Formation of electrically conductive nanocomposites with three-dimensional networks of carbon nanotubes for bioelectronics

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Carbon and protein bioelectronics

- Smart bioelectronics fabricated from nanocarbons have the potential to enable seamless integration with electrogenic cells and tissues [1].

- With favorable stability and biocompatibility, natural proteins are an exceptional alternative to the currently used synthetic materials [2].

- In the field of bioelectronics, the use of nanocomposites is effective, since the matrix can be biological, and the filler can impart functional properties.


Carbon nanotubes welding methods

Technology of forming 3D SWCNT networks by laser welding

Used single wall carbon nanotubes

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, nm</td>
<td>~1,4-1,6</td>
</tr>
<tr>
<td>Length, μm</td>
<td>~0,3-0,8</td>
</tr>
<tr>
<td>Clusters diameter, μm</td>
<td>~0,3</td>
</tr>
</tbody>
</table>

Scanning electron microscopy of single-walled carbon nanotube clusters

Formation of thin films by centrifugation at a speed of 300-1000 rpm for 2 minutes

Laser irradiation

1,25x1,25 mm²
Laser irradiation

1 - laser radiation source, 2 - galvanometric scanner with two mirrors, 3 - lens, 4 - distance sensor, 5 - focused laser beam, 6 - composite nanomaterial sample, 7 - optical table, 8 - axis of laser beam motion

Laser setup scheme
Structure of 3D networks SWCNT

SEM images of the structure of samples of thin SWCNT films with a SWCNT concentration of 0.68 wt%: before irradiation (a), after laser radiation power of 1.5 W (b), 1.8 W (c), 4.4 W (d)

SEM images of the structure of samples of thin SWCNT films with a SWCNT concentration of 0.13 wt%: before irradiation (a) after laser radiation power of 1.2 W (b), 1.5 W (c), 1.8 W (d)
Technology of forming 3D SWCNT networks in biopolymer matrices by laser welding

Dispersion of components: 0.001 wt% SWCNT, 25 wt% albumin, 1 wt% collagen, 2 wt% chitosan

Scheme of the formation of 3D SWCNT networks in biopolymer matrices

Experimental samples of 3D SWCNT networks in biopolymer matrices in various shapes: square (a), rectangle (b), circle (c)

The procedure for implantation of experimental samples: incision (a), suture (b). The operation was carried out in conjunction with the Russian State Agrarian University - Moscow Agricultural Academy. K.A. Timiryazeva
Effect of 3D SWNCT networks on biological tissues and blood

1 - space between the 3D network and surrounding tissues, 2 - connective tissue, 3 - muscle tissue, 4 - SWCNT clusters

Implantation area after 10 days (a) and 1 month (b). Dry samples were prepared by the Russian State Agrarian University - Moscow Agricultural Academy named after K.A. Timiryazeva

Raman spectra of SWCNTs obtained at the excitation laser wavelengths of 514 nm (a) and 633 nm (b)

Raman spectra of blood smears of laboratory birds obtained at the excitation laser wavelength of 514 nm (a) and 633 nm (b)
Electrical conductivity

Nanocomposites obtained by laser formation technology have improved conductivity values compared to nanocomposites formed without laser exposure.

The highest conductivity values were achieved in rectangular samples; therefore, this form of nanocomposites is the most optimal for further bioelectronic applications.
Results

- A laser welding of carbon nanotubes method has been developed. The formation of welded joints of nanotubes at a laser irradiation power from 1.2 W to 1.8 W was proved using scanning electron microscopy.

- A technology for laser formation of biopolymer nanocomposites with high electrical conductivity CNT networks for bioelectronic applications has been developed.

- The specific electrical conductivity of 3D SWCNT networks in biopolymer matrices, depending on the sample area, ranged from $16.44 \pm 0.27$ S/m to $40.20 \pm 0.50$ S/m. The electrical conductivity values of the networks exceed the electrical conductivity values for the natural muscle (0.16-0.61 S/m).

- It has been histologically proven that 3D SWCNT networks promote muscle tissue regeneration.

- With the help of Raman spectroscopy of blood smears of laboratory birds, the removal of the 3D SWCNT network from the body has been proven 3 months after implantation.

- The technology for creating biocompatible nanocomposites with controllable electrical conductivity and mechanical characteristics opens up wide opportunities for use in bioelectronics, in particular, for the production of piezoresistive strain sensors, artificial muscles, three-dimensional tissue engineering frameworks.
Thank you for your attention!

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