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Light scattering by elongated clusters of a-C:H nanoparticles

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Abstract

We present here the light scattering by elongated clusters consisting of linear chains of spherical a-C:H nanoparticles. The results are compared with light scattering by spherical nanoparticles. This simple experiment, performed by utilizing plasma-grown elongated nanoparticles, demonstrates a possibility and an opportunity to examine the validity of the Davis and Greenstein mechanism: Interstellar polarization might be due to aligned, elongated nanoparticles.

Introduction

The universe is not empty but filled with stars and diffuse material between them, called interstellar medium (ISM). Interstellar Dust (ISD) grains play an important role in the ISM and they shape the spectra of galaxies [1]. Since Trumpler provided the first proof of ISD grains [2], authors have investigated ISD grains regarding their size, shape, and compositions (e.g. see review articles, Ref. [1] and [3]). The composition of ISD grains remains still controversial, but the (most important) candidate materials are both amorphous and crystalline silicates (SiO_x), carbonaceous, silicon carbide (SiC), and ice.

We pay special attention to elongated clusters of spheres in order to get a better understanding of the polarization of light scattered by ISD particles (interstellar polarization). The origin of this interstellar polarization (IP) is not fully understood, but it is assumed that the IP is caused by the starlight passing through or scattered by aligned nonspherical ISD in interstellar magnetic field (Davis and Greenstein mechanism): In order to explain the IP curve, there must exist a population of aligned, nonspherical grains with a typical size of $r > 0.1\mu$m responsible for the peak polarization at $\lambda \sim 0.55\ \mu$m [1, 3].

In this paper, we present a novel method to investigate the IP in laboratory to examine the Davis and Greenstein mechanism using plasma grown elongated nanoparticles aligned by electric/magnetic fields. Our elongated nanoparticles are consisting of individual spherical a-C:H nanoparticles with known optical properties and internal structure measured by Rayleigh-Mie scattering ellipsometry and by micro-Raman spectroscopy, respectively.

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Experiments

The experimental setup and the experimental conditions for the nanoparticle formation are described in our previous publication in detail [4].

For the scattering measurements, the polarization of a 680 nm diode laser is set either vertical ($\updownarrow$) or horizontal ($\leftrightarrow$). Two polarizers placed in front of the laser ensure pure linear polarization states. The scattered light is measured under 90° relative to the primary laser beam. The scattered light is then passing through an rotating analyzer (polarizer) and an interference filter for the wavelength of 680 nm, and detected by a photomultiplier (Hamamatsu R5929). The rotation frequency of the analyzer is about 0.02 Hz and the detected signal and the angle of the analyzer are recorded simultaneously by a computer in-situ.

