

Fractal Growth of Giant Amphiphiles in Langmuir-Blodgett Films

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Abstract Fractal structures have attracted considerable scientific interest, and fractal geometry is an effective tool to study the complicated structure and dynamic processes, such as dilation symmetry of disorder structure, percolation, gelation, and metal-insulator transition. Here, we summarized our findings of fractal growth of giant amphiphiles in Langmuir-Blodgett (LB) film. Giant amphiphiles composed of polyhedral oligomeric silsesquioxanes (POSS) derivatives and poly(ethylene oxide) (PEO), with structural diversities of POSS head modification, POSS head number, PEO chain length, are precisely synthesized. The effect of molecular structures and operation parameters on the fractal growth patterns are discussed, in addition, other fractal growth patterns in LB films and in Langmuir films are included, aiming to understand the basic molecular principle of fractal growth in LB system.

Keywords Fractal growth; Langmuir-Blodgett (LB) film; Langmuir film; Giant amphiphiles; Poly(ethylene oxide) (PEO) crystallization

Citation: Wang, W. J.; Xu, X.; Shao, Y.; Liao, J. W.; Jian, H. X.; Xue, B.; Yang, S. G. Fractal growth of giant amphiphiles in langmuir-blodgett films. *Chinese J. Polym. Sci.* 2022, 40, 556–566.

INTRODUCTION

In nature, ice flowers, snowflakes, plant leaves, butterfly wings, coastline, and so on, show interesting pattern of self-similarity, which are called as fractal structures. Mandelbrot published the book titled as “The Fractal Geometry of Nature”, which described many fractal phenomena, and provided mathematical tool to study the fractal structure and dynamic process.^[1–3] In the past decades, fractal structures have drawn considerable attention in the field of chemistry, physics, biology, materials science, and even financial and economics.^[4–11]

Langmuir monolayers and Langmuir-Blodgett (LB) films, which are referenced as molecular layers on water surface and solid surface respectively, offering effective platforms to investigate molecular interaction and basic information on molecular level.^[12,13] In addition, Langmuir monolayers and LB films are ideal platforms for studying molecular assembly and aggregation in two-dimension (2D).^[14–16] Since its invention in 1935,^[17–19] LB technique has become a valuable tool for microfabrication of ultrathin films which have been exploited for numerous applications, such as separation membranes, optical filters, chemical and biological sensors, and photoelectronic devices.^[20–36]

Various species showing amphiphilic feature, such as surfactants, polymers, colloids, and nano-materials, are explored to fabricate LB films.^[20–28] LB films of small molecule surfac-

tants and lipids have been widely and deeply investigated.^[12] The amphiphilic polymer, such as block copolymer, dendrimer, and graft polymer are used to prepare thin films by LB technique with development of polymer science.^[25–36] Not limited with amphiphilic organic molecules, the inorganic items, metal, magnetic and semiconductive nanoparticles are also utilized to construct nano-structured functional thin films.^[20–24] Cheng and Zhang *et al.* put forward a strategy to synthesize giant molecule with precisely controlled structure, such as sequence, topology, tacticity and size.^[37–39] The molecular nanoparticles with size persistence, no entanglement, and capacity for further functionalization, such as polyhedral oligomeric silsesquioxane (POSS), fullerenes (C₆₀), polyoxometalate (POM), are used as main building units.^[40–42] These giant molecules can be further divided into giant amphiphile and giant polyhedra according to their structure character, which show colorful bulk and solution assembly structures and interesting dynamic behaviors.^[43–50]

The assembly behaviors of giant molecules (mainly giant amphiphiles) at interface or 2D space have been less studied compared with their bulk and solution behaviors. We study interfacial assembly of giant amphiphiles with Langmuir films and LB films using model giant amphiphiles composed of modified POSS and soft PEO segment (Fig. 1). LB films of POSS-PEO giant amphiphiles will present fractal growth continuous pattern while traditional block copolymer containing PEO segment, such as polystyrene-*b*-poly(ethylene oxide) (PS-*b*-PEO),^[25–28] does not. In this work, we discuss the fractal growth pattern of the giant amphiphiles, briefly review other fractal patterns in LB films, and illustrate the requirements

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Special Issue: Ordered Structure of Polymers

Received January 26, 2022; Accepted February 22, 2022; Published online April 25, 2022

