Nanotech Energy

Inkjet **Graphene Inks**

High Quality Graphene Inks for a Variety of Applications

Nanotech Energy provides a highly conductive, cost-effective and environmentally friendly custom-made graphene inks for inkjet printing.

- Graphene, Silver Nanoparticles and Nanowires
- Fast Drying, Eco-Friendly and Chemically Stable
- Good for Printed and Flexible Electronics
- Water & Solvent Based Inks
- Large Quantities Available

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Why Graphene Ink?

WORLD'S FIRST

Nanotech Energy owns what can arguably be considered the world's first graphene patent filed in May of 2002. Nobel Prize winning researchers Sir Andre Geim and Konstantin Novoselov first work on graphene was published two years later. Since 2002, Nanotech Energy has staked its claims on 28 patients in graphene production, processing, applications and much more.

HIGHEST SURFACE AREA OF ANY GRAPHENE IN THE MARKET

Graphene offers impressive combination of high strength, chemical stability and excellent conductivity. We are currently producing graphene via rapid and environmentally friendly methods, which represents a key to low-cost manufacturing of flexible and printed electronics, composites and novel energy solutions. We also offer two forms of graphene whose electronic conductivity has been optimized to meet the needs of our customers. With over 2000 m^2/g, Nanotech Energy offers graphene with the world's largest specific surface area of any commercial graphene. As a result, this graphene shows potential to transform the industry of printed electronics enabling devices such as solar cells, flexible displays, thin film transistors, photodectors, supercapacitors, batteries, sensors, etc.

	HG	PG
Material	Graphene, Process H	Graphene, Process P
Surface area* (m^2/g)	2519	2057
Conductivity (S/m)	1047	3615
Sheet size	Adjustable (0.1 to 10 μm)	Adjustable (0.1 to 10 μm)

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Inkjet Printable Graphene Inks: Water Based GO Inks

Nanotech Energy is developing inkjet printable inks based on graphene with tunable viscosity and surface tension that are ideal for inkjet printing and down stream applications. With its thermal and chemical stability and intrinsic flexibility making our inks ideal for flexible electronics. Unlike graphene, our functionalized graphene oxide results in stable dispersions in water and organic solvents allowing for faster processing with various printing techniques. The resulting films demonstrate superior mechanical properties with excellent adhesion to the substrates. These GO circuits can be converted back to graphene with excellent electrical conductivity using a number of methods presented in page 6.

	Nanoink-IJG04-W50	Nanoink-IJG06-W50	Nanoink-IJG08-W50	Nanoink-IJG09-W50	Nanoink-IJG010-W50
Chemistry	Graphene Oxide	Graphene Oxide	Graphene Oxide	Graphene Oxide	Graphene Oxide
Solvent	Water	Water	Water	Water	Water
Viscosity (cps)	6 cps@6 rpm; and 5 cps@60 rpm	9 cps @ 6 rpm; and 11 cps @ 60rpm	31 cps @6 rpm; and 15 cps @60 rpm	50 cps @ 6rpm; and 28.6 cps @ 30rpm	121 cps @ 6 rpm; and 38 cps @ 60rpm
Particle size distribution (nm)	50-800	50-800	50-800	50-1717	80-2621
Solid content, concentration (mg/mL)	4	6	8	9	10
Applications	Inkjet, Spray & Spin coating				
Quantity	50 mL	50 mL	50mL	50 mL	50 mL
Curing conditions	RT for 30 min or 60C for 5 min	RT for 30 min or 60C for 5 min	RT for 30 min or 60C for 5 min	RT for 30 min or 60C for 5 min	RT for 30 min or 60C for 5 min
Activation conditions	See page 5				

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Inkjet Printable Graphene Inks: Solvent Based GO Inks

Likewise, we also provide graphene oxide based inks in a variety of organic solvents, see specs below.

	GRAPHENE, GRADE H	GRAPHENE, GRADE P
Chemistry	Graphene Oxide	Graphene Oxide
Solvent	Ethylene Glycol	Dimethyl Formamide
Viscosity (cps)	21 cps @6 rpm	3 cps @ 6 pm
Particle size distribution (nm)	50-800	100-800
Solid content, concentration (mg/mL)	1	4
Applications	Inkjet, Spray & Spin coating	
Quantity	50 mL	50 mL
Curing conditions	100C for 5 min	100C for 5 min
Activation conditions	See page 5	

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Product Code SKU Reader

Nanotech Energy offers conductive inks with several formulations enabling the users to define the ink best for their application. The chart below allows our customers to read the composition of our conductive inks based on the application method, type of the conductive material, the solvent and the amount of the ink.

