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Diamond Technology for Infrared Seeker Windows

K. V. Ravi*
Lockheed Missiles and Space Company, Inc., Palo Alto, California 94304

The attractions of low-pressure synthesized diamond films and thick diamond slabs for endoatmospheric kinetic energy weapons (endo-KEW) seeker window applications are presented. The use of diamond in two forms, as thin films in combination with silicon windows and as thick, free-standing windows, is discussed. A novel concept of internally cooled silicon/diamond windows that can withstand the rigors of high-velocity, endoatmospheric flight and that do not suffer from window emittance resulting from aero-optic effects and have the potential for application as multispectral windows is discussed. The synthesis and processing aspects of thin diamond films and free-standing diamond windows are presented, with an analysis of the significant advantages of silicon and diamond for the fabrication of endo-KEW seeker windows.

Nomenclature

n_0 = refractive index of air
n_1 = refractive index of diamond
n_2 = refractive index of silicon
R = reflection of radiation from front surface of window

Introduction

ONE of the key components of endoatmospheric kinetic energy weapons (endo-KEW) seekers is a multispectral window for protecting optics and focal plane arrays. Such windows have to possess a number properties for their successful use. These include optical transmission over a broad spectral range, high thermal conductivity and thermal shock resistance, very good abrasion and erosion resistance, good mechanical properties, and ease of fabrication. Endo-KEW seekers are designed to operate at very high interceptor velocities that place severe requirements on infrared (IR) windows. In addition to the requirement that the windows survive the severe operating conditions, it is also necessary that window temperatures be maintained below values that cause the windows to emit radiation. Increasing window temperatures result in a degradation in the signal-to-noise ratio in the IR detectors, eventually resulting in the window becoming opaque. As a consequence, attempts have been made to cool the windows. One approach to window cooling that has been tested is external film cooling, whereby an appropriate gas, such as helium, is passed across the external surface of the window during flight. This results in lower window temperatures, but is attended by image distortion and other optical aberrations as a result of aero-optic effects due to the creation of a turbulant mixing region at the window surface resulting from the external film coolant.[1] In this paper, these issues are addressed by the choice of novel materials and fabrication concepts.

Of all of the candidate materials for the fabrication of IR windows, diamond is by far the best. In Table 1 some of the key properties of typical IR materials are compared to those of diamond. The compound semiconductors (ZnS, GaAs, and GaP) are optically attractive but suffer from the problem of poor thermal conductivities and mechanical properties and are consequently unsuitable for interceptors operating at high velocities in endoatmospheric conditions. Germanium is also unsuitable for similar reasons. Silicon is suitable for multispectral applications if oxygen-free silicon is utilized. Apart from an intrinsic absorption band at ~ 5 μm, diamond is an excellent multispectral window material. This property, coupled with its unexcelled thermal conductivity, superior thermal shock resistance, and mechanical properties, makes diamond very attractive for the fabrication of seeker windows for endo-KEW applications.

In this paper, the attractions of diamond as a material, both by itself and in combination with silicon, for the fabrication of seeker windows are discussed. The various design, fabrication, and operational issues that have to be considered to develop workable diamond windows are discussed. A novel concept for the fabrication of internally cooled windows for multispectral applications, incorporating diamond as an essential component of the window, is presented.

The superior physical properties of diamond can be exploited both by the use of diamond in the form of thin films on silicon windows as well as by the fabrication of thick diamond windows that are free standing. The design and process issues attending these two approaches for the incorporation of diamond into seeker windows will be discussed next

Low-Pressure Diamond Synthesis Technology

Although the various attributes of diamond as an exceptional material have been generally recognized, its widespread utility in engineering applications has had to await the development of a new, cost-effective approach to the synthesis of diamond. This approach to diamond synthesis, the plasma-enhanced chemical vapor deposition (PECVD) technique, is of relatively recent origins and has the very important attribute of making possible the fabrication of films of diamond. This approach is dependent on activation of hydrocarbon gases, to create active species of the carbon-containing entities, and on the presence of high concentrations of atomic hydrogen in the ambient. High concentrations of atomic hydrogen in the plasma ambient suppress the formation of graphite, as well as preferentially dissolving any graphite that might form during the synthesis process. A variety of activation means are being investigated, including the use of microwave discharges, hot filaments, dc glow discharges, dc and rf arc jets and the use of the combustion reaction between oxygen and acetylene. The key attributes of these processes are discussed further here.

Internally Cooled Silicon/Diamond Windows

The attractive optical, thermal, and mechanical properties of silicon and diamond have been combined to develop novel IR seeker

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*Senior Staff Scientist, O/93-10, B-204, Research & Development Division, 3251 Hanover Street.

Table 1 Selected properties of IR transmitting materials

	ZnS	GaAs	GaP	Si	Ge	Diamond
Density gm^{-3} (23°C)	4.08	5.317	4.13	2.33	5.232	3.52
Flexure strength, psi (23°C)	14,000	8,000	15,000	18,500	13,500	427,000
Young's modulus, GPa (23°C)	74.5	85.5	102.6	130.1	103.3	1,050
Coefficient of thermal expansion 10-6/K (23°C)	6.8	5.73	5.3	2.3	6.0	1.0
Thermal conductivity, W cm^{-1} K^{-1}	0.17	0.53	0.97	1.412	0.60	20

windows that are internally cooled.[1] Internal cooling obviates the problem of excessive window irradiation under high thermal conditions of flight, avoids aero-optic distortions resulting from external film cooling, and prevents the oxidation of diamond at high temperatures in oxygen-containing atmospheres. Next the critical materials and processing issues that have led to the development of these windows are discussed.

