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SOME PROPERTIES OF DIAMOND*

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Abstract

Measurements have been made of some of the optical, electrical, and other physical properties of more than eleven hundred gem diamonds. Tests included infrared transmission, spectrographic analyses, fluorescence under ultraviolet light, and conductivity measurements.

Introduction

Many of the differences found in the properties of natural diamonds could be understood if it were possible to prepare diamonds with no impurity or with controlled amounts uniformly dispersed throughout the crystal. As many as thirteen elements have been found in small amounts in diamonds although any one diamond is not likely to contain traces of more than seven elements. It has often been suspected that the non-uniformity in the impurity content was associated with some of the differences in properties.

One of these differences is in the ultraviolet and infrared absorption spectra (1). All diamonds show an absorption band in the five micron region and all but a few per cent also have considerable absorption over the 8 to 10 micron region and have been designated type I; only about one per cent have low absorption in this region and have been known as type II. This absorption band is not temperature sensitive, but the five micron band is sensitive to temperature and is connected with the thermal vibrations of the atoms (2). In the ultraviolet the type II is opaque at wavelengths less than about 2250 angstroms but type I is opaque below about 3000 angstroms. The opacity is lowered somewhat by long exposures (3). Those with values in between might be considered a modified type.

Experimental Data

Out of eleven hundred gem-cut diamonds which were tested here recently for infrared transmission it was found that about seventy-four per cent were type I with very high absorption in the 8 to 10 micron region; twenty per cent were type I, modified, with moderate to high absorption; and only five per cent with moderate to low absorption which might be called type I, highly modified. Just ten gems were "pure" type II. Typical infrared patterns from a single beam spectrometer are shown in Figs. 1, 2, and 3, and contain the air bands present when a single

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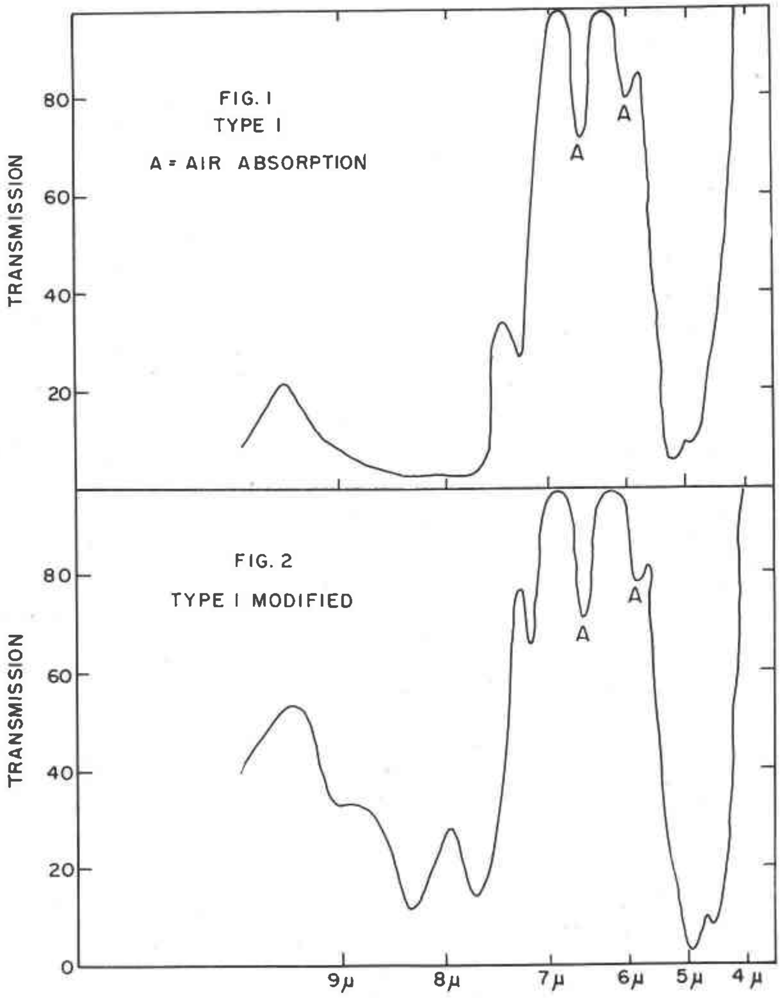

Figs. 1 and 2. Infrared transmission in type 1 diamonds.

beam instrument is used. The resolution was not sharp because a wide 1 mm. slit was needed to obtain a suitable pattern for the gems without reducing them to a powder. Since most of the diamonds were between 0.2 and 0.5 carat and were not as long as the slit in the spectrometer, a platform had to be used in front of the slit to block off part of it and fix the gem so that the thin end just covered the top of the slit. When the gem was turned into the proper position, with two facets opposite one another, enough energy was admitted to give an acceptable pattern.

