

# TECHNICAL NOTE



SPI Supplies  
206 Garfield Avenue,  
West Chester, PA 19380, USA

## SPI Supplies HOPG

### Introduction

HOPG, is a relatively new form of high purity carbon and provides microscopists with a renewable and smooth surface. Unlike mica, HOPG is completely non-polar, and for samples where elemental analysis will also be done, it provides a background with only carbon in the elemental signature. The extreme smoothness of HOPG gives results in a featureless background, except at atomic levels of resolution. The SPI Supplies brand of HOPG should not be confused with the SPI Supplies brand of glassy carbon.

### Cleaving properties

Because of its layered structure, HOPG cleaves almost like mica. The usual approach is to take a piece of tape (e.g. 3M® "Scotch Brand" double sided tape), press it onto the flat surface, pull it off and the tape invariably takes with it a thin layer of HOPG. This freshly cleaved surface is what is used as sample substrate material. How many cleavings per sample? This is not easy to answer, but per a 2 mm thick block of the best grades (e.g. SPI-1 or ZYA), it is reported that one can get 20-40 cleavings. We do not guarantee a fixed number of cleavings. For the lower level grades the number of cleavings per 2 mm thickness will be less, but again just how much less we can not predict with accuracy.

### Basal plane image

In an atomic resolution scanning tunneling microscope image of the graphite structure of HOPG, there are two possible images. The image normally obtained looks like a close packed array, where each atom is surrounded by six

nearest neighbors. The distance between any two of these atoms is 0.246 nm. Under ideal conditions, particularly if the probe tip is truly a single atom, you will see the "chicken wire" structure that shows the hexagonal rings that are the true structure of graphite, where the center to center atomic distance in this image is 0.1415 nm. This distance in either case is an atomic property of carbon and it does not depend on the grade of graphite. The image shown here is the close packed array and that is the image obtained from the basal plane of HOPG under most circumstances.

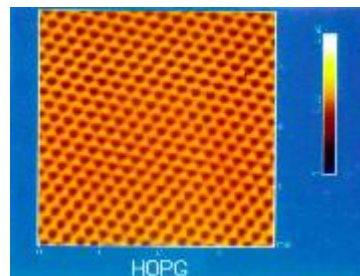


Figure 1: STM image of HOPG

### Use as graphite monochromators:

The HOPG offered by SPI Supplies, especially the SPI-1 and ZYA grades, are reported to diffract x-rays and neutrons with a higher efficiency than any other material. For x-rays the intensities are increased up to five times greater than what would be possible with the lithium fluoride crystal it would replace. A singly bent focusing monochromator using these highest quality grades of HOPG, i.e. those with the smallest mosaic spread, result in intensities three times that of LiF at the same resolution.

## Flatness/Roughness

The HOPG has a structure of polycrystals, the size of which varies, the maximum being 10 mm for the highest quality. The freshly cleaved surface consists of atomic steps, 0.2–0.3 nm, and steps of several or dozens of atomic layers. The higher the quality, the less the roughness of the surface, and the smaller the number of such steps on a freshly cleaved surface.

## Mosaic spread

This term is a measure of just how highly ordered is the HOPG. The lower the mosaic spread, the more highly ordered is the HOPG, resulting in a cleaved surface that exhibits virtually no steps. Lower mosaic spreads are also associated with higher prices. However, since the lower mosaic spread material is more "cleavable", one usually realizes more "cleavings" from the more expensive material, so the increased cost is a bit less than it might first appear.

Product	Mosaic Spread	Product	Mosaic Spread
Grade SPI-1	0.4+/-0.1 degrees	ZYA	0.4+/-0.1 degrees
Grade SPI-2	0.8+/-0.2 degrees	ZYB	0.8+/-0.2 degrees
Grade SPI-3	3.5+/-1.5 degrees	ZYH	3.5+/-1.5 degrees

Table 1: Mosaic spread of two brands HOPG offered by SPI

SPI Supplies offers two different "brands" HOPG: the SPI Supplies Brand and the GE Advanced Ceramics Brand. The quality of both is excellent. Available from both brands are three grades, the top one being the "calibration" grade, the second being "research" grade which is acceptable for most experiments and a "technical" grade where less demanding material is needed, perhaps when one is mainly interested in demonstrating cleavage properties.

## Use at elevated temperatures

As more and more applications are found for HOPG in research and technology, more and more applications are requiring good high temperature characteristics. We can report the following information which should be useful for those contemplating such usage:

Environment	Starts to burn Temperature
Air	500°C/932°F
Vacuum at 0.1 torr	2500°C/4532°F
Inert Atmosphere (N, Ar, He)	3500°C/6332°F

Table 2: Starts to burn temperatures of HOPG

## Chemical inertness:

HOPG exhibits high chemical inertness to just about everything including osmium tetroxide. The one environment, however, where it will "disappear" quickly is in the presence of an oxygen plasma of the type generated in the SPI Supplies Plasma Prep II plasma etcher.

## Calibration in z direction:

The hills and valleys on a cleaved HOPG surface are not calibrated as to their height. However, the crystallographic planes do have a definite structure and the height of a single step is 0.34 nm [1].

You may find random steps on the cleaved HOPG. An alternative method is to create etch pits by oxidizing the surface in an oven in air.

## Measurement side:

X-ray diffraction is done on only one of the two sides of each HOPG plate and the value obtained is the value reported. The two sides are not exactly the same, and there can be a slight asymmetry through the cross-section of each plate. When the HOPG is manufactured, one side ends up relatively flat looking and the other size somewhat "bubbly". Believe it or not, the tightest mosaic spread is the side that is "bubbly". The

opposite side will be either the same mosaic spread or slightly less tight. We are changing over the packaging of the HOPG of the SPI Supplies brand so that there will be a bit of tape on that "opposite" side so that there could never be any question as to which side is which.

### Ferromagnetism:

Some low levels of ferromagnetism has been observed in HOPG. This not a contamination issue but rather due to the highly ordered structure of HOPG, as compared to natural graphic which does not have such a structure.

### References:

1. L. Pauling, The Nature of the Chemical Bond, p. 235, 3rd. Edition 1960.

### Physical properties (at 300 K):

Density (g/cm <sup>3</sup> )	2.27
Basal plane interlayer distance (Å)	3.354-3.358
Thermal conductivity along the basal plane (W/(m·K) )	1800 ± 200
Thermal conductivity perpendicular to the basal plane (W/(m·K) )	8 ± 2
electrical conductivity along the basal plane ((Ω·m) <sup>-1</sup> )	(2.1±0.1) × 10 <sup>6</sup>
electrical conductivity perpendicular to the basal plane ((Ω·m) <sup>-1</sup> )	(5±0.1) × 10 <sup>2</sup>
Purity	>99.99%

Table 3: Physical properties of HOPG

**Revised by:** Junhang Luo

**Date:** 08/31/2015