Silicon as a Multispectral Window Material

The IR transmission characteristics of silicon are governed by the presence of impurities in grown silicon crystals. There are two commercial approaches to grow silicon crystals from high-purity polycrystalline silicon. These are the Czochralski technique and the floating zone technique of crystal growth. The Czochralski process, which is used for the growth of the majority of silicon single crystals utilized by the semiconductor industry, is a process whereby high-purity polysilicon is melted in a quartz crucible, contained within a protective chamber, a seed crystal dipped in the molten silicon and withdrawn from the melt in a controlled fashion to solidify the melt into a single crystal boule. Crystals of diameters up to 20 cm are grown by this technique. The use of quartz crucibles to contain the molten silicon results in an interaction between the molten silicon and quartz (silica), leading to the reduction of the quartz and incorporation of the oxygen in the silicon. The oxygen is incorporated into the silicon crystal at bonded interstitial sites bridging two host lattice atoms. The resulting Si-O-Si structures can be visualized as bent triatomic molecules, embedded in the silicon lattice. Oxygen in this form in the silicon lattice gives rise to the well-known 9-μ absorption band in the IR spectrum. The solubility of oxygen in silicon has been extensively measured and is in the range of 1 to 8×10^{21} atoms/cm^3, and is a strong function of the thermal treatment that the silicon is subjected to following growth of the crystal.

The second impurity in silicon crystals, which is not deliberately added, is carbon. The source of carbon is not as readily identifiable as the source of oxygen. Carbon contamination is typically a result of the difficulty of completely removing carbon from the polysilicon utilized to grow the crystals. Other sources of carbon can be related to the apparatus used for the growth of the crystals. Carbon concentrations in silicon range from 2×10^{17} atoms/cm^3 to about 2×10^{18} atoms/cm^3. Unlike oxygen, carbon contracts the silicon lattice when it is dissolved in the silicon and exists as an isovalent impurity occupying substitutional sites in the silicon lattice. This gives rise to an absorption band at 16.5 μ. Like oxygen, the solubility of carbon in silicon is temperature dependent and post-crystal growth heat treatment can cause it to precipitate as silicon carbide. Apart from the primary 9- and 16.5-μ absorption bands due to oxygen and carbon, respectively, a number of subsidiary absorption bands have been identified as being due to interactions between these elements and silicon vacancies. Figure 1 shows a typical IR transmission spectrum of oxygen- and carbon-containing silicon. This material is suitable for use in the short wavelength infrared [(SWIR), up to ~3 μm] amd medium wavelenth infrared [(MWIR), 3 to 5 and μm] ranges of operation, but not long wavelength infrared [(LWIR), 8 to 12 μm] applications.

The second technique for the growth of silicon crystals is the floating zone technique that does not utilize a container for the molten silicon. In this process a rod of polycrystalline silicon is converted into a single crystal by forming and traversing a molten zone from one end of the crystal to the other. The molten zone, which is suspended between the polycrystalline feed stock and the growing single crystal by capillary forces, is created using a moving induction coil with melting achieved by induction heating of the silicon. The absence of a quartz crucible results in the oxygen-free crystals. Figure 2 is an IR transmission spectrum of oxygen-free silicon. The absorption band due to oxygen at 9 μ is absent but the 16.5-μ absorption band due to carbon is still observed. However, this material is suitable for use in the LWIR (8 to 12 μm) range of operation. Consequently, oxygen-free silicon is a multispectral window material suitable for operation in SWIR, MWIR, and LWIR applications.

Window Emission

One of the key problems with silicon windows that has to be overcome for their utility in high stressing environments such as obtained in endoatmospheric homing is that of window emission with increasing window temperature. To minimize window emission, the silicon window has to be cooled and its temperature maintained below ~ 500 K. Figure 3 presents the results of computations showing the effects of intercept altitude on window emission for cooled and uncooled silicon windows. The data shown are for the 3- to 5-μ range at an intercept velocity of 4 km/s, 4 s after the window is exposed to aerodynamic forces by removing the protective shroud on the window. Uncooled windows lead to excessive window emission leading to increased noise and poor discrimination of the target by the sensor.

To avoid the problem of window emission, internally cooled silicon windows have been developed that are characterized by the presence of internal coolant channels spaced at a specified distance from each other to maximize cooling while minimizing window obscuration by the coolant in the passages. Figure 4 shows a schematic sketch and photograph of such windows. The silicon windows are coated with diamond films. Aspects of diamond film coatings are discussed in the next section.

Thin Diamond Films on Silicon

There are three primary reasons for the use of thin diamond films on silicon in the fabrication of internally cooled windows.

1) Diamond functions as an antireflection (AR) coating on silicon, enhancing optical performance of the window.[3]

2) As a result of its extreme hardness, diamond films function as erosion-resistant coatings on the silicon windows.

3) Diamond is chemically inert and changes in optical properties of diamond-coated windows resulting from interactions with the environment are not an issue.

To compute the maximum transmission through a diamond-film-coated silicon sample, the following simple relationship between the refractive indices of air, silicon, and diamond can be used[4]:

$$R=[(n_1^2-n_0n_2/n_1^2+n_0n_2)]^2$$

From this equation it can be computed that the maximum transmission through an uncoated silicon is ~ 50% and the maximum transmission through a diamond-film-coated silicon, with the diamond film on one surface, is ~ 63%. By coating the silicon on both surfaces with diamond, the transmission can be further increased to ~ 76%.