SAMPLE PRODUCT NAMES ARE: Nanoink-SPGO-W50 | Nanoink-IJHG-D50

Nanoink **use** **material** **solvent** **quantity**

- **quantity**
  - 50: 50mL
  - 100: 100mL
  - 500: 500mL
  - 1000: 1Liter
- **solvent**
  - W: Water
  - N: NMP
  - D: DMF
  - E: Ethylene Glycol
- **material**
  - HG: Graphene, process H
  - PG: Graphene, process P
  - GO: Graphene oxide
- **use**
  - IJ: Inkjet
  - SP: Screen Printing
- **Nanoink**
  - Product name

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Sintering and Activation of the Inks

The next step is to establish electrical conductivity for the printed GO circuits. We suggest one of the following methods:

UV Curing

GO exhibits strong light absorption capability. The absorbed light is converted into heat causing the deoxygenation of GO into graphene. The treatment of GO circuits with a UV lamp (wavelength < 210 nm) is an effective method for the reduction of GO within 30-60min.

[1] Tu, Yudi, Hiroshi Nakamoto, Takashi Ichii, Toru Utsunomiya, Om Prakash Khatri, and Hiroyuki Sugimura. “Fabrication of reduced graphene oxide micro patterns by vacuum-ultraviolet irradiation: From chemical and structural evolution to improving patterning precision by light collimation.” Carbon 119 (2017): 82-90

[2] Giardi, R., S. Porro, A. Chiolerio, E. Velasco, and M. Sangermano. “Inkjet printed acrylic formulations based on UV-reduced graphene oxide nano composites.” Journal of Materials Science 48, no. 3 (2013): 1249-1255

Flash activation

This is probably the fastest and most effective technique. GO can be photo thermally reduced upon exposure to a pulsed Xenon flash at ambient conditions. Compared to chemical and high temperature thermal treatments, flash reduction is rapid, chemical-free, and energy efficient. It could be an enabling technique that holds great promise for patterning. GO films in device and composite applications. Pulse duration is usually in the millisecond timeframe.

Promaster FA-1000 Flash is a good option
https://www.amazon.com/FA-1000-Electronic-Flash-41495/dp/B000928KJM/ref=sr_1_1?ie=UTF8&qid=1543346411&sr=8-1&keywords=promaster+fa1000

Sunpak Super 383 flash would work
https://www.amazon.com/SUNPAK-383-Sunpak-Super-Flash/dp/B00007E8D1/ref=sr_1_1?ie=UTF8&qid=1543345822&sr=8-1&keywords=Sunpak+383

Technically any flashlight would work as long as it has the power

[3] Gilje, Scott, Sergey Dublin, Alireza Badakhshan, Jabari Farrar, Stephen A. Danczyk, and Richard B. Kaner. “Photothermal deoxygenation of graphene oxide for patterning and distributed ignition applications.” Advanced Materials 22, no. 3 (2010): 410-423.

[4] Cote, Laura J., Rodolfo Cruz-Silva, and Jiaxing Huang. “Flash reduction and patterning of graphite oxide and its polymer composite.” Journal of the American Chemical Society 131, no. 31 (2009): 11027-11032

IR Treatment

Deoxygenation of GO can be realized by infrared heating under ambient environment. Experiments showed that exposure of GO circuits to a 250W IR lamp leads to significant reduction in sheet resistance after 10 minutes only. See this reference.

[5] Kong, De, Linh T. Le, Yue Li, James L. Zunino, and Woo Lee. “Temperature-dependent electrical properties of graphene inkjet-printed on flexible materials.” Langmuir 28, no. 37 (2012): 13467-13472.

Laser Sintering

Transparent conducting electrodes were also produced through laser annealing using a 500 mW green laser. CO2 laser table is also a good option. Laser pulses causes local heating to reduce GO without affecting the substrate.

[6] Del, Sepideh Khandan, Rainer Bornemann, Andreas Bablich, Heiko Schafer-Eberwein, Jiantong Li, Torsten Kobalt, Mikael Ostling, Peter Haring Bolivar, and Max C. Lemme. “Optimizing the optical and electrical properties of graphene ink thin films by laser-annealing.” 2D Materials 2, no. 1 (2015): 011003.

[7] El-Kady, Maher F., and Richard B. Kaner. “Direct laser writing of graphene electronics.” ACS nano 8, no.9 (2014): 8725-8729.

[8] Hwang, Jee Y., Maher F. El-Kady, Mengping Li, Cheng-Wei Lin, Matthew Kowal, Xu Han, and Richard B. Kaner. “Boosting the capacitance and voltage of aqueous super capacitors via redox charge contribution from both electrode and electrolyte.” Nano Today 15 (2017): 15-25.