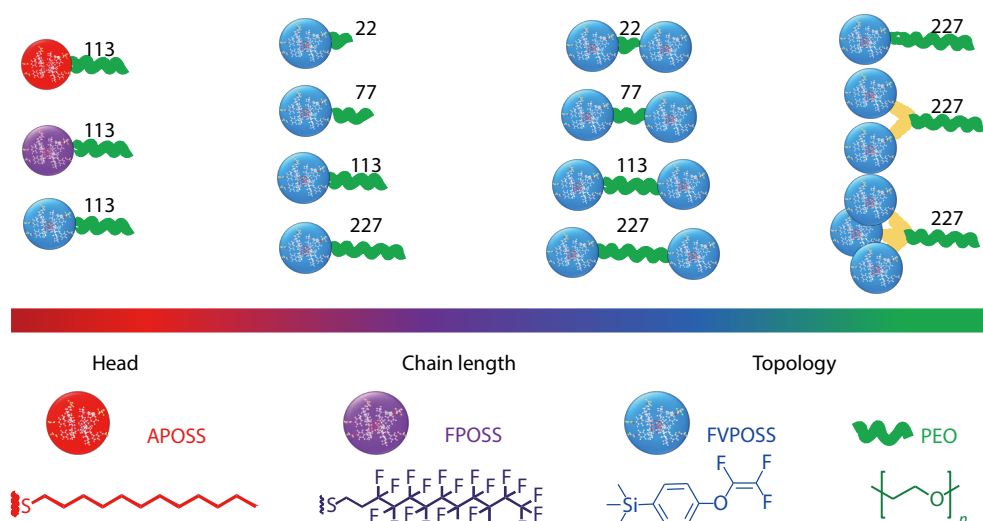


Fig. 1 Giant amphiphiles used for LB film preparation. The numbers indicate polymerization degree of PEO.

that fractal growth pattern will form in LB film systems.

Firstly, the synthesis of giant amphiphiles and the preparation of LB films are introduced. Then, we discussed the influence of giant amphiphiles structure, such as diverse hydrophobic heads, different PEO chain lengths, and various molecular topologies, on the fractal growth of LB film. Next, fractal morphologies of LB films transferred at different surface pressures are compared. In addition, the fractal growth in other LB systems is discussed. At last, we make summary and outlook for the development of fractal growth of giant amphiphiles in LB films.

GIANT AMPHIPHILES SYNTHESIS AND LB FILM DEPOSITION

Giant amphiphiles (Fig. 1) are synthesized by precisely linking building blocks by “click chemistry”. The polymer chain (PEO) is functionalized by azide group, while the hydrophobized POSS head is linked with an alkyne group. Cu(I)-catalyzed (3+2) azide-alkyne cycloaddition (CuACC) reaction was used to link PEO tail and modified POSS head.^[51–54]

The giant amphiphiles are dissolved in chloroform, and then spread on water surface of polytetrafluoroethylene (PTFE) trough (Fig. 2, KSV Nima: 580 mm of length, 145 mm of width, and 4 mm of height with a deposition well in the center). The monolayer of the giant amphiphiles on water surface is compressed by sliding barriers to a certain degree, and then transferred to the substrate of silicon by upward withdrawal protocol. The surface pressure was measured with Wilhelmy plate technique.

EFFECT OF MOLECULAR STRUCTURE

The effects of hydrophobic modification of POSS, the length of PEO chain, and the head number of POSS linked at the end of PEO chain on the fractal growth pattern of LB films are discussed.

POSS Head Modification

The length of PEO chain is fixed (PEO₁₁₃, the polymerization

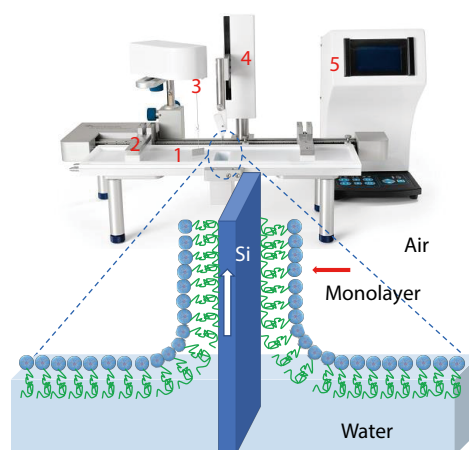


Fig. 2 Illustration of the LB system and the preparation of LB film. (1) PTFE trough, (2) sliding barrier, (3) surface pressure detector, (4) dip coating motor, and (5) system controller.

degree is 113, polymer dispersity index is 1.03), and one end of the PEO chain is linked with hydrophobically modified POSS head.^[55] POSS are modified with alkyl, fluorinated alkyl, and trifluorovinyl groups, which are marked as APOSS, FPOSS and FVPOSS, respectively (Fig. 1). The corresponding giant amphiphiles APOSS-PEO₁₁₃, FPOSS-PEO₁₁₃, and FVPOSS-PEO₁₁₃ are spread on water surface separately, and their π -A isotherms are shown in Fig. 3.