Figure 5 is an example of the IR transmission through diamond-film-coated oxygen-free silicon, demonstrating that the diamond functions as an AR coating on silicon over the entire wavelength

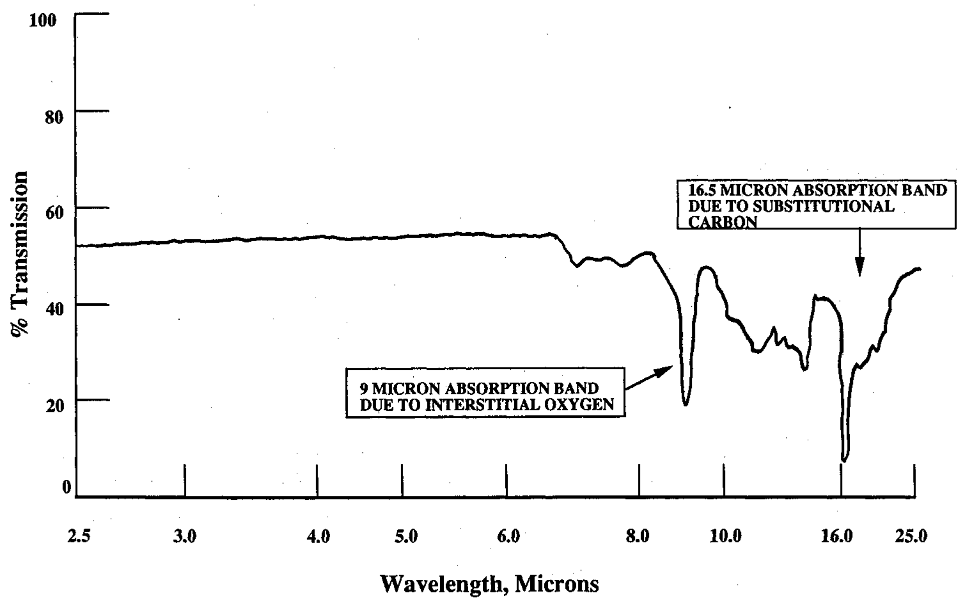

Fig. 1 Typical IR transmission spectrum of oxygen- and carbon- containing silicon grown by the Czochralski technique.

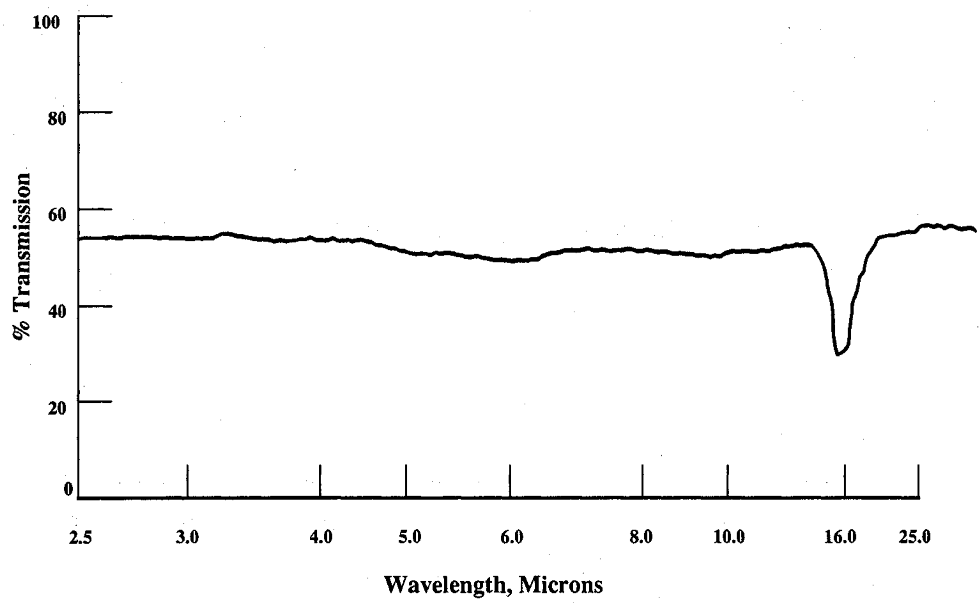

Fig. 2 IR transmission spectrum of oxygen-free silicon grown by the floating zone technique.

range of interest. In this case, the diamond film is only on one side of the silicon.

The other attribute of diamond is its superior hardness and wear resistance. Figure 6 shows data on the rain erosion resistance of polished silicon and a diamond-film-coated silicon sample. The data were obtained utilizing 3.5-mm water drops impacting on the samples at 60 deg to the normal. The diamond enhances the rain erosion resistance of silicon by about a factor of 3 for the water drop impact test conditions utilized.[5]

A critical issue in the use of diamond-coated windows is their response to environmental effects, with particular reference to the oxidation of diamond. Figure 7 is a comparison of the oxidation characteristics of diamond films with natural diamond and two forms of graphite. The data show that CVD-synthesized diamond films display a lower rate of oxidation than natural diamond single crystals and are significantly superior to graphite.

