Charge Transport Anisotropy in Ultrananocrystalline Diamond

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Transport properties of ultra-nanocrystalline diamond (UNCD) films synthesized by MWCVD using $Ar/CH_4/H_2/N_2$ gas mixtures with nitrogen concentration changing from 0 to 15% have been investigated in the dark and by transient photocurrent technique. Film characterization was performed using both coplanar and sandwich contact configurations. At low electric field strength, linear electrical characteristics are detected, independent of then nitrogen content. In this regime, the dark conductivity of UNCD films spans over several order of magnitude according to the amount of incorporated nitrogen, preferentially distributed at the grain boundaries. At variance, a supralinear voltage dependence of the dark current is found at higher bias in nitrogen containing films, in relation to a space charge limited transport mechanism.

Under light excitation at λ = 193 nm with 3 ns pulses, a similar behaviour is observed in the voltage dependence of the photocurrent peak, suggesting the occurrence of field assisted charge detrapping effects.

More precisely, the transient photocurrent signal in coplanar configuration show a pulse decay according to a single exponential time dependence, with a time constant τ=7 ns, for N_2=0%. Similar pulse shape are detected in sandwich configuration, in agreement with the randomly oriented diamond nanocrystalline structure observed in absence of nitrogen addition during film synthesis [1].

At higher N_2%, the shape of the current signal in the time domain 10^{-9}-10^{-6} s largely changes, showing not only a nanosecond time response, but also a long tail extending towards the μs time domain, indicating a dispersion of carrier transit times. More precisely, after the initial fast decay in the nanoseconds range, the photocurrent signal decreases according to two power-laws with slopes intersecting at a characteristic transit time Tt. Such slope values are related to an average parameter α which reflects dispersion of carrier trapping times into band tail states.

For UNCD films deposited with N_2=5%, a short time constant τ=12 ns is found when coplanar contact configuration is used. The persistence of photocurrent signal towards the μs time scale, indicates a transit time Tt=0.4 μs, a dispersion parameter α= 0.7 and a band tail state slope E_0 = 35 meV.

The relative weight between slow and fast photocurrent components, as well as transit time and dispersion parameter values largely change in sandwich contact configurations, where shorter transit time and smaller band tail state slopes are found.

Charge transport anisotropy is observed in the dark also when the N_2 content in the gas phase reaches 15%. In this case, only a persistent photocurrent contribution is clearly detected.

Such results suggest the occurrence of nitrogen induced morphology changes, in agreement with previous findings in similar UNCD films [1-2] and support the existence of a nitrogen induced partial orientation of elongated diamond domains.

[1] R. Arenal, P. Bruno, D.J. Miller, M. Bleuel, J. Lal, D.M. Gruen, *Phys. Rev. B* **75**, 195431 (2007).
[2] I.I. Vlaslov, O.I. Lebedev, V.G. Ralchenko, E. Goovaerts, G. Bertoni, G. Van Tendeloo, V. Konov, *Adv. Mater.* **19**, 4058 (2007).