The homopolymer of PEO₁₁₃ chain is water-soluble, but it can form a stable monolayer on the water surface.^[56,57] The surface pressure of PEO₁₁₃ increases gradually and keep stable at 7.9 mN/m during the surface compression (Fig. 3). APOSS-PEO₁₁₃, FPOSS-PEO₁₁₃ and FVPOSS-PEO₁₁₃ all show higher surface pressures than that of PEO₁₁₃ with the same area per molecule occupied when the monolayers compressed to a certain degree (Fig. 3). As the surface pressure increases, the giant amphiphiles on the water surface will show gas, liquid expand, liquid condense, solid phase, and the final collapse.^[58]

The giant amphiphiles are transferred to silicon substrate in

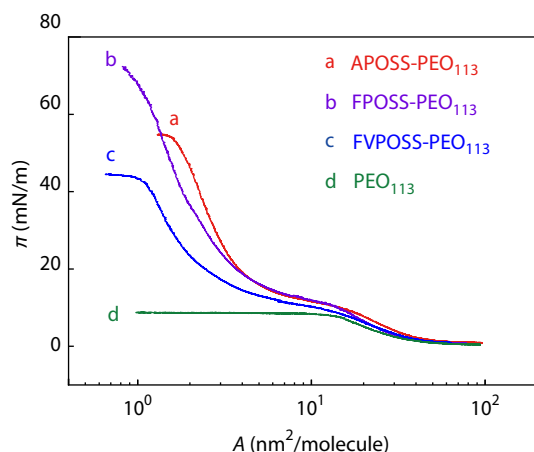


Fig. 3 π -A isotherms of PEO₁₁₃, APOSS-PEO₁₁₃, FPOSS-PEO₁₁₃ and FVPOSS-PEO₁₁₃. (Reproduced with permission from Ref. [55]; Copyright (2021) American Chemical Society).

liquid condensed phase at surface pressure of 25 mN/m to fabricate LB films, and their morphologies are shown in Fig. 4. APOSS-PEO₁₁₃ formed film with an island morphology, while FPOSS-PEO₁₁₃ and FVPOSS-PEO₁₁₃ grow featured fractal morphologies.

From differential scanning calorimetry (DSC) curves, we can further understand the crystal behavior of these giant molecules (Fig. 5). APOSS-OH and FPOSS-OH are both crystalline nanoparticles, their DSC curves show melting and crystallization peaks, but FVPOSS-OH is amorphous (Figs. 5A and 5B). The crystalline PEO chain of these giant molecules shows an endothermal peak between 50 and 60 °C and an exothermal peak between 20 and 40 °C, respectively. (Figs. 5C and 5D). APOSS-PEO₁₁₃ exhibits another transition (an endothermal peak at 10 °C and an exothermal peak at 5 °C), which is endowed by the crystallization of APOSS nanoparticle.^[55] The degree of crystallinity of homopolymer PEO can reach 79.5%.^[59] Introducing POSS to the chain end of PEO will confine the crystallization of PEO. As calculated by the integration of melting peaks from DSC curves, the crystallization of PEO chain of giant molecule APOSS-PEO₁₁₃ decreased to

21.5%, while PEO crystallinity of giant molecule FPOSS-PEO₁₁₃ and FVPOSS-PEO₁₁₃ reached up to 70%, which is much higher than that of APOSS-PEO₁₁₃.^[55] Therefore, a weaker crystallization ability of PEO chain in APOSS-PEO₁₁₃ can hardly crystallize on the surface of substrate which only generate an island morphology. On the contrary, giant amphiphiles of FPOSS-PEO₁₁₃ and FVPOSS-PEO₁₁₃ with higher PEO crystallinity can produce the regular fractal patterns.

