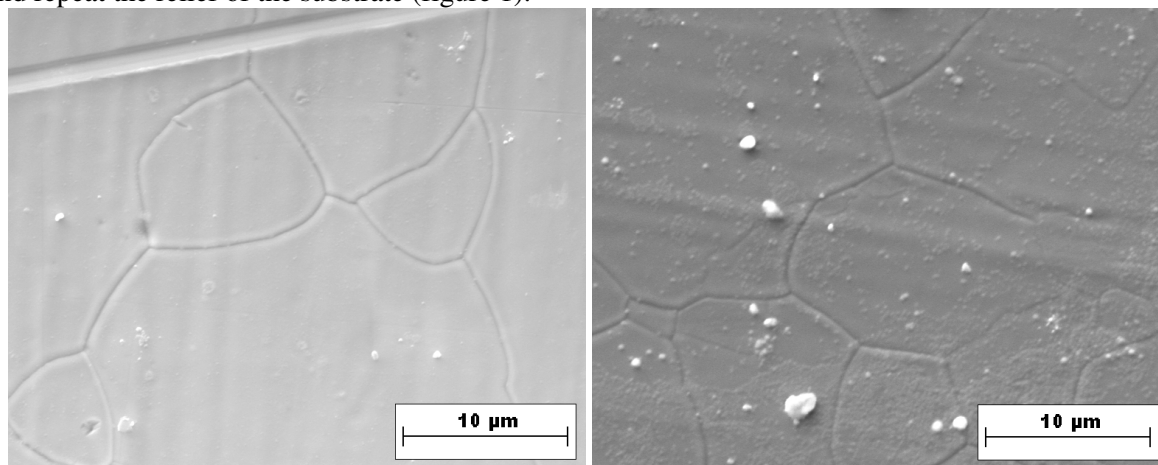

Figure 1. SEM image of the surface polished tantalum substrate (left) and diamond-like thin film thickness d = 3.7 µm on tantalum substrate (right)

2. Experimental

Measurements of the frequency dependence of the complex dielectric permittivity (dielectric constant $\mathcal{E}$ ' and loss factor $\mathcal{E}$ ") and complex conductivity were conducted on the dielectric spectrometer "Concept 41" of NOVOCONTROL Technologies GmbH & Co (Germany), in a wide range of frequencies ($f = 10^{-1} - 10^6$ Hz) at room temperature [3]. The device consists of a frequency analyzer, impedance measuring cell, temperature control system, automatic data collection with evaporation system and the supply of nitrogen. The spectrometer comprises an alternating voltage generator, which

is fed to the sample analyzer and a current value measuring current and its phase shift relative to the voltage generator.

The complex impedance is given by:

$$Z^*(\omega) = R + \frac{1}{i\omega C} = Z' + iZ'' = \frac{U_0}{I^*(\omega)}$$

(1)

"Concept 41" is connected to a personal computer with software for data acquisition and processing. As the experimental data collected values of the imaginary and the real part of the impedance measured with the sample cell. The spectra of the complex permittivity and complex conductivity and impedance spectra were calculated from the following formulas:

$$\varepsilon^* = \varepsilon' - i\varepsilon'' = \frac{-i}{\omega Z^*(\omega)} \frac{1}{C_0}$$

(2)

where $C_0 = \dfrac{\varepsilon_0 S}{d}$ - capacity of the empty cell, $C_0 = \dfrac{\varepsilon \varepsilon_0 S}{d}$ - capacity of the sample cell.

Complex conductivity is expressed through the impedance:

$$\sigma^* = \sigma' - i\sigma'' = \frac{-i}{\omega Z^*(\omega)} \frac{S}{d}$$

(3)

The experimental curves are approximated by a function of Havriliak-Negami [4]:

$$\varepsilon^*(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon}{[1 + (i\omega\tau)^{\alpha_{HN}}]^{\beta_{HN}}}$$

(4)

where ε_∞ - high-frequency limit of the real part of the dielectric constant, $\Delta\varepsilon$ - dielectric increment (the difference between the low-frequency and high-frequency limits), $\omega = 2\pi f$, α_{HN} and β_{HN} - shape parameters that describe respectively the symmetric ($\beta = 1$ - the distribution of the Cole-Cole) and asymmetric ($\alpha = 1$ - the distribution of the Cole-Davidson) extension of the relaxation function.

3. Experimental results

The obtained values of the relaxation parameters α and β (Table 1) suggest that in the studied range of frequencies observed non-Debye relaxation process with an asymmetric distribution of relaxation according to the Cole-Davidson model. This fact is confirmed by the views of the Cole-Cole diagram (Figure 2)

Table 1. The values of the relaxation function parameters Havriliak-Negami.

