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# On the inorganic carriers of the 21 micron emission feature in post-AGB stars

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**Abstract.** The mysterious 21 $\mu$m emission feature seen in only 12 C-rich proto-planetary nebulae (PPNe) remains unidentified since its discovery in 1989. Over a dozen materials have been suggested as the carrier candidates while none of them has received general acceptance. We investigate the inorganic carrier candidates by applying the observational constraints of the feature strength and associated features. It is found that: (1) three candidates, TiC clusters, fullerenes with Ti impurity atoms, and $SiS_2$, are not abundant enough to account for the emission power of the 21 $\mu$m band, (2) five candidates, doped-SiC, $SiO_2$-mantled SiC dust, carbon and silicon mixtures, $Fe_2O_3$, and $Fe_3O_4$, all show associated features which are either not detected in the 21 $\mu$m sources or detected but with a much lower strength, and (3) FeO, which satisfies the abundance constraints, does not display any associated features which are not seen in the 21 $\mu$m sources. Moreover, FeO is more likely to survive in the C-rich environment than $Fe_2O_3$ and $Fe_3O_4$. Thus FeO seems to be the most plausible one among the inorganic carrier candidates.

**Keywords.** Infrared: stars, (stars:) circumstellar matter, stars: AGB and post-AGB

## 1. Introduction

The so-called "21 $\mu$m feature" has been well identified in 12 proto-planetary nebulae (PPNe; Kwok *et al.* 1999; also see Hrivnak *et al.* in this proceeding for two new 21 $\mu$m sources). This feature, peaking at $\sim$20.1 $\mu$m with a FWHM of $\sim$2.2–2.3 $\mu$m, has little shape variation among different sources (Volk *et al.* 1999). Most of these sources exhibit quite uniform characteristics: metal-poor, carbon-rich F and G supergiants with strong infrared (IR) excess and over abundant s-process elements (see Kwok *et al.* 1999 and Zhang *et al.* 2006).

Since its discovery by Kwok *et al.* (1989), over a dozen of both organic and inorganic carrier candidates have been proposed. The inorganic candidates are: (a) TiC nanoclusters (von Helden *et al.* 2000, but see Li 2003), (b) large-cage carbon particles (fullerenes) coordinated with Ti atoms (Kimura *et al.* 2005), (c) $SiS_2$ dust (Goebel 1993), (d) SiC dust with carbon impurities (Speck & Hofmeister 2004, but see Jiang *et al.* 2005), (e) carbon and silicon mixtures (Kimura *et al.* 2005), (f) SiC core-$SiO_2$ mantle grains (Posch *et al.* 2004), (g) FeO (Posch *et al.* 2004), (h) $Fe_2O_3$, and (i) $Fe_3O_4$ (Cox 1990). However, none of these carrier candidates have received general acceptance. The carrier of the 21 $\mu$m feature remains unidentified. In this paper we report our recent efforts in testing the above-listed inorganic candidates in terms of the elemental abundance budget and spectral shape (with special emphasis on the possible accompanying features).

## 2. General Constraints: Band Strength and Associated Features

We assess the applicability of a proposed carrier candidate by examining (1) whether it is capable of emitting the observed large amount of energy in the 21 $\mu$m band without requiring more dust material than available, and (2) whether the candidate carrier produces additional feature(s) with intensities inconsistent with those observed. HD 56126, a prototypical 21 $\mu$m feature source, is taken as the test case object.

The total energy emitted in the 21 $\mu$m band $E_{\rm tot}$ is related to the abundance (relative to H) of element X of the carrier by $[{\rm X/H}] = \frac{n_{\rm X}\, E_{\rm tot}}{\mu_{\rm d}\, M_{\rm H} \int_{21\,\mu{\rm m\ band}} \kappa_{\rm abs}(\lambda) \times 4\pi B_\lambda(T_{\rm d})\, d\lambda}$ (see Zhang *et al.* 2008). Knowing the dust temperature $T_{\rm d}$ and the mass absorption coefficient $\kappa_{\rm abs}$, one can calculate the element abundance required for a dust species (containing $n_{\rm X}$ X atoms in each molecule with a molecular weight $\mu_{\rm d}$) to account for the observed intensity of the 21 $\mu$m band. This constraint effectively excludes those candidates with scarce elements such as Ti. On the other hand, some of the proposed carrier candidates exhibit strong features in addition to the 21 $\mu$m band which are not seen in the 21 $\mu$m sources. Using lab optical constants and the stellar parameters, we calculate the intensity ratios of the associated features to the 21 $\mu$m band and compare with the observed spectra. In this way we exclude most of the candidates which display associated feature(s), such as SiC-bearing dust.

## 3. Results

Our results on individual carrier candidate are shown in Table 1. We investigate nine inorganic carrier candidates. Three of them are excluded due to abundance deficiency and another five suffer from producing strong associated features not seen in the 21 $\mu$m sources. At this moment, FeO nano particles seem to be the most promising candidate.

**Table 1.** Summary of the test on the carrier candidates (✓: pass; ×: fail)

| Candidate | Abundance (element) | Associated features |
|---|---|---|
| TiC nanoclusters | × (Ti) | ✓ |
| fullerenes coordinated with Ti atoms | × (Ti) | ✓ |
| $SiS_2$ | × (S) | × (16.8 $\mu$m) |
| SiC dust with carbon impurities | ✓ | × (11.3 $\mu$m) |
| carbon and silicon mixtures | ✓ | × (9.5 $\mu$m) |
| SiC core-$SiO_2$ mantle grains | ✓ | × (8.3 $\mu$m, 11.3 $\mu$m) |
| FeO | ✓ | ✓ |
| $Fe_2O_3$ | ✓ | × (9.2, 18, 27.5 $\mu$m) |
| $Fe_3O_4$ | ✓ | × (16.5, 24 $\mu$m) |

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