Fluorinated alkyl chain has lower surface tension than alkyl chain, therefore, FPOSS and FVPOSS have lower surface tension than that of APOSS. A higher surface tension can restrict the fluid thin-layer mobility on the surface and make it prefer de-wetting.^[60] The fractal growth of the LB film is owing to the diffusion-limited crystallization of the PEO chain. Fractal growth of PEO homopolymers can also be produced in ultrathin films prepared by spin-coating method.^[11] The morphology of ultrathin film is dependent on the supercooling and molecular weight, which is related to the diffusion limited crystallization process of the chains. The properties of hydrophobic POSS head are vital for the crystallization and fractal growth of PEO chain. If the surface tension of hydrophobic POSS head is lower, it will be more helpful for the fractal growth of PEO chain. In this system, FVPOSS-PEO₁₁₃ with lower surface tension is more beneficial to fractal growth compared with FPOSS-PEO₁₁₃ because of its shorter hydrophobic POSS head. Therefore, the hydrophobic FVPOSS head is used to discuss other factors on the impact of fractal growth.

PEO Chain Length

Following, giant amphiphiles of one FVPOSS head with various length of PEO tails (one head one tail named as FVPOSS-PEO_n) and two FVPOSS heads linked to the both ends of various length PEO tails ("bola-form" labeled as FVPOSS-PEO_n-FVPOSS) are discussed ($n=22, 77, 113$, and 227) (Fig. 1).

The π -A isotherms of these giant amphiphiles are presented in Fig. 6. Similarly, the surface pressure increased during the compression, but the surface pressure becomes higher if the PEO chain becomes longer. In addition, at the same molecule per area, the surface pressure of "bola-form" giant amphiphile is higher than that of the one head and one tail gi-

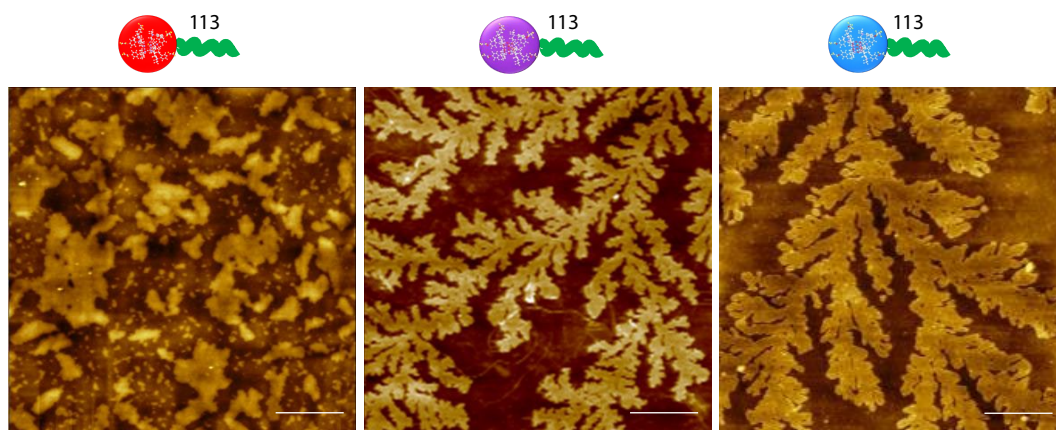


Fig. 4 Atomic force microscopy (AFM) images LB films of giant amphiphiles APOSS-PEO₁₁₃, FPOSS-PEO₁₁₃, and FVPOSS-PEO₁₁₃ prepared at 25 mN/m surface pressure. The scale bar is 2 μ m. (Reproduced with permission from Ref. [55]; Copyright (2021) American Chemical Society).