This result is tentatively explained on the basis that the oxidation rate is orientation dependent. Polycrystalline diamond films tend toward a (110) texture, which may account for the observed low oxidation rates.[6] From Fig. 7 it is clear that diamond will begin to oxidize at ~650°C in a flowing oxygen environment, and as such, diamond seeker windows on ground-based interceptors and, in particular, for endoatmospheric applications either have to be coated with oxidation-resistant coatings, or they have to be cooled to maintain their temperature below the oxidation temperature at the partial pressures of oxygen encountered in operation. Oxidation resistant coatings may adversely impact the optical properties of the window, as well as its surface heat conductivity. Consequently, for the effective performance of diamond-coated windows, it is necessary that low window temperatures be maintained.

Diamond Film Microstructure Control

Since diamond films synthesized on substrates such as silicon are polycrystalline in nature, with the films being composed of individual diamond crystals aggregated together, the surface smoothness of such films will be determined by the nucleation density of the individual diamond crystals, as well as any anisotropies in the growth of the crystals following nucleation.

A critical issue in the deposition of diamond films on substrates of interest is that of nucleation of diamond. Because of the large

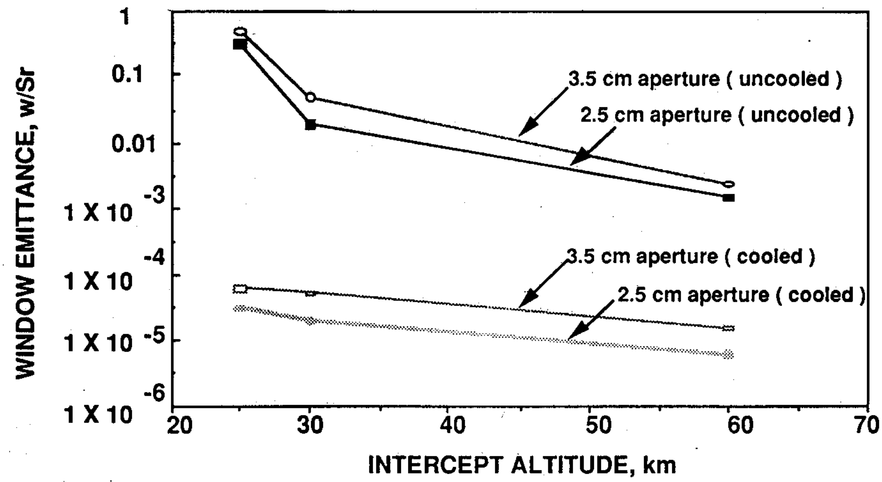

Fig. 3 Window irradiance as a function of intercept altitude for 3.14-mm-thick silicon window in the uncooled and cooled conditions.[2]

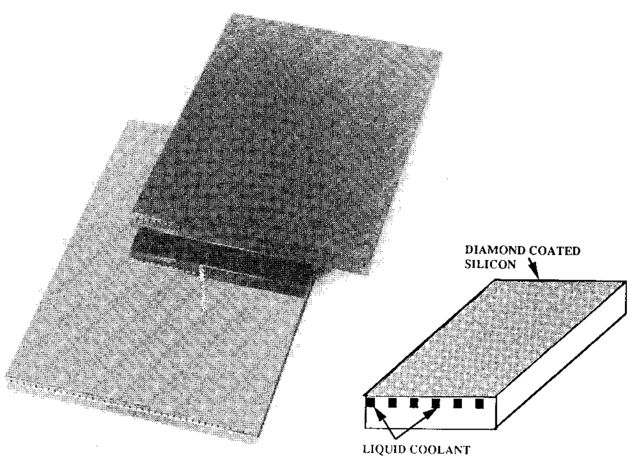

Fig. 4 Photo and schematic sketch of internally cooled silicon/diamond windows for endoatmospheric homing applications.

bond and surface energies of diamond, nucleating diamond crystals on nondiamond surfaces is generally difficult. There has been significant research conducted in this area of technology, and generally it is found that to promote diamond nucleation the substrates have to be mechanically abraded to create very small damage sites. These local damage sites on the substrates promote the nucleation of diamond crystals. The higher the density of local damage sites on the substrate, the higher the nucleation density of diamond. Representative data demonstrating this effect are shown in Fig. 8. Scanning electron micrographs of the surface structure of diamond films on silicon are shown. As the density of nucleation sites on the substrate is increased, the density of diamond crystallites in the film is increased and the size of the individual crystallites reduced. Diamond film grain sizes have been reduced from ~10 to < 0.2 μm. This results in smoother films that in turn lead to reduced surface scattering of the incoming radiation. Surface smoothness becomes critical at shorter wavelengths. As a consequence, smoother films are more important for SWIR and MWIR applications than LWIR applications.

Free Standing Diamond Windows

An all-diamond window would have all the attractions of the silicon/diamond window just discussed. In addition, the superior physical properties of diamond would further enhance the performance capability of an internally cooled window. The attractions of an internally cooled diamond window can be enumerated as follows:

1) By utilizing internal cooling approaches, as just discussed for the silicon/diamond windows, the key problem of diamond oxidation at temperatures in excess of ~ 600°C is obviated.

2) Internal cooling also has the very important benefit of minimizing window irradiance as well as maintaining image quality. This feature is not achievable with external film cooling.

3) An all-diamond window can be thinner than a silicon/diamond window since the modulus of diamond is a factor of 8 higher than that of silicon and the flexure strength of diamond is over an order of magnitude larger than that of silicon (Table 1). Thinner windows lead to reduced temperature gradients through the thickness of the windows and to reduced weight.

4) The very high thermal conductivity of diamond will permit the use of significantly fewer coolant channels within the window thus decreasing the optically opaque area of the window and minimizing window obscuration. In the current silicon/diamond window design just discussed, the obscuration due to the coolant channels results in the transmitted image peak intensity being reduced by ~20%. This is based on the placement of coolant channels of the required dimensions at the required spacing for removing the heat generated at the window surface.