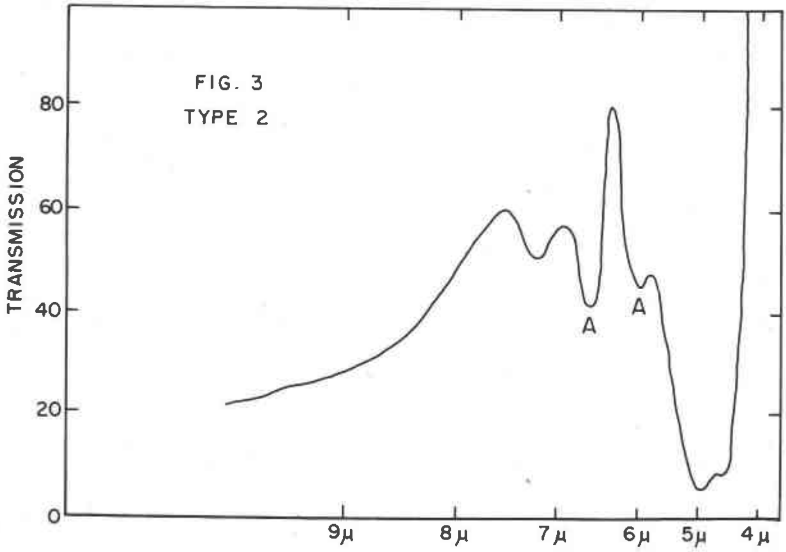

Fig. 3. Infrared transmission in type 2 diamonds.

It is apparent that this procedure does not give a quantitative measure of the transmission but is sufficient to indicate the type of gem being measured.

It is well-known that traces of impurities can change the color of some materials and it has been thought that the 8 to 10 micron absorption was an illustration of this fact. Some substantiation of this view has been reported by Chesley who found that the purest diamond among thirty-three was the only one which was a type II (4).

Three of each type were analyzed by spectrographic methods in our laboratories. The surfaces of the gems were cleaned with alcohol, aqua-regia, and distilled water before being analyzed. The results are given in Table 1. Thirty-six other elements were tested for but not found. No test was made for cesium, lithium, potassium, rubidium, or the rare-earth elements. There appears to be no evident correlation between the amount of impurity and the type of diamond, as one type I was as low as the type II in contaminants. To confirm further this conclusion, five additional diamonds, all type II, were analyzed and most of them were found to have as much impurity as any of the type I in the first group. These tests indicate that differences in impurity content cannot account for the variations in the absorption spectra. There is still the possibility that the presence of traces of the elements not tested for may be connected with the differences in absorption. Among others, Brophy (5) and Bishui (6) are of the opinion that the absorption differences between the two types are due to impurities, while Raman (7) believes these differences are connected with crystal structure variations.

Another variable property is the intensity and color of fluorescence under ultraviolet light. None of the ten type II, or of the type I highly modified gems showed any fluorescence. Those of type I which fluoresced always gave a blue or blue-green color. Several of the type I, slightly modified, and some of the type I, modified, also gave this color. No other color was noted in any of the gems tested, but one of the modified type which had a yellow-green fluorescence was reported by Rendall (8). This phenomenon has been thought to be connected either with structural differences or with the presence of the right impurities in the proper proportions. From ten to fifteen per cent of any batch of fifty or more gems showed fluorescence under a commercial ultraviolet lamp, emitting radiations between 2400 and 4000 Å, with peak emission at 3200 Å, and with about 700 microwatts per cm^2 of U-V energy.

Table 1. Results of Spectrographic Analyses

Element	Type I			Type II		
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Al	T	—?	T	FT	—?	—?
B	T	—?	T	—	VW	—
Ca	W	—	W	VW	T	—
Cu	VW	FT	T	VW	FT	FT
Fe	T	—?	T	VW	T	FT
Mg	T	FT	T	VW	T	FT
Na	W	—	W	W	—	—
Si	VW	FT	T	VW	T	FT

In general the symbols indicate the following concentration ranges as parts per millon of metal in the diamonds: W, 100–1000 ppm; VW, 10 to 100 ppm; T, 1 to 10 ppm; FT, less than 1 ppm; and dash (—), not detected. The gems weighed from 25 to 50 mg. each.

Although the diamond crystallizes in the cubic system and would be expected to be isotropic, the type I often shows birefringence. The type II is isotropic, or nearly so. It might seem plausible to attribute any anisotropy to the presence of impurities which could be expected to cause internal strain. Variations in the distribution of the contaminants might account for the various birefringence patterns that have been observed. We made no tests for birefringence.

Some diamonds have been found with a graphite coating which could have been formed while hot under diminished pressure, as the change always begins at the surface. Although diamond is not stable under ordinary conditions, its rate of transformation to graphite is practically zero and only above about 1300° C. does the rate become perceptible (9). When the thermal vibrations of its atoms become large enough to exceed 0.14 Å, the change to graphite can occur only under very high pressure. At 1500° C. this pressure must be greater than about 40,000 atmospheres and becomes higher with increasing temperature (10). One of the values used in calculating the graphite-diamond equilibrium is the thermal expansion. Previous measurements had not been made above 1000° C., but recently the thermal expansion has been determined here by *x*-ray methods to temperatures as high as 1400° C. (11). From 0° to 1400° C. the linear thermal expansion was found to be 0.58 per cent, with the coefficient changing from 1.3×10^{-6} at 25° C. to 7.0×10^{-6} at 1400° C.

Nearly all diamonds are good electrical insulators but a new rare type which is a semi-conductor was reported by Custers and designated type IIb (12). All blue diamonds are type IIb but not all of this type are blue. Their conductivity is attributed to the presence of many lattice defects probably produced by radiations from radioactive substances at one time in the vicinity of the crystal. This type will act as a crystal rectifier for small alternating currents. Types I and II do not conduct appreciably except at elevated temperatures. In measurements we made it was found that the conductivity versus temperature curve for these types showed a marked inflection at 750° to 800° C. which was present on both heating and cooling in helium from a maximum of 1250° C. Above 800° C. the conductivity increased much faster than at lower temperatures. No difference between the two types was shown by this test.

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