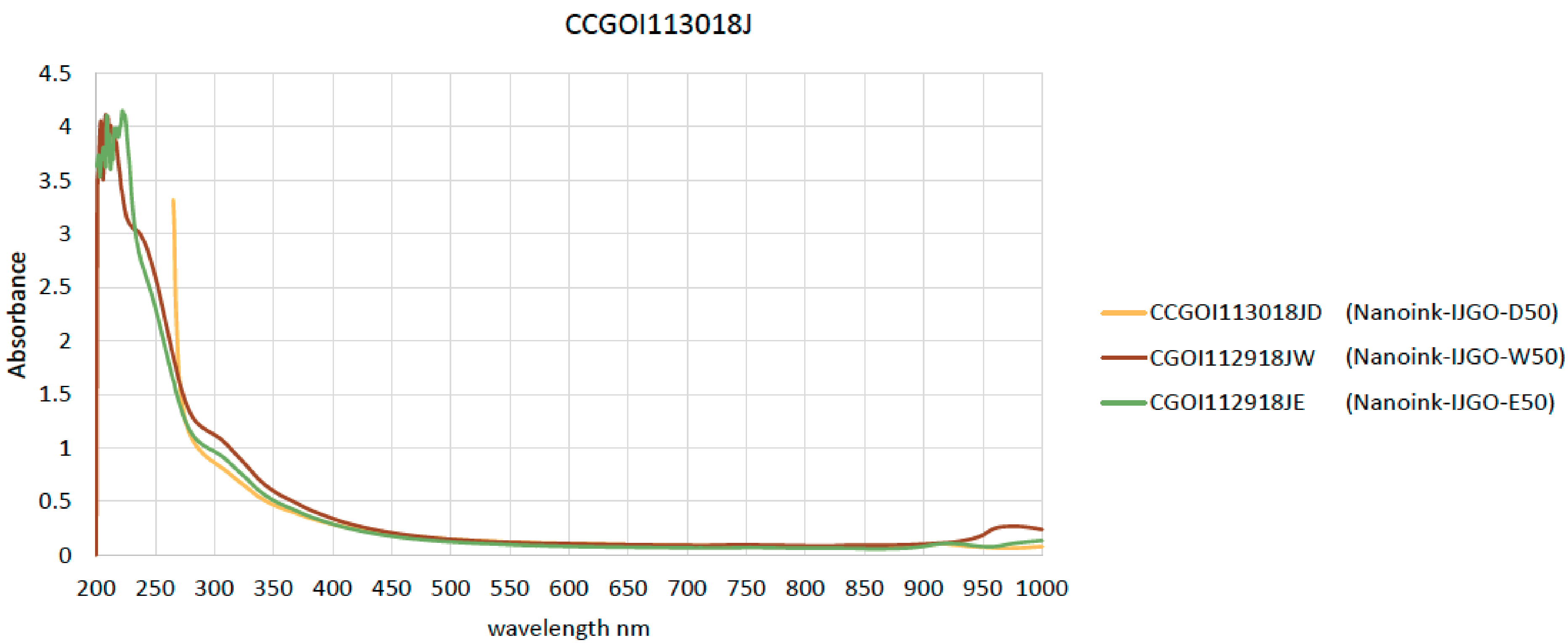
Pulsed Light Annealing

A high-intensity pulsed light from a Xenon lamp can do the same job. Once again, the huge difference in the optical absorption of graphene oxide and the underlying substrate causes selective annealing and reduction of GO without damaging the substrate.

[9] Secor, Ethan B., Bok Y. Ahn, Theodore Z. Gao, Jennifer A. Lewis, and Mark C. Hersam. “Rapid and versatile photonics annealing of graphene inks for flexible printed electronics.” Advanced Materials 27, no. 42 (2015): 6683-6688.

UV-Vis Spectra and Stability of the Inks

UV-Vis absorption spectroscopy can be used to obtain further insights into the solvent's ability to disperse graphene oxide. The UV-Vis spectra in different solvents were obtained under identical conditions so that proper comparisons could be made between solvents. Figure below shows the UV-Vis absorption spectra for three stable graphene oxide dispersions, specifically in water, dimethylformamide and ethylene glycol. Two characteristic features can be observed in the spectrum that can be used as a means of identification: The first is a shoulder at ~310 nm, corresponding to n-π* transitions of C=O bonds and a maximum at 230 nm, which can be attributed to π-π* transitions of aromatic C-C bonds. The presence of these peaks confirms the successful dispersion of GO sheet in the solvent. Note that the spectra were recorded in the wavelength range from 200 to 1000 nm, except for DMF, for which the data were collected above 265 nm as a result of the strong absorption of the solvent at smaller wavelength.



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