If we assume that the percentage of the window volume to be occupied by the coolant channels is a function of the thermal conductivity of the window material, an all-diamond window would need considerably fewer coolant channels resulting in a reduction of the transmitted image peak intensity by only about 2.6% as compared to a window without coolant channels.

5) A cooled diamond window can be coated with suitable antireflection coatings to enhance optical transmission. Antireflection coatings on uncooled diamond windows are unlikely to withstand high surface temperatures without delamination, ablation, etc. Also, the resistance of antireflection coatings to high-velocity rain impact has to be assessed.

6) Internal cooling, as opposed to edge cooling, will permit the use of thinner diamond windows, which in turn will reduce the weight and manufacturing cost of the windows.

Fabrication Issues

For the realization of practical, cost-effective diamond windows, a number of technical developments are required involving techniques of diamond synthesis and fabrication. To assess the state of the technology, a brief discussion of the key approaches to the low-pressure synthesis of diamond is presented.

The various processes being developed for the synthesis of diamond films and slabs at low pressures can be broadly divided into low-growth-rate plasma techniques and high-growth-rate thermal techniques. The plasma techniques use microwave discharges, dc glow discharges, and refractory metal filaments heated to incandescence to generate the requisite energies needed to activate process gases, which are typically mixtures of methane and hydrogen. Figure 9 is a schematic sketch of a microwave-enhanced CVD

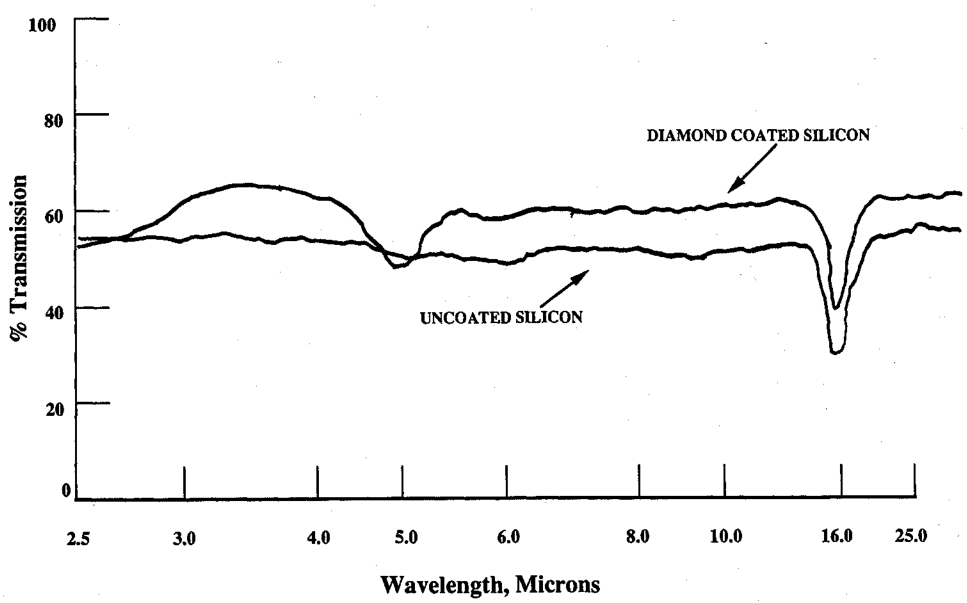

Fig. 5 IR transmission spectrum of diamond-film-coated, oxygen-free silicon grown by the floating zone technique.

apparatus for the synthesis of diamond films. This is the most widely used technique of diamond synthesis and has the attraction of enabling the synthesis of high-quality diamond films on substrates up to 10 cm in diameter. Recent developments in this technology include the availability of equipment that permits diamond synthesis on 20-cm-diam substrates. The primary disadvantage of this process is the relatively slow growths that are achievable. Typical growth rates for diamond deposition on 10-cm-diam substrates are <1 μ/h. As the area of the substrate is increased, the growth rates are reduced. Consequently, this and similar plasma techniques are not suitable, based on the current state of the technology, for the fabrication of free-standing diamond windows whose thicknesses are expected to be in the 1- to 2- mm range.

Two high-growth-rate techniques for producing diamond that are currently receiving increasing attention are the arc jet process and the combustion flame synthesis process. These techniques achieve high growth rates by using significantly higher energies for activating the process gases, as compared to the plasma techniques, and by conveying activated species to the substrate at high velocities.

The importance of growth rate in the achievement of practical and cost-effective manufacturing processes is illustrated in Fig. 10, which is a plot of the time required for the growth of diamond films (slabs) of two thicknesses that would be needed for the fabrication of diamond windows. From this figure, it is clear that the plasma techniques are impractical for the production of free-standing diamond windows, whereas the thermal techniques are viable candidates for this application.

In the arc jet technique of diamond synthesis, mixtures of methane and hydrogen are activated by the use of a dc arc. Figure 11 is a schematic diagram of the dc arc jet apparatus. The gas mixture flows at high velocity through an annular electrode, across which is applied a high potential to generate an arc. The high-current arc activates the gas mixture which is then sprayed onto a temperature-controlled substrate to achieve high-rate diamond deposition. Growth rates as high as 1000 μ/h have been demonstrated on small-area (~1 cm^2) substrates. This technique has been scaled to achieve diamond deposition on substrates up to 12.5 cm in diameter. However, the growth rates are reduced considerably as the substrate area is increased.