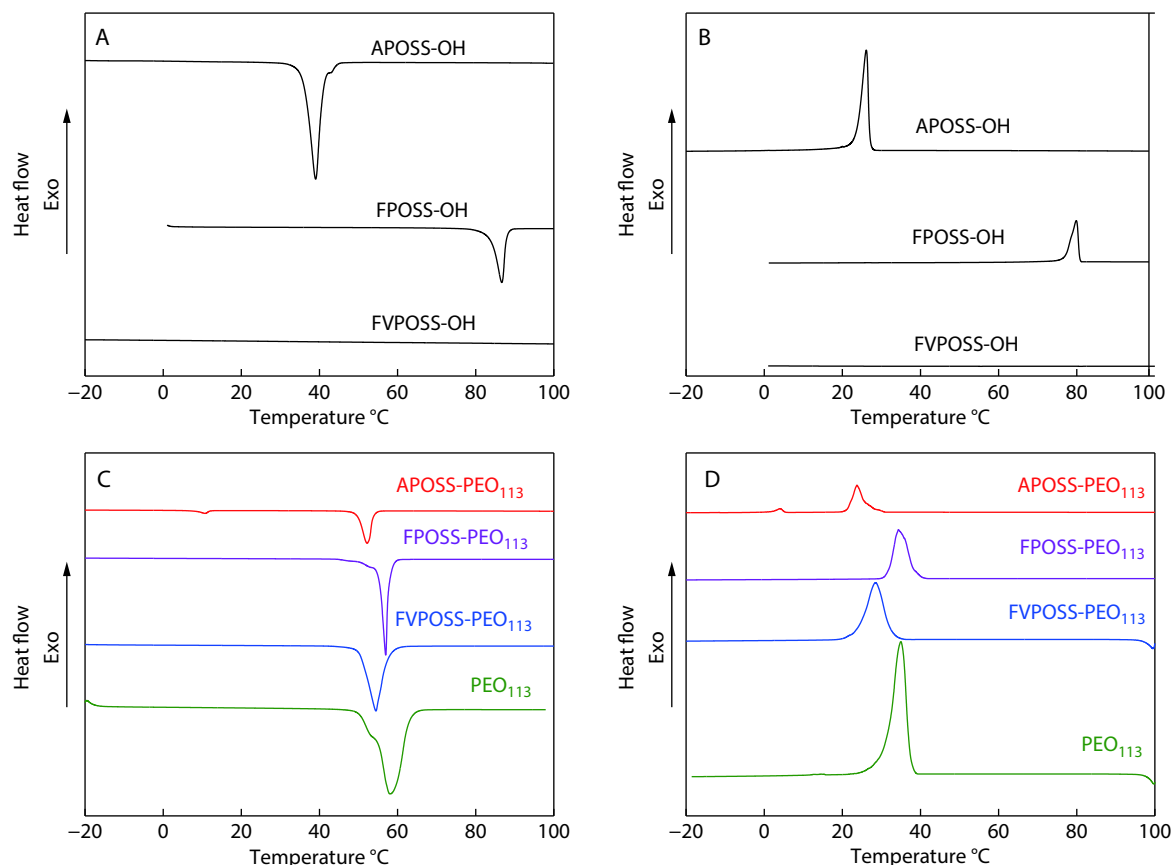


Fig. 5 DSC curves of (A) the heating process and (B) the cooling process of different POSS heads, and (C) the heating process and (D) the cooling process of giant amphiphiles with diversity hydrophobic heads. (Reproduced with permission from Ref. [55]; Copyright (2021) American Chemical Society).

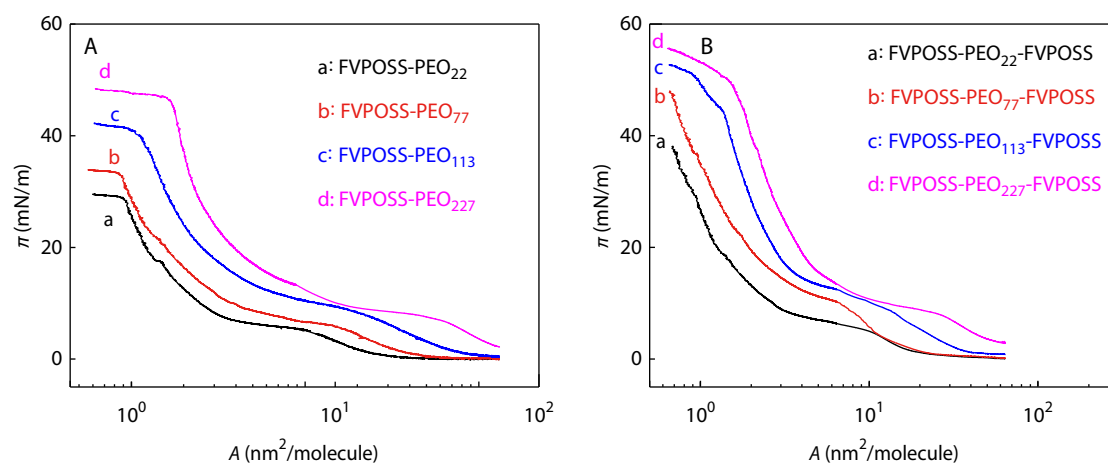


Fig. 6 π -A isotherms of giant amphiphiles with different chain length (A) one head one tail FVPOSS-PEO_n, and (B) "bola-form" FVPOSS-PEO_n-FVPOSS, ($n=22, 77, 113$, and 227). (Reproduced with permission from Ref. [61]; Copyright (2020) Elsevier).

