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Graphene films on silicon carbide (SiC) wafers supplied by Nitride Crystals, Inc.

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Nitride Crystals, Inc. is a privately held US corporation with a subsidiary in St.-Petersburg, Russia. Nitride Crystals supplies high quality epitaxial graphene films on silicon carbide (SiC) wafers. Our graphene films are manufactured by the method of thermal decomposition of silicon carbide.

Graphene

Graphene is a two-dimensional crystal comprised of a monolayer of carbon atoms arranged in a hexagonal honeycomb lattice by sp2 bonding.

Graphene has unique properties like high surface-to-volume ratio, low electrical noise, and exceptional transport properties, associated with its two-dimensional structure. It is about 300 times stronger than the strongest steel. It efficiently conducts heat and electricity and is nearly transparent.

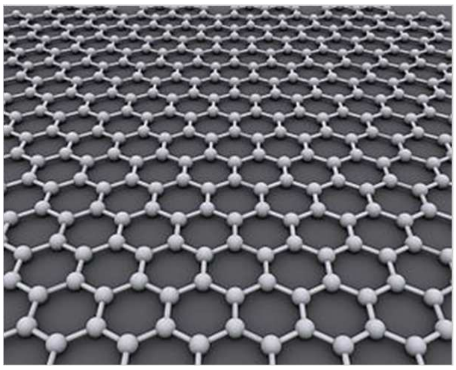

Fig. 1. Graphene hexagonal lattice

Due to its outstanding properties, graphene is a promising material for electronic applications and sensors. Possible applications of graphene include microwave transistors, optics, gas and bio sensors, spintronics, micromechanics.

Methods of graphene films manufacture

Graphene was first demonstrated in 2004 by Andre Geim and Konstantin Novoselov, the Noble Prize winners in 2010. Since then graphene has been produced by different techniques, among them exfoliation, chemical intercalation, chemical vapor deposition (CVD) and thermal decomposition of silicon carbide (SiC).

There are different methods of obtaining graphene, which can be divided into several main groups: mechanical methods, chemical methods, methods of growth on different wafers and the method of thermal decomposition of SiC.

The method of mechanical exfoliation was developed by A. Geim and K. Novoselov. They initially used an adhesive tape to pull graphene sheets away from graphite. Achieving monolayer graphene typically requires multiple exfoliation steps. The exfoliation method has no analogs for manufacture of large size (up to ~1 mm) samples suitable for transport and optical measurements.

The method of chemical intercalation implies intercalation of graphite by acids with the subsequent ultrasonic splitting. This method is characterized by large material output, however, small size of the obtained films (~10-1000 nm). Another disadvantage the method is the destruction of the crystalline lattice of graphene, leading to a considerable degradation of its electric properties.

The most perspective methods of graphene manufacture from the point of view of industrial application are chemical vapor deposition (CVD) and thermal decomposition of SiC.

Chemical vapor deposition is rather cheap and easy method of obtaining graphene of relatively high quality. Graphene films are mostly deposited to surfaces of such metals as Ni, Pd, Ru, Ir, Cu and others. Today large size polycrystalline graphene films can be grown by CVD. The advantage of this method is scalability of the obtained samples. Difficulties of the CVD method relate to control of monolayer growth as well as occurrence of defects in the grown material. At present the majority of manufacturers of graphene films for industrial applications use this technique.

Technology used by Nitride Crystals

Nitride Crystals has developed the technology for growth of graphene films on SiC wafers by thermal decomposition of the SiC surface in argon ambient. This graphene film technology on SiC wafers can be used for production of gas sensors and bio sensors.

Fig. 2. System for growth of graphene films on SiC

Realization of this method requires heating of the SiC wafer to rather high temperatures (>1400°C). Fig. 2. shows the image of the system for growth of graphene films. Heating of the growth cell is carried out by the inductive method. For heating we use a high-frequency transistor generator with a multi-coil inductor with a growth camera and a graphite crucible inside.

Growth of graphene on SiC can be carried out either in high vacuum, or in inert gas (argon) ambient. It is known that the use of argon in the growth process makes possible to improve structural perfection of a graphene film, as well as to improve considerably the homogeneity of graphene coverage.

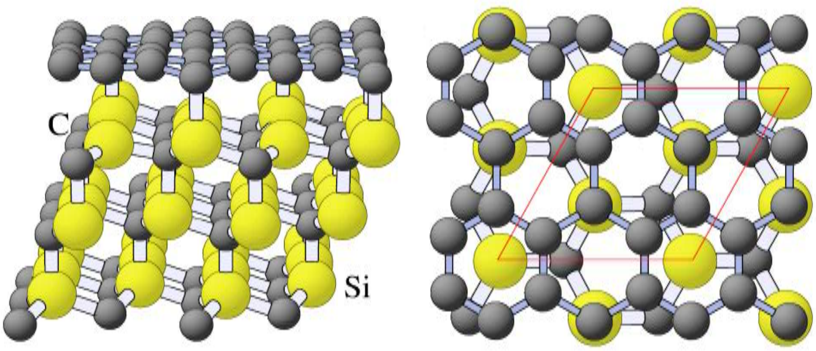

Fig. 3. Graphene on silicon carbide

The main advantages of growth of graphene films on silicon carbide include:

- A possibility to obtain large-size graphene films. Graphene films can be grown on an area as large as the SiC wafer. At present wafers up to 6 inch (150 mm) are available commercially.
- A possibility to grow graphene on insulating silicon carbide wafers, which is essential to eliminate the effect of conductivity on characteristics of graphene devices.
- Silicon carbide wafers available today offer high structural perfection and low dislocation density, that have a positive effect on the graphene quality.