Another high-growth-rate process uses the combustion reaction between acetylene and oxygen to generate the requisite temperature to activate the process gases. Figure 12 shows a schematic diagram of an oxyacetylene torch used in this process. Combustion is achieved in the torch and the process is operated with a slight excess of acetylene in the gas mix. The uncombusted carbon in the

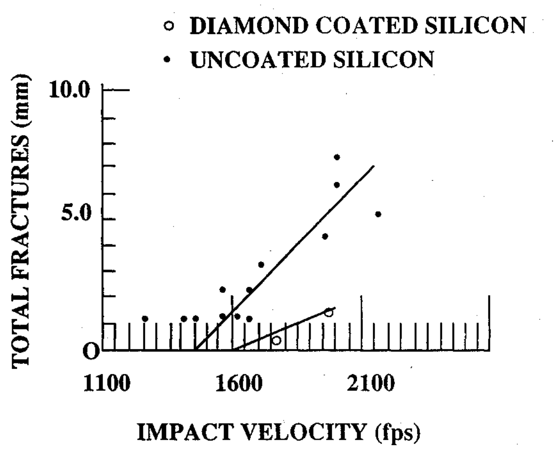

Fig. 6 Water drop impact test results of uncoated and diamond-film-coated silicon.

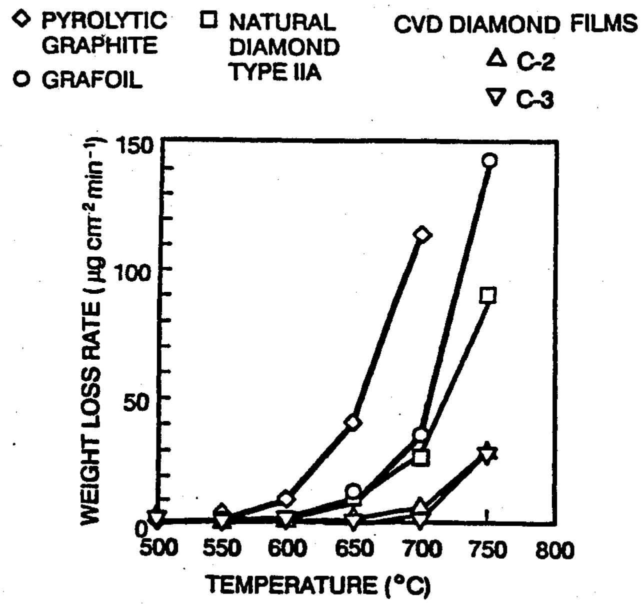

Fig. 7 Oxidation weight loss of graphite, natural diamond, and CVI diamond films as a function of temperature.

gas mix functions as the feedstock for diamond synthesis. When the torch is caused to impinge onto a temperature-controlled substrate, diamond films are deposited on the substrate at high rates. Growth rates up to several hundred microns/hour have been achieved on small-area substrates and rates in excess of 30 μ/h have been achieved on 10 cm×5 cm substrates.

The oxyacetylene torch technique is unique in that it is operated in open air without the need for chambers or protective atmospheres, and it is possible to scale this process to achieve diamond deposition on larger-area substrates at high rates. The simplicity of the equipment and the ability to synthesize diamond films in atmosphere make this an inexpensive process for scaling and manufacture, as compared to alternative approaches. The primary cost of diamond fabrication in this process is that of process gases.

Process Considerations

In addition to the requirement of achieving practical growth rates to synthesize thick diamond structures economically, there are several process issues that have to be addressed. Since the growth of thick diamond structures entails long process runs with, for example, 10 hour deposition times at 100 μ/h for the synthesis of 1-mm-thick diamond windows, the stability of the process over these long production runs has to be assured. This requires that control be exercised over process variables, such as the chemistry of the process gases, substrate temperature, gas flow rates, etc. The purity of the diamond must also be maintained over its thickness and across the area of the window. This is achieved by maintaining the hydrocarbon-to-hydrogen (or oxygen) ratio at the level that results in diamond synthesis. If the hydrocarbon concentration is allowed to exceed the amount in this ratio, graphitic and other non-

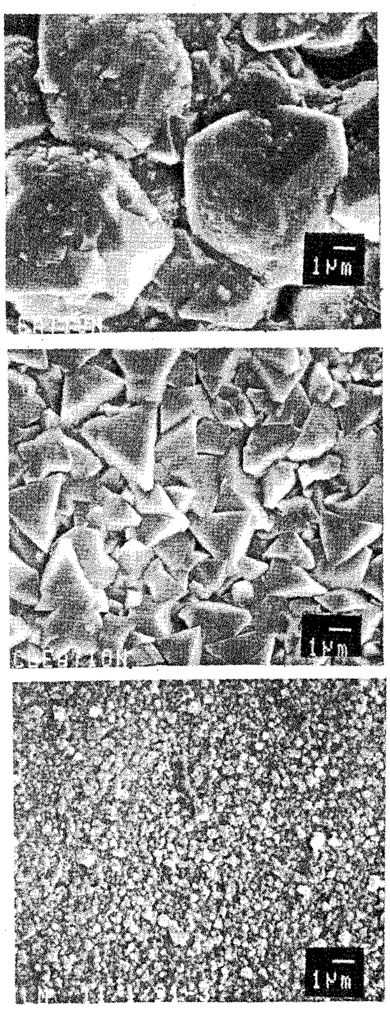

Fig. 8 Scanning electron micrographs of the surface structure of diamond films on silicon.