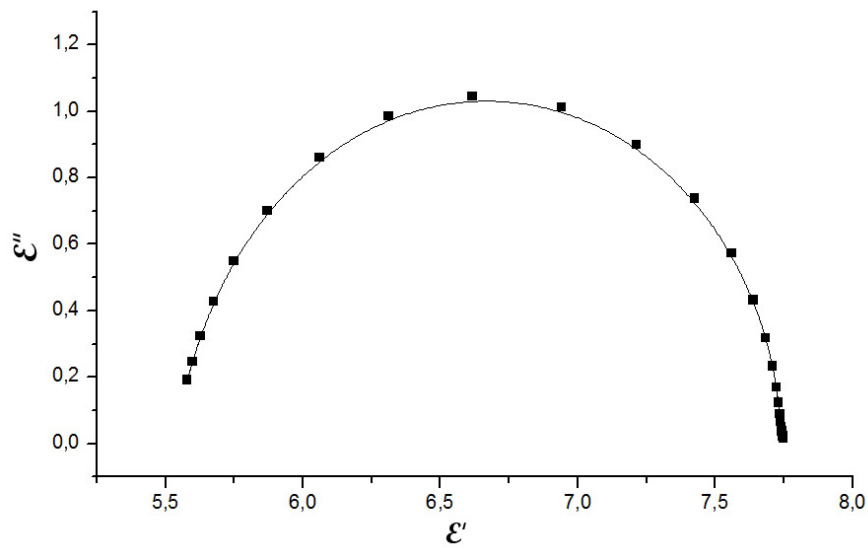| τ_{max},	$\Delta\varepsilon$	α	β
$2,48 \cdot 10^{-6}$	2,29	0,97	0,89

Figure 2. Cole-Cole diagram for the diamond-like film at room temperature

The observed maximum of $\mathcal{E}''$ (figure 3) and a sharp increase in $\mathcal{E}'$ (figure 4) to the steady-state value in the midrange, indicate the existence of a mechanism of dipole relaxation and interfacial polarization. Dipole relaxation polarization caused by jumps of charge carriers between the centers with different energy to produce quasi dipoles. The charge carriers may be various impurities, absorbed on the surface after the film growth process. The interfacial polarization is related to the structural characteristics of the films, namely the existence of amorphous carbon clusters, the size of which increases with increasing film thickness.
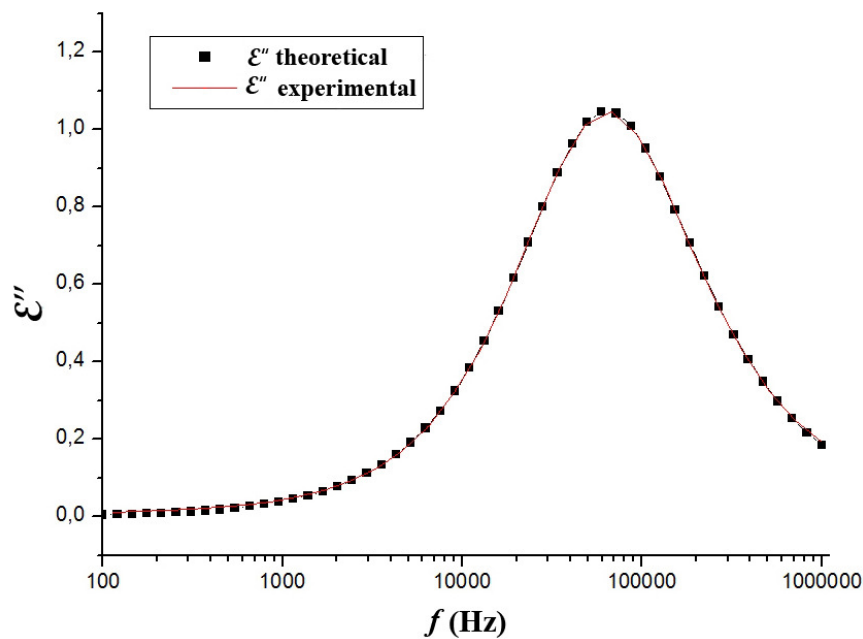

