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Letter to the Editor

Fitting the unusual UV extinction curve of V348 Sgr

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Abstract. We have produced new types of carbonaceous condensates from the ejecta of a hydrocarbon plasma. These condensates are named Quenched Carbonaceous Composites (QCC). There are various types of QCC formed around the center of the ejecta that show an absorption feature in the spectral range 220–250 nm. The QCC with an absorption feature at 220 nm is composed of onion-like spherules; that with an absorption feature at 230–240 nm are composed of polyhedral particles; and that with an absorption feature at 250 nm is composed of ribbons with bent graphitic layers. The 240–250 nm absorption feature of the hot evolved star V348 Sgr can be matched by the ribbon-like QCC, suggesting that this type of QCC may be present in the circumstellar shell of this star.

Key words: stars – RCB stars-carbon: laboratory – dust, extinction

1. Introduction

The origin of the strong interstellar 217 nm absorption is a long-standing problem of astrophysics (Draine 1989). One approach to the problem is to study the variations of the absorption band in various circumstellar environments. A promising avenue has been the study of the ultraviolet absorption in hydrogen-deficient, post-asymptotic giant branch stars such as those of the R Coronae Borealis (RCB) type (Greenstein 1981, Hecht et al. 1984, Buss et al. 1989, Drilling & Schönberner 1989, Drilling et al. 1997). Such stars have an ultraviolet absorption maximum near 250 nm (Jeffery 1995b) and are thought to be post-AGB stars in the final stage of helium shell flash (Clayton 1996). Because they are active producers of dust, they provide important clues about the nature of the absorbing material.

V348 Sgr is an important member of this class of stars. It is a hot extreme helium star which exhibits RCB characteristics (Clayton 1996). It is one of the few that are bright enough to obtain good ultraviolet spectra, and therefore it has been extensively studied (Drilling et al. 1997; Hecht et al. 1998). We present in this paper evidence for a possible laboratory analog for the dust producing the 250 nm absorption around V348 Sgr. This laboratory analog is a carbonaceous material named quenched carbonaceous composite (QCC), and it is produced in the ejecta from a hydrocarbon plasma (Sakata et al. 1994). We have previously shown that such material has spectral properties which have much in common with that of the interstellar extinction curve (Sakata et al. 1983, 1994, 1995). In this paper we show that one type of hydrogen-deficient QCC can match the 250 nm absorption band observed in V348 Sgr, and we also show the structure of this material with high resolution electron micrography.

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2. Experiment and results

2.1. Production of QCC with different types of source gas mixtures

QCC is formed from the ejecta of a plasma which is generated by a microwave discharge using CH_4 as a source gas. The experimental setup was reported in the previous papers (Sakata et al. 1994). We measured the UV and infrared spectra of the QCCs with a Hitachi U3300 spectrophotometer with a resolution of 0.5 nm and with a Perkin Elmer FTIR spectrometer (Spectrum 2000) with a resolution of 2 cm^{-1}. Three kinds of source gas were used for the QCC formation as described below.

Experiment 1: Source gas of H_2(0%), CH_4(100%). Pure CH_4 source gas was used previously by Sakata et al. (1994). At the center of the ejecta from the plasma, "dark QCC" was formed at the point where the ejecta struck the substrate and condensed. As deposited the dark QCC shows an absorbance peak at 200–210 nm as shown in Fig. 1(a). By washing the dark QCC with acetone using a pipette we can remove much of the organic material from the dark QCC. The dark QCC shows a 220 nm absorbance peak after washing with acetone.

During the production of the dark QCC, a yellow-brown material is produced on the walls of the vacuum chamber. This "filmy QCC" has interesting properties and has been reported earlier by Sakata et al. (1990). The filmy QCC has infrared absorption bands at 3.29–3.31, 3.38, 3.42, 3.49, 3.53, 6.2, 7.0, 7.3,