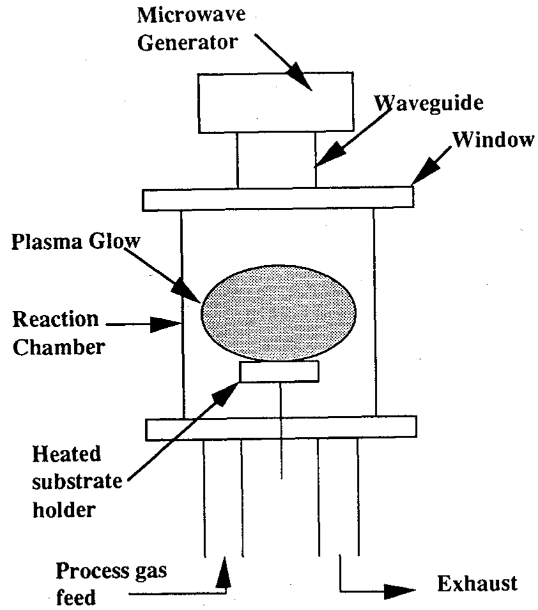

Fig. 9 Schematic diagram of microwave-enhanced CVD apparatus foı diamond film synthesis.

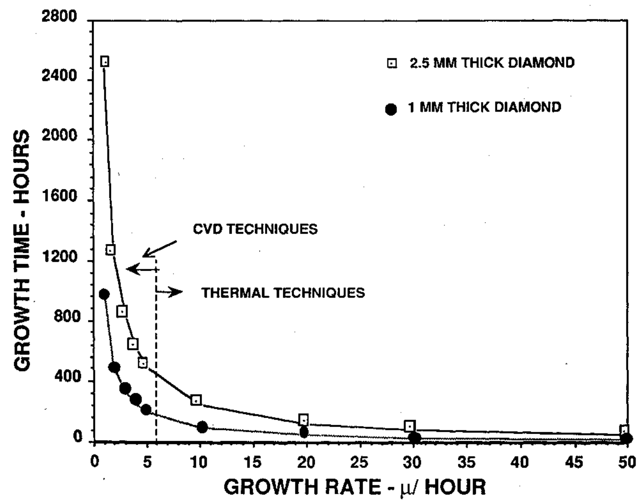

Fig. 10 Plot of growth time as a function of growth rate for the fabrication of diamond structures of two different thicknesses.

diamond phases can form and be incorporated into the growing diamond, leading to degradation in the properties of the diamond.

To achieve dense diamond structures that possess the requisite degree of structural integrity, a very important requirement is the achievement of control over the microstructure of the diamond film/slab. There is considerable ongoing research in determining the influence of process variables on controlling diamond film microstructure. It has been shown that process gas chemistry, surface chemistry, and surface structure of the growing diamond film determine the microstructure and thus properties of the films. An example of the effects of process variables on the structure of diamond films is shown in Fig. 13. The surface orientation of diamond crystallites in a film is governed, among other factors, by the surface microstructure of individual diamond crystals in the film.

By using a process that has been termed alternating chemistry synthesis of diamond, it is possible to modify the surface orientation of diamond films. This process involves the periodic activation of the diamond surface by oxygen during diamond growth.[7] Figure 13 shows the influence of this periodic activation process. The top electron micrograph shows the surface structure of the diamond film when it is grown in a steady-state manner without any interruptions in the process. The surface of the film is very rough

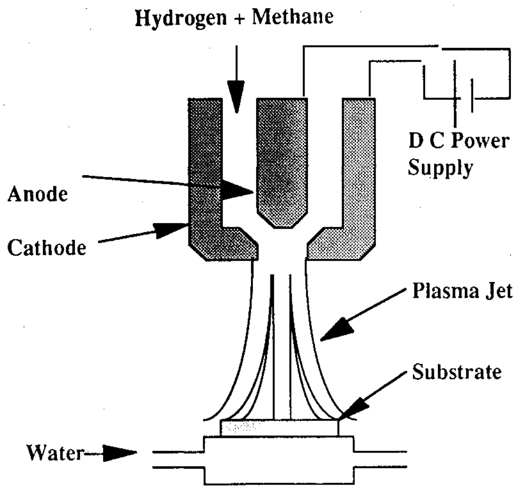

Fig. 11 Schematic diagram of the dc plasma jet apparatus of diamond synthesis.

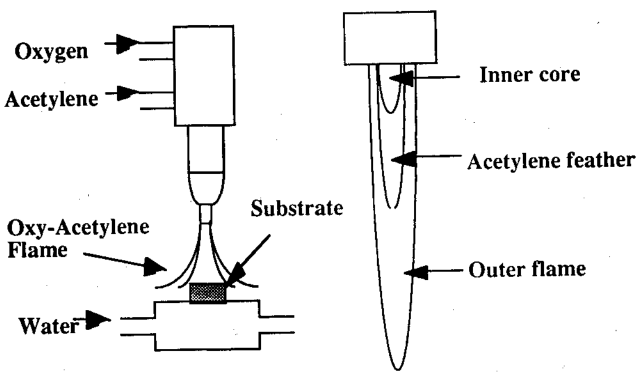

Fig. 12 Schematic diagram of the dc plasma jet apparatus of diamond synthesis.