Figure 3. The frequency dependence of the imaginary part of the complex dielectric permittivity at room temperature
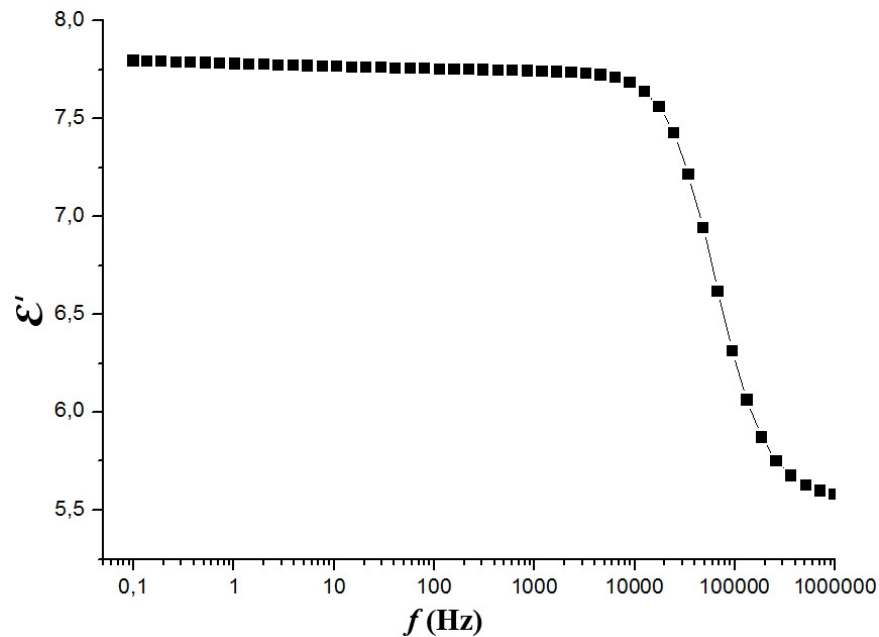
Figure 4. The frequency dependence of the real part of the complex dielectric permittivity at room temperature

Over the whole range of frequencies, for the real part of the complex conductivity, revealed the existence of dependence of the form $\sigma'(\omega) \sim \omega^s$, which is a sign of manifestation of hopping conduction mechanism. In this area there are two variance σ': first - high for $f > 10^3$ Hz, the second - the region of lower frequencies (figure 5). In both areas, the exponent is a frequency-dependent parameter and takes values $s = 0.65 \ldots 0.95$.
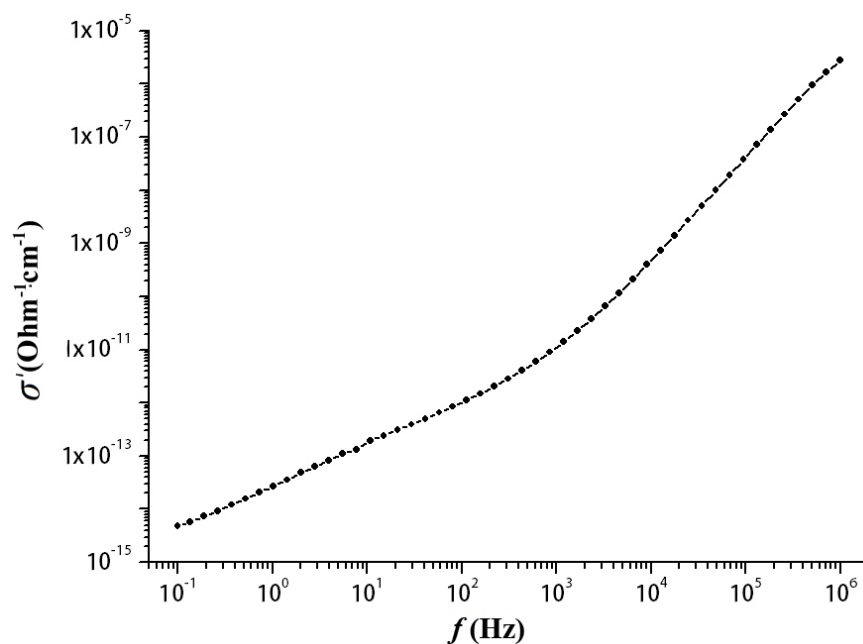

Figure 5. The frequency dependence of the real part of the complex conductivity at room temperature

Conclusions

The dispersion of the dielectric parameters indicates the existence of non-Debye relaxation mechanism correlates with structural changes. The charge transfer is temperature activated hopping process. The mechanism of the dipole relaxation and interfacial polarization due to the presence of impurities and the different phases in the film. The dielectric properties of diamond-like films was found that the relative permittivity of samples $\mathcal{E} \sim 11$.

References

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