ON THE MECHANISM OF MATERIAL CONSOLIDATION DURING SPARK PLASMA SINTERING

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Spark plasma sintering (SPS) is a modern method of electrostimulated consolidation of substances and materials under high pressure and temperature. The SPS has been described for a wide range of objects [1]. The presented work provides consolidated samples of graphene nanoflakes (GNFs), hetero-substituted with N, P, and Si atoms GNFs, as well as their surface oxidized analogues. To identify the mechanism and influence of the SPS processing parameters, the contributions of temperature (as the input heat *Q*) and pressure (as the performed work *A*) were estimated tale into account that both parameters affect the change in internal energy ΔU, according to the first law of thermodynamics:

$$\Delta U = A + Q$$

The mechanical work *A* used to shrink the samples can be calculated as the product of the applied force *F*, expressed in newtons, and the displacement *d* (sample shrinkage), expressed in meters:

$$A = F \cdot d$$

The force *F* was calculated as the multiplication of the pressure *P* and the area *S* of the sintered sample:

$$F = P \cdot S$$

The shrinkage of the samples over time strongly depended on the nature of the sintered sample. The greatest shrinkage and, consequently, the greatest mechanical work were characterized for P-doped GNFs. Surface oxidized GNFs were more compacted than GNFs.

The work of electric current *Q* was calculated using the equation:

$$Q = \Sigma i_n \cdot U_n \cdot (\tau_{n+1} - \tau_n),$$

where *i* – the current expressed in amperes, *U* is the voltage expressed in volts, and τ is the exposure time expressed in seconds.

The work of the current exceeded the mechanical work by several orders, which implies that it plays a significantly greater role in the consolidation of samples. The work *Q* strongly depends on the nature of the sample: non-conductive materials, as well as the presence of non-conductive impurities, lead to local overheating and breakdown [2]. This is why the greatest morphological changes occurred with the oxidized MGF sample, as the surface oxygen-containing groups are non-conductive.

1. Suslova E.V., Kozlov A.P., et. al. // Russ. Chem. Bull. 2023. Vol. 72, Nr 2. P 345–366. https://doi.org/10.1007/s11172-023-3804-4

2. Suslova E.V., Epishev V.V., et al. // Appl. Surf. Sci. 2021. Vol. 535. P. 147724. https://doi.org/10.1016/j.apsusc.2020.147724

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