Specifications

Nitride Crystals currently offers epitaxial graphene films on conductive and semi-insulating 4H-SiC wafers with the following specifications:

Sample parameters	
Material	Epitaxial graphene on SiC
Growth method	Thermal decomposition of SiC surface
Substrate polytype	4H
Substrate thickness	500µm
Face	Si (0001)
Sample size	5x5 mm, 11x11 mm
Surface coverage	100% covered by graphene. Sample properties are dominated by monolayer graphene.
Root mean square (RMS) of surface roughness	0.5 – 1 nm
Graphene parameters	
Thickness variation	80-90% of monolayer areas
Conductivity type	n type
Sheet carrier density	0.5×10^{12} - $1 \times 10^{12} cm^{-2}$
Mobility	$4000\text{-}5000 cm^2/Vs$

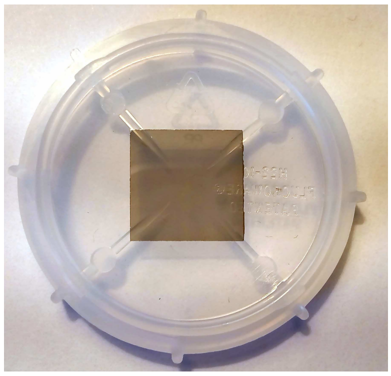

Fig. 4. Epitaxial graphene on SiC (sample size 11x11 mm)

Characterization of graphene films manufactured by Nitride Crystals

Measurements of our graphene films show their excellent quality.

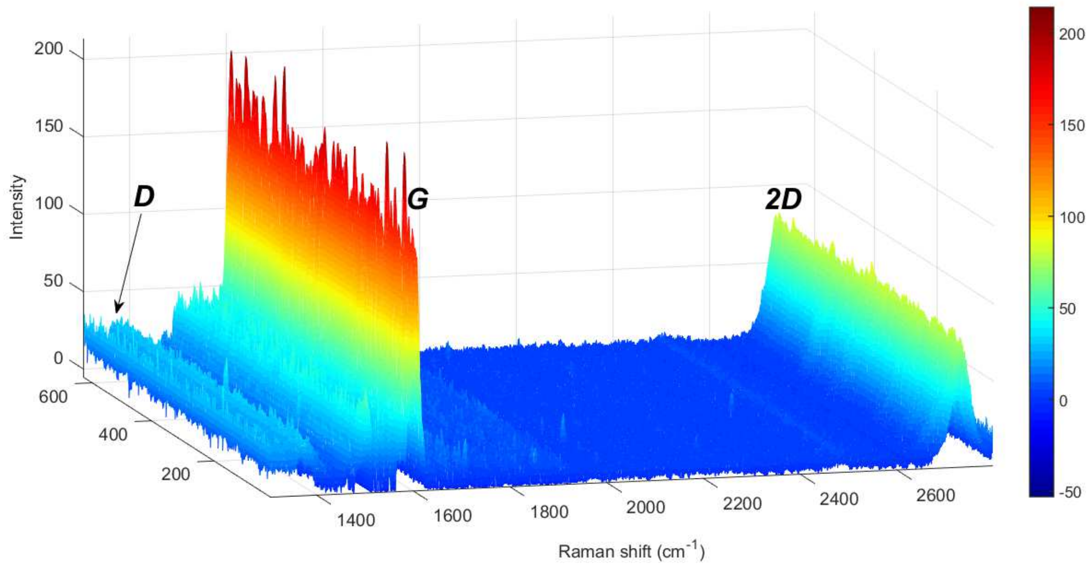

Fig. 5. Micro-Raman spectra, graphene scanning area 12.5x12.5 µm²

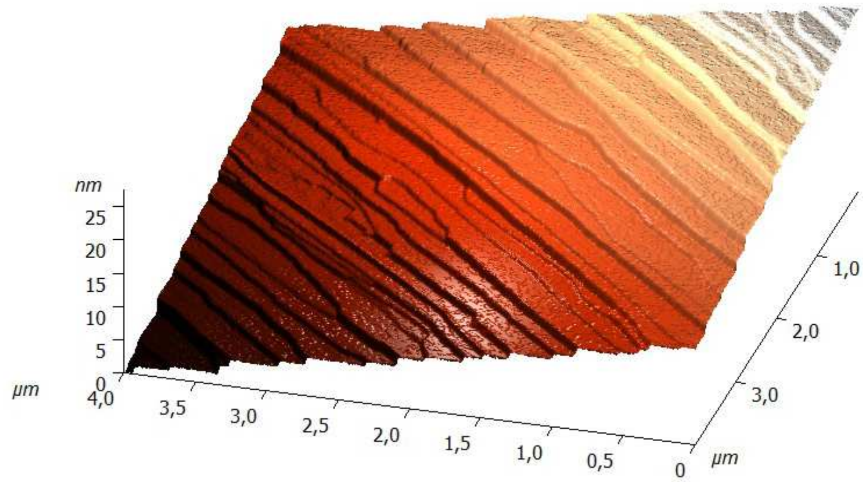

Fig. 6. 3D-AFM topography of SiC substrate with graphene film. (RMS – 0.5 nm, terrace width - 200-500nm, step height - 1-2 nm.)