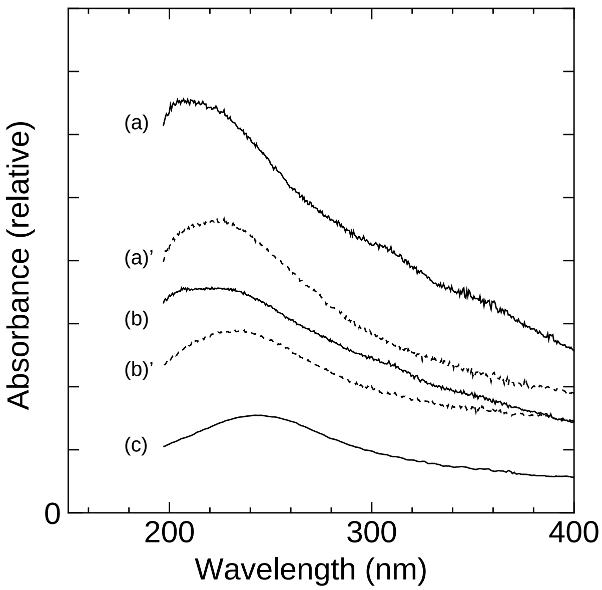

Fig. 1. UV spectra of various QCCs. (a) Formed from H_2 (0%) and CH_4 (100%). (a)′ After washing (a) with acetone. (b) Formed from H_2 (50%) and CH_4 (50%). (b)′ After washing (b) with acetone. (c) Formed from H_2 (70%) and CH_4 (30%).

7.6, 8.8, 11.4, 12.0, and 13.2 μm. It is composed of various types of organic condensates, such as polycyclic aromatic hydrocarbons, polyenes and polyynes. After washing with acetone, the dark QCC also has some of the infrared absorption bands listed above. However, the absorption bands at 3.3, 12.0, and 13.2 μm are weaker.

Experiment 2: Source gas of H_2(50%), CH_4(50%). The dark QCC as deposited shows a broad absorbance peak around 210–230 nm (Fig. 1b). The material shows a set of infrared absorption bands similar to the condensate of Experiment 1, although all of the absorption bands are weaker. After removal of organic material from the dark QCC by washing with acetone, the material shows an absorbance peak ∼230 nm.

Experiment 3: Source gas of H_2(70%), CH_4(30%). The dark QCC as deposited shows a peak at 235–250 nm as shown in Fig. 1(c). After washing the dark QCC with acetone, the spectrum was unchanged. The filmy QCC was not produced on the vacuum wall of the apparatus, and this confirms that the organic condensates were not produced in abundance with this source gas mixture. In the infrared spectrum of the dark QCC, weak absorption bands at 3.38, 3.42 and 3.51 μm are detected, but the bands at 3.3 and 11–13 μm are not. The 3 μm bands seem to be caused by a small amount of methyl groups or hydrogen atoms attached to the carbon atoms on the periphery of the QCC particles. The lack of 3.3 and 11–13 μm bands indicates little or no aromatic C–H bonds. This suggests that the hydrocarbon radicals in the plasma reacted with hydrogen to form CH_4 again, and the CH_4 was subsequently removed by the vacuum pump in the apparatus. Therefore the dark QCC formed from the hydrogen-rich plasmic gas contains only a small amount of hydrogen.

2.2. High resolution imaging of QCC samples

We obtained high resolution images of the dark QCC that were washed with acetone. A Hitachi H-9000EM electron microscope was used. Onion-like spherules are found in the dark QCC with a peak at 220 nm and these results are discussed separately by Wada et al. (1998). In contrast, the particles containing in the dark QCC with a peak around 230–240 nm have a polyhedral concentric shell structure (Fig. 2a, 2b). As the shells become larger they become more polyhedral in shape and the absorbance peak shifts to longer wavelengths.

In the QCC showing the 249 nm absorbance peak, ribbon-like patterns are observed (Fig. 2c). The ribbons have 3–13 layers with an interlayer distance similar to that of graphite. The number of the layers in the ribbons is nearly the same as the numbers of shells of the onion-like spherules formed in Experiment 1. The ribbons extending more than 10 nm are bent very abruptly. In the QCC sample shown in Fig. 2(c), we cannot see particles such as seen in Fig. 2 (a, b). Furthermore, we cannot see the ends of the ribbon-like structure. This suggests that it is composed of fused polyhedrons or long entangled bent ribbons. We do not see flat graphitic particles which are constructed from large sheets of PAH. The image has some similarities to those of polyhedral particles of carbon black heated at high temperature (2,800 C), cokes, and glassy carbon (Oberlin 1989; Jenkins & Kawamura 1971). These are all carbon materials produced at high temperature.

