

# Self-Lubricating, Wear-Resistant Diamond Films Developed for Use in Vacuum Environment

Diamond's outstanding properties--extreme hardness, chemical and thermal inertness, and high strength and rigidity--make it an ideal material for many tribological applications, such as the bearings, valves, and engine parts in the harsh environment found in internal-combustion engines, jet engines, and space propulsion systems.

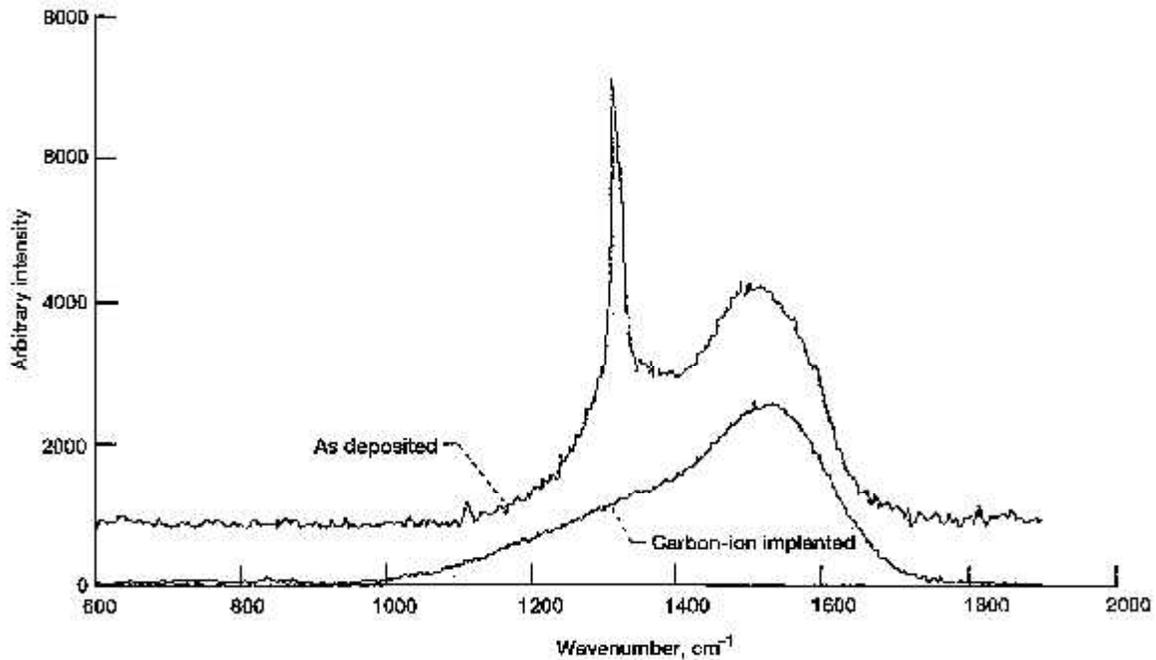
It has been demonstrated that chemical-vapor-deposited diamond films have low coefficients of friction (on the order of 0.01) and low wear rates ( $<10^{-7}$  mm<sup>3</sup>/N-m) both in humid air and dry nitrogen but that they have both high coefficients of friction ( $>0.4$ ) and high wear rates (on the order of  $10^{-4}$  mm<sup>3</sup>/N-m) in vacuum. It is clear that surface modifications that provide acceptable levels of friction and wear properties will be necessary before diamond films can be used for tribological applications in a spacelike, vacuum environment. Previously, it was found that coatings of amorphous, nondiamond carbon can provide low friction in vacuum. Therefore, to reduce the friction and wear of diamond film in vacuum, carbon ions were implanted in an attempt to form a surface layer of amorphous carbon phases on the diamond films.

Diamond films with grain sizes ranging from 20 to 3300 nm were deposited on silicon, silicon carbide, and silicon nitride by microwave-plasma-assisted chemical vapor deposition. Carbon ions were implanted into the as-deposited diamond films at an accelerating energy of 60 keV and a current density of 50 microamperes/cm<sup>2</sup> for approximately 6 min, resulting in a dose of  $1.2 \times 10^{17}$  carbon ions/cm<sup>2</sup>. The substrate temperatures during ion implantation did not exceed 200 °C. The as-deposited and ion-implanted diamond films were characterized at the NASA Lewis Research Center through the use of a variety of techniques--such as scanning and transmission electron microscopy, surface profilometry, and Raman spectroscopy. The friction and wear properties of these films in contact with a natural bulk diamond pin at a mean hertzian contact pressure of 2 GPa were examined in an ultrahigh vacuum of  $7 \times 10^{-7}$  Pa at room temperature.

The results indicate that carbon ion implantation structurally modified the diamond lattice and produced a thin surface layer of amorphous, nondiamond carbon (as verified by the Raman data in the figure). The amorphous, nondiamond carbon greatly decreased both the friction and wear of the diamond films. The coefficients of friction for the carbon-ion-implanted, fine-grain diamond films were less than 0.1, factors of 20 to 30 lower than those for the as-deposited, fine-grain diamond films. The coefficients of friction for the carbon-ion-implanted, coarse-grain diamond films were approximately 0.35, a factor of 5 lower than those for the as-deposited, coarse-grain diamond films. The wear rates for the carbon-ion-implanted diamond films were on the order of  $10^{-6}$  mm<sup>3</sup>/Nm, factors of 30 to 80 lower than those for the as-deposited diamond films, regardless of grain size.

The friction of the carbon-ion-implanted diamond films was greatly reduced because the

amorphous, nondiamond carbon, which exhibited a low shear strength, was restricted to the surface layers (<0.1-micrometer thick) and because the underlying diamond materials retained their high hardness. The size and morphological characteristics of the wear debris particles were related to the wear rates. Much finer wear particles were generated on the surfaces of the carbon-ion-implanted diamond films than were generated on the surfaces of the as-deposited diamond films. Thus, the carbon-ion-implanted, fine-grain diamond films can be used effectively as wear-resistant, self-lubricating coatings for ceramics, such as silicon nitride and silicon carbide, in ultrahigh vacuum.



*Raman spectra of as-deposited and carbon-ion-implanted, coarse-grain diamond film on an alpha-SiC substrate. Spectra are vertically displaced for viewing purposes.*

## **Bibliography**

Miyoshi, K., et al.: Physical and Tribological Characteristics of Ion-Implanted Diamond Films, NASA TM-106682, Nov. 1994.