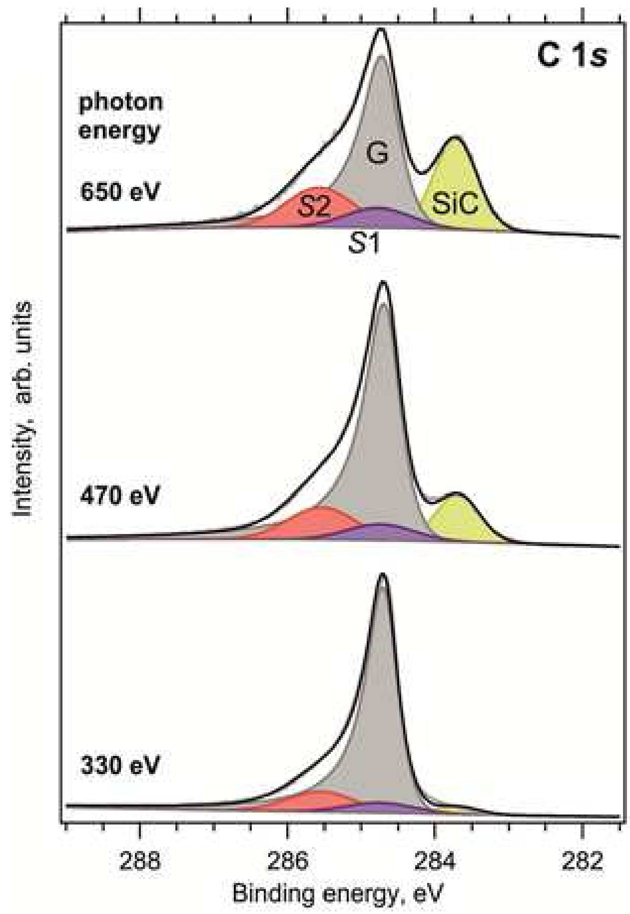

Fig. 7. X-ray photoelectron spectra measured in the C1*s* area at different photon energies

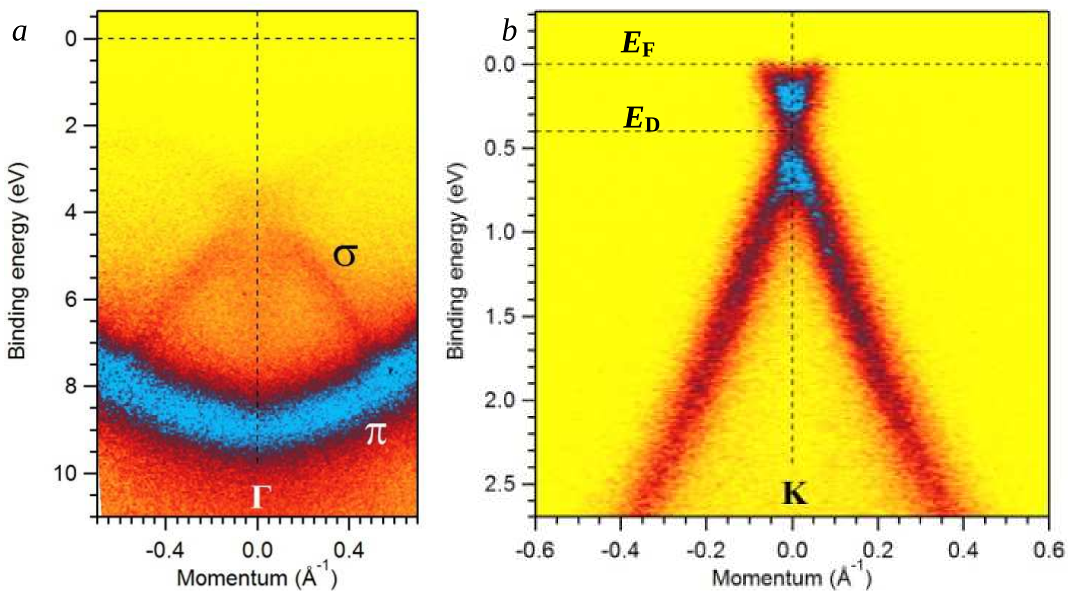

Fig. 8. Structure of the electron valence band in the vicinity of points Γ (a) и К (b) of the Brillouin zone. Angle-resolved photoemission spectroscopy data are obtained using He II emission (40.8 eV)