ant amphiphile.^[61]

LB films of FVPOSS-PEO_n and FVPOSS-PEO_n-FVPOSS with different PEO chain lengths ($n=22, 77, 113$, and 227) are prepared at surface pressure of 30 mN/m and the atomic force microscope (AFM) images are displayed in Fig. 7. LB films of FVPOSS-PEO₂₂, FVPOSS-PEO₇₇, FVPOSS-PEO₂₂-FVPOSS, and FVPOSS-PEO₇₇-FVPOSS have no featured patterns, while LB films of FVPOSS-PEO₁₁₃, FVPOSS-PEO₂₂₇, FVPOSS-PEO₁₁₃-

FVPOSS, and FVPOSS-PEO₂₂₇-FVPOSS present fractal morphologies. DSC curves reveal the crystallization behavior of the giant amphiphiles at the bulk state (Fig. 8). FVPOSS-PEO₂₂ presents a very weak melting peak at 28 °C, while the crystallization of PEO chains of "bola-form" giant amphiphile FVPOSS-PEO₂₂-FVPOSS is strictly inhibited. Therefore, they cannot generate fractal growth. Although, the giant amphiphiles FVPOSS-PEO₇₇ and FVPOSS-PEO₇₇-FVPOSS show obvious

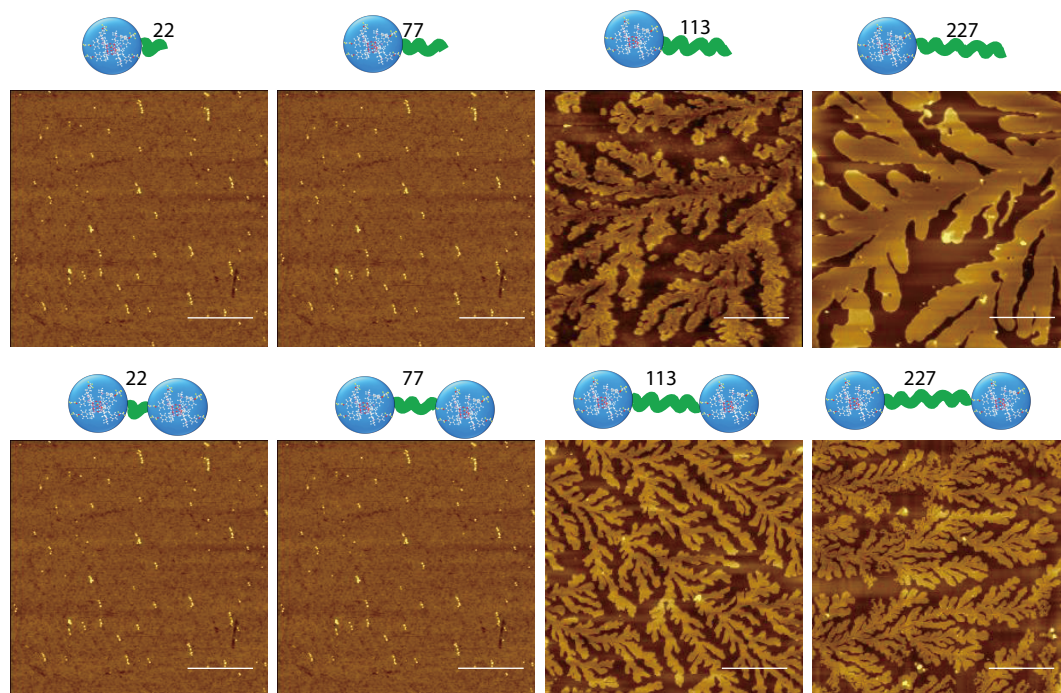


Fig. 7 AFM images of LB films of giant amphiphiles FVPOSS-PEO_n and FVPOSS-PEO_n-FVPOSS with different PEO chain lengths ($n=22, 77, 113$, and 227). The film is prepared at the surface pressure of 30 mN/m , and the scale bar in the pattern is $2 \mu\text{m}$. (Reproduced with permission from Ref. [61]; Copyright (2020) Elsevier).