2.3. Comparison to the UV absorption of V348 Sgr

The UV extinction of the dust surrounding V348 Sgr has an absorption feature located at 242–250 nm (Drilling et al. 1989, 1997). In Fig. 3 we compare the V348 Sgr feature with that of the dark QCC with 246 nm peak. Matching of the absorption maximum wavelength and width is good. Since the spectrum of V348 Sgr is noisy at the shorter wavelength side of the absorption maximum, the profile of the feature is not known precisely. We assume the structure in the spectrum at 200–250 nm is noise and that a smooth fitting curve is appropriate.

3. Discussion

The circumstellar dust of carbon-rich evolved stars tend to show an absorption maximum at 230–250 nm. For example, the UV absorption maximum occurs at 230 nm in HD 213985 (post AGB star, Buss et al. 1989), 240–250 nm in RY Sgr and R CrB (RCB stars; Hecht et al. 1984) and 242.5–250 nm in V348 Sgr (hot RCB star/WR star; Drilling et al. 1989, 1997). The temperature of the central stars are estimated to be 9,000 K in HD 213985 (Buss et al. 1989), 6,900 K in R CrB (Asplund et al. 1997), and 22,000 K in V348 Sgr (Jeffery 1995a). The extremely high carbon to hydrogen ratio and high effective temperatures of these

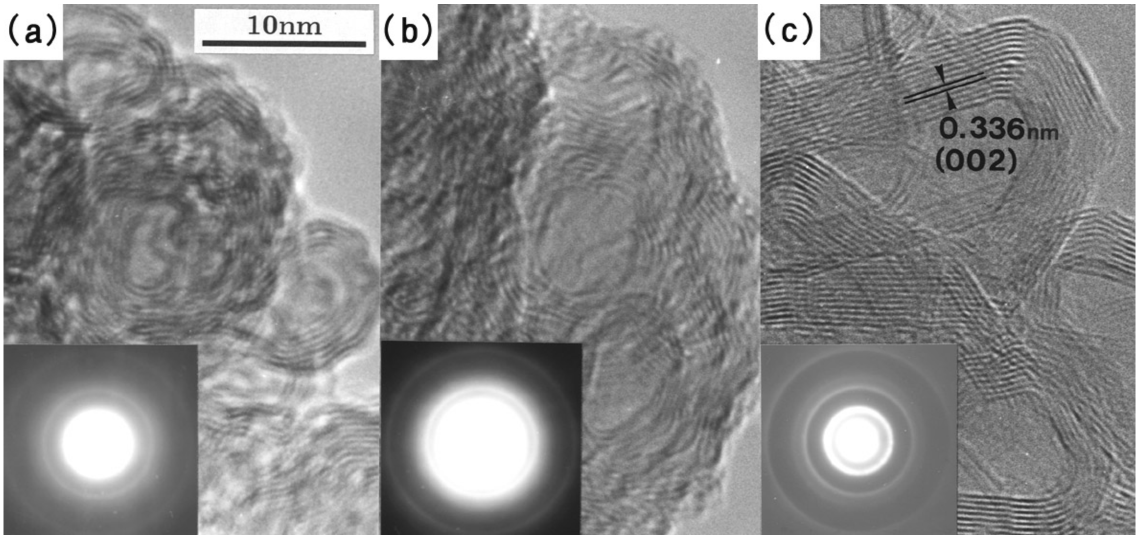

Fig. 2a–c. Images of QCCs by high resolution electron microscopy. QCCs with a peak at: **a** 233 nm, **b** 241 nm, and **c** 249 nm, respectively. The insert at the lower left of each figure shows the diffraction pattern of the sample. The interlayer distance is 0.336 nm in **c**.

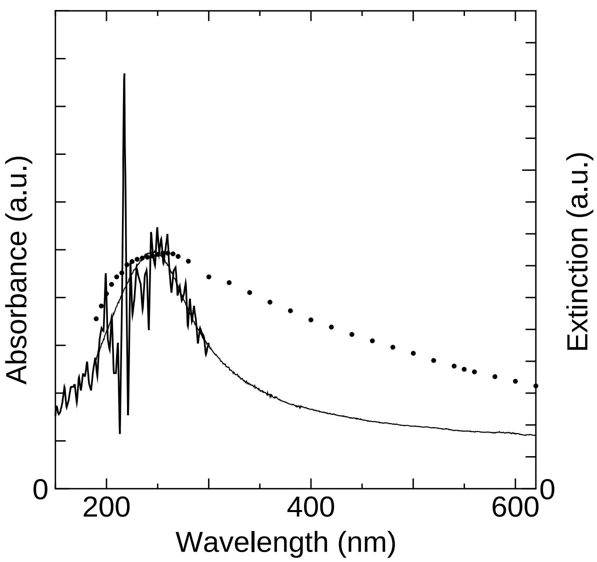

Fig. 3. Comparison of the UV absorption curve of V348 Sgr with the QCC formed from H_2 (70%) and CH_4 (30%). The dotted curve is a UV spectrum of a soot made from acetylene (after Sakata et al. 1995).

stars is very favorable for the formation of carbon solids such as amorphous carbon and graphite (Oberlin 1989).

