

SYNTHESIS OF DIAMOND USING A COMBUSTION FLAME IN THE ATMOSPHERE

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The author reports on a newly developed diamond synthesis technique. Diamonds have been formed by using a combustion flame in the air. The combustion gases used are mixed gases such as oxygen (O_2) and hydrocarbons such as acetylene (C_2H_2), ethylene (C_2H_4), propane (C_3H_8) and methane (CH_4). The utilized gas, mainly a mixture of acetylene and oxygen, is introduced into the torch and is incompletely burned in air. Then, the diamond is deposited on the substrate in the inner flame (reducing flame, acetylene feather). The diamond films and particles are characterized by X-ray diffraction, scanning electron microscopy (SEM) and Raman spectroscopy. The films and particles are relatively highly deposited with a growth rate of 100–170 $\mu\text{m}/\text{h}$ which is faster than other CVD methods. The present method needs no vacuum vessel, and thus is easy to handle. The growth conditions are not strict. Therefore, the diamond synthesis is easily performed, and this technique may be promising for use in industry.

1. Introduction

Diamond has various excellent properties, such as extreme hardness, high thermal conductivity, high electrical resistivity and corrosion resistance.¹⁾

Recently, the synthesis of diamond by Chemical Vapor Deposition (CVD) have attracted the interest of many investigators. These synthesis methods are mainly microwave plasma CVD,²⁾ dc plasma CVD,³⁾ rf plasma CVD,⁴⁾ rf induction thermal plasma CVD,⁵⁾ dc plasma jet CVD⁶⁾ and arc discharge plasma CVD⁷⁾ using methane (CH_4), ethanol (C_2H_5OH) and hydrogen (H_2). The diamond growth mechanism from the vapor phase is not clear.

However, the author reviewed the fundamentals of diamond synthesis methods published to date and noted that the above-mentioned CVD methods use plasma to decompose source gases (CH_4 , C_2H_5OH , H_2) containing carbon. Well, it is known that combustion flames are plasmas which occur in the air. From various experimental results, the author has confirmed diamond synthesis using combustion flames in air.⁸⁾

In this paper, diamond synthesis using oxygen-acetylene combustion flames in the atmosphere and the remarkable points of the newly presented

method will be described. The obtained diamonds are also characterized by X-ray diffraction, scanning electron microscopy (SEM) and Raman spectroscopy. The diamond films are deposited with a growth rate of 100–170 $\mu\text{m}/\text{h}$ and are highly crystalline, without graphitic carbon.

2. Experimental

The combustion gases used are mixed gases such as oxygen (O_2) and hydrocarbons such as acetylene (C_2H_2), ethylene (C_2H_4), propane (C_3H_8) and methane (CH_4). Figure 1 shows a sketch of the diamond synthesis experimental setup using a combustion flame. In the present method, the utilized gas, mainly a mixture of acetylene and oxygen, is introduced into the torch (a commercial oxy-acetylene torch for cutting) and is incompletely burned in the air. That is, the present method employs an acetylene-rich flame as the combustion flame. The flow of acetylene and oxygen is measured by calibrated flow meters. The acetylene and oxygen purities are above 98.5% and above 99.995%, respectively. In Fig. 1(a), the acetylene rich-flame has an inner flame (reducing flame) and an outer flame (oxidizing flame). This inner flame is the so-called "acetylene feather" and the acetylene

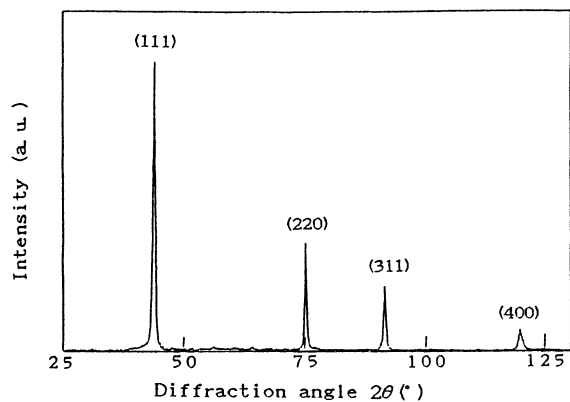


Fig. 3. Typical X-ray diffraction pattern of the diamond film.

Table 2. Observed interplanar spacings and reported values of natural cubic diamonds

Natural diamond (ASTM6-675)		Synthetic diamond
hkl	d (Å)	d (Å)
111	2.06	2.060
220	1.261	1.261
311	1.0754	1.074
400	0.8916	0.891

value ($a=3.5667 \text{ \AA}$, ASTM6-675) of natural cubic diamond in diffraction angles and intensities. Therefore, the present samples are identified as diamond.

Raman spectra are measured in the range of $1100\text{--}1700 \text{ cm}^{-1}$ by a JOVIN YVON Raman spectrometer with 514.5 nm laser excitation. Figure 4 shows a Raman spectra of the same film as in Fig. 2(a). The spectra indicates one intensive peak at 1333 cm^{-1} , which is very close to the value of natural diamond,¹⁰⁾ and a weak Raman peak based on amorphous carbon at $1350\text{--}1550 \text{ cm}^{-1}$. However, the Raman peak based on graphite does not appear.

In speculating on the diamond growth mechanism in a combustion flame the author notes that there are two kinds of flame, a whitish outer flame and a bright inner flame. The outer flame cannot be used, because it exerts an oxidizing action, converting carbon atoms (C) into CO_2 . On the other hand, the inner flame is lacking in oxygen, and therefore the combustion is incomplete. Also, since the temperature of the flame is about 3000°C ,

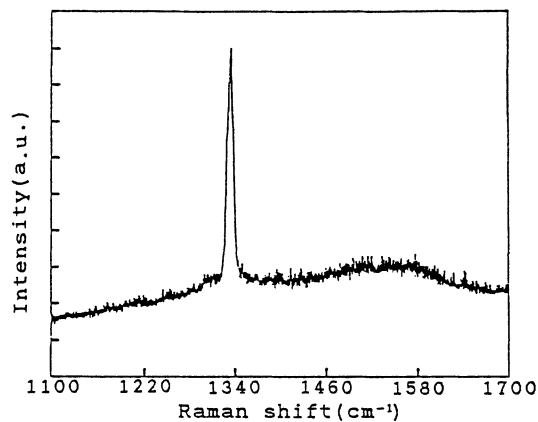


Fig. 4. Raman spectra of the same film as in Fig. 2(a).

source gases are relatively decomposed to excited species. The inner flame is the so-called “reducing flame”, which includes a large number of excited species (atoms, ions and molecules). Therefore, the excited radicals (C_2 , CH , H , OH) in the inner flame induce a chemical reaction on the substrate surface and gradually grow into a diamond. Since acetylene gas as a carbon source is supplied in great amounts onto the substrate, the growth rate of diamond also can be high.

4. Conclusion

The author has succeeded in synthesizing diamond using a combustion flame in the atmosphere. The diamond could only be deposited on a substrate inside the inner flame (acetylene feather). Various experimental results lead me to the conclusion that: 1) A vacuum vessel (reaction chamber) is not required. 2) The diamond films and particles are relatively quickly deposited with a growth rate of $100\text{--}170 \mu\text{m/h}$, which is faster than other CVD methods. 3) It is possible to deposit on a large area of substrate, on a curved surface and on the edge of a substrate. 4) This method is easy to handle and the synthesis conditions are not strict. Therefore the diamond synthesis is easily performed, and this method may be promising for future use in industry. Since the newly presented synthesis method uses a combustion flame, the author has named the newly developed technique “Flame Deposition Technology”.

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