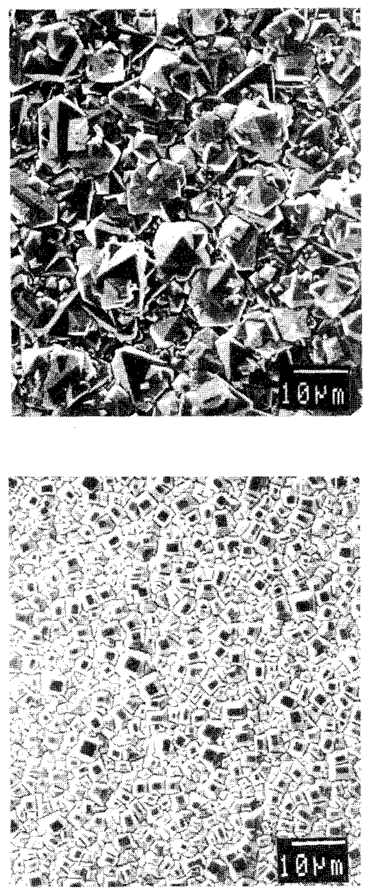

Fig. 13 Scanning electron micrographs of the surface structure of thick (~200 μ) diamond films synthesized by a steady-state process (top) and a cyclic process involving the periodic activation of the diamond surface with oxygen (bottom). Periodic surface activation results in films with (100) oriented crystallites and a significantly enhanced surface smoothness.

and the individual crystallites display (111) orientations on the facets. The bottom micrograph shows the effect of periodically interrupting the growth process to subject the diamond surface to brief oxidation steps using oxygen in the process gas mix. The structure that results is composed almost entirely of (100) oriented crystallites aggregated into a film. The surface smoothness of such a film is also superior to that of a film resulting from steady state growth.

The implications of microstructure control of this type for diamond seeker windows lie in the fact that a key issue with thick diamond structures is surface smoothness of the films. As the thickness of diamond films is increased, the surface smoothness is found to be degraded due to the differing growth rates of different crystal planes on the individual crystallites in the film as well as a result of statistical variations in the growth rates of individual crystallites. High rate growth is characterized by a phenomenon termed "morphological instabilities" that can lead to very rough surfaces.[8] Consequently, controlling the morphology of the crystallites to insure that all of the crystals exhibit the same orientation, as shown in Fig. 13, enhances surface smoothness and facilitates subsequent polishing of the diamond surface for further improving surface smoothness.

Thick diamond slabs have to be polished to be usable for optical applications. Three polishing approaches are available to achieve smooth surfaces on diamond films. Briefly, these are as follows:

1) The first technique is mechanical polishing whereby the rough diamond surface is polished, utilizing fine diamond powder as a polishing medium on conventional optical polishing wheels. This technique is extremely slow and laborious since the hard diamond surface is polished by using diamond powder and the approach depends on the mutual wear of the diamond film surface and the diamond particles used to polish the film.

2) A second technique is a chemical-mechanical technique whereby the diamond film is polished with an iron polishing wheel at an elevated temperature (~600°C). The diamond interacts with the iron at elevated temperatures resulting in the conversion of the surface layer of diamond into graphite, followed by the diffusion of the graphite into the iron. A source of atomic hydrogen has to be available to remove the carbon from the iron to avoid saturating the iron with carbon.

3) The third approach involves the use of pulsed laser irradiation of the diamond surface in an oxygen-containing atmosphere. By using a grazing-angle incident laser beam, the tips of diamond crystallites in a film are heated and the excess diamond removed by transformation to graphite and vaporization in an oxygen atmosphere.

Concluding Remarks

Diamond, in combination with silicon and as a free-standing entity, is a superior material for the fabrication of multispectral windows for endo-KEW seeker applications. The feasibility of synthesizing diamond films and slabs using low-pressure-activated techniques enables the practical production of IR seeker windows.

Both diamond and silicon, in addition to exhibiting superior physical properties compared to other common IR materials, are amenable to various fabrication processes including machining using mechanical, chemical, and beam processing techniques; coating with antireflection coatings; and integration into seekers by joining and assembly techniques. With the vast background in silicon processing that has been developed by the semiconductor industry, this material can be fabricated and shaped into a variety of desirable geometrical configurations. Techniques such as micromachining, lithographic patterning, and chemical and ion beam etching are readily available to fabricate silicon windows. High-quality silicon is available up to dimensions of 20 cm in diameter for the fabrication of windows of various sizes. The relative ease with which silicon can be coated with diamond films further extends the utility of this material in harsh environments. The internally cooled silicon/diamond window discussed in this paper is the first manifestation of the synergistic combination of the attractive properties of these two materials to solve a unique problem facing endo-KEW interceptors.

Diamond is by far the most attractive material for the fabrication of seeker windows. In addition to multispectral transmission across the IR spectrum, diamond is also transparent in the visible regions of the spectrum. Furthermore, diamond exhibits the lowest dielectric constant of all the ceramic materials (5.4) with the dielectric constant being relatively insensitive to temperature-induced changes.[9] This property, coupled with the superior optical properties, makes diamond a very attractive candidate for the fabrication of dual mode (IR and MMW) radomes/windows. Unlike silicon technology, however, low-pressure diamond synthesis technology is relatively new and further work remains before the full potential of this material can be realized. Areas of technology that require addressing include the enhancement of growth rates, achievement of control over the microstructure, and hence the properties of the material, and the development of processing and fabrication technologies such as machining, polishing, joining, and interfacing of diamond windows with other materials for integration into seeker forebodies.

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Ronald K. Clark
Associate Editor