We have shown in the previous section that QCC with different absorption maxima can be produced and that the particles in the QCC have different shapes and sizes as seen in the high resolution electron microscope images shown in Fig. 2. In addition, they contain different amounts of aromatic C-H bonds. The particles in the QCC showing a 220 nm absorption feature are onion-like spherules (Wada et al. 1998). As the particles become larger, the peak of the QCC shifts toward longer wavelengths and the particles become more polyhedral in shape. The graphitic dark QCC with ribbon-like pattern shows a peak near 250 nm and lower absorbance at the visual wavelength region.

A recent infrared spectrum of R CrB obtained with the Infrared Space Observatory presented by Walker et al. (1996) shows no 11.3 μm band. This means that there is little aromatic C-H in the circumstellar dust like that of the graphitic dark QCC (shown in Fig. 2c). We could detect small peaks at 3.38, 3.42 and at 3.51 μm in the graphitic dark QCC that were caused by a very small amount of hydrogen atoms attached to sp^3-hybridized carbon. However no peak was found at 3.3 and 11.3 μm.

Various types of carbon have been proposed as the carrier of the UV absorption band in V348 Sgr. One is a glassy carbon which is proposed by Hecht et al. (1984). They calculated the UV absorption of the particles using the optical constants of a bulk material although the glassy carbon is thought to be amorphous.

Another material is a soot produced by acetylene (Schnaiter et al. 1996). They deposited the soot in a solid argon matrix and obtained the wavelength of the UV absorption feature after a correction for the matrix effect. They showed that the matrix-isolated particles have a narrower band compared to coagulated particles. The absorption profile of the 250 nm feature of this matrix-isolated soot is very similar to that of V348 Sgr.

Another material which shows a 250 nm absorption band is an amorphous carbon smoke which was produced by laser evaporation (Stephens 1980). Particles of smokes with 13 nm and 6 nm of mean radius showed an absorption maximum at 250 nm and at 235 nm, respectively. In another type of experiment, Borghesi et al. (1985) made amorphous carbon particles by arc discharge and burning benzene and xylene in air. These materials produced an absorption band at 240–250 nm. The very broad absorption of this material matches the UV absorption band of Abell 30 well but not that of V348 Sgr (Muci et al. 1994). The absorption band of V348 Sgr is sharper than Abell 30.

Extinction curves of V348 Sgr were presented by Drilling et al. (1989, 1997). The peak of the extinction curve for V348 Sgr is relatively sharp. The absorbance ratio at the UV peak to that at 550 nm of V348 Sgr is about 3.55, while that of Abell 30 is about 2. Carbon and carbonaceous materials show high absorption in visual region. For example, soot obtained from burning acetylene shows high extinction in the visual wavelength region (see Fig. 3). The absorbance ratio at the UV peak to that at 550 nm of the acetylene soot is about 2.0.

Two materials, dark QCC with low hydrogen abundance and matrix-isolated soot, match the 250 nm absorption band of V348 Sgr. The dark QCC is not amorphous but graphitic, and the particles are coagulated on the substrate. On the other hand, the matrix-isolated soot is well dispersed in the matrix. The structure of the matrix-isolated soot is not known but it is likely to be amorphous. Which type of material is formed in V348 Sgr? Because graphitic dust formation occurs in a high temperature environment, the high temperature of V348 Sgr may favor graphitic dust formation.

4. Conclusions

We have presented QCCs which show an absorption peak at 230–250 nm. High resolution electron microscopic imaging reveals that they are composed of different particle shapes. In the electron microscope image of a QCC with a 250 nm peak, bent ribbon-like structures with many layers are observed, and this indicates that the graphitic layers are well developed. The UV absorption feature is very similar to 348 Sgr whose central star is very hot. We suggest that graphitic dust formation may occur in the high temperature circumstellar environment of this star.

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