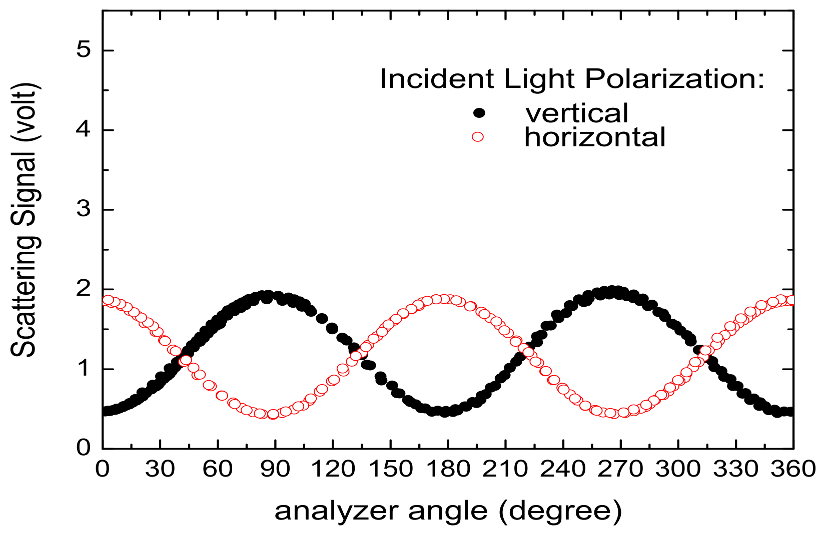
Generation of Elongated Nanoparticles

Nanoparticles are formed between two parallel plate electrodes of a standard GEC reference cell in an Ar-C_2H_2 mixture. Except for the cauli-flower shaped surface structure, the nanoparticles have spherical form and they are growing up homogeneously with a narrow size distribution. Their growth and optical properties are investigated by means of in-situ Rayleigh-Mie scattering ellipsometry [5], in-situ FTIR spectroscopy [6], and ex-situ micro-Raman spectroscopy [7] in detail, and it is found that our a-C:H nanoparticles are a good candidate as an interstellar dust analog.

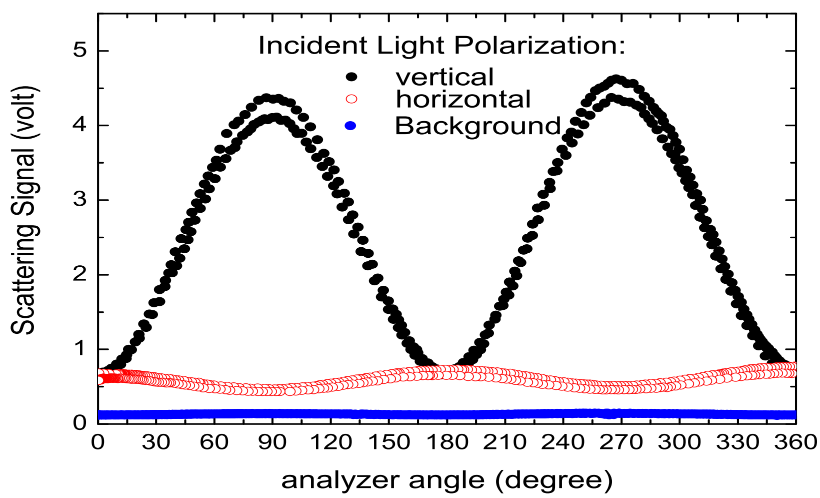
At a specific condition, the spherical particles merge together and build linear chains. The individual particles have a radius of about 200 nm, and the length of the chains ranges from several μm to mm. Similar to plasma crystals of spherical particles, the chains are aligned spontaneously in a 3-D structure and levitating between the electrodes. The chains are aligned by electric field so that the long axis of the chain is directed along the direction of the electric field (vertical direction). Similar observations are made by other authors [8].

Light Scattering by Elongated Particles

Figure1 shows the measured light intensity scattered by spherical and elongated particles as a function of the analyzer angle. The incident light was polarized either vertically (parallel to the long axis) or horizontally (perpendicular to the long axis of the elongated grains). In the case of spherical particles the scattered light intensity shows no dependence on the polarization state of the incoming laser beam [Fig. 1(a)]. This is due to the spherical symmetry. On the other hand, in the case of elongated particles the scattered light intensity strongly depends on the polarization state of the incoming light: When the light is polarized vertically, i.e. parallel to the long axis, the incident light induces a large dipole moment along the long axis. When the light is polarized



(a) spherical particles.



(b) elongated particles.

Figure 1: Scattered light intensities by both spherical and elongated nanoparticles as a function of analyzer angle.

horizontally, i.e. perpendicular to the long axis, a much smaller dipole moment is induced. Thus, the scattered light intensities show strong dependency on the polarization state of the incident light. This means that the light is selectively scattered according to the preferential direction given by the long particle axis: An ensemble of aligned elongated particles acts as a polarizer. This simple experiment demonstrates a possibility and an opportunity to examine the validity of the Davis and Greenstein mechanism by utilizing plasma-grown elongated nanoparticles:

Interstellar polarization might be due to aligned, elongated nanoparticles.

Summary and Outlook

We have investigated the light scattering by elongated nanoparticles which consist of individual spherical nanoparticles, and compared it with that of spherical particles. As a result, we have observed pronounced differences in light scattering between spherical and nonspherical particles. A comparison of our experimental results with theoretical calculations using the discrete-dipole approximation (DDA) [9] is under way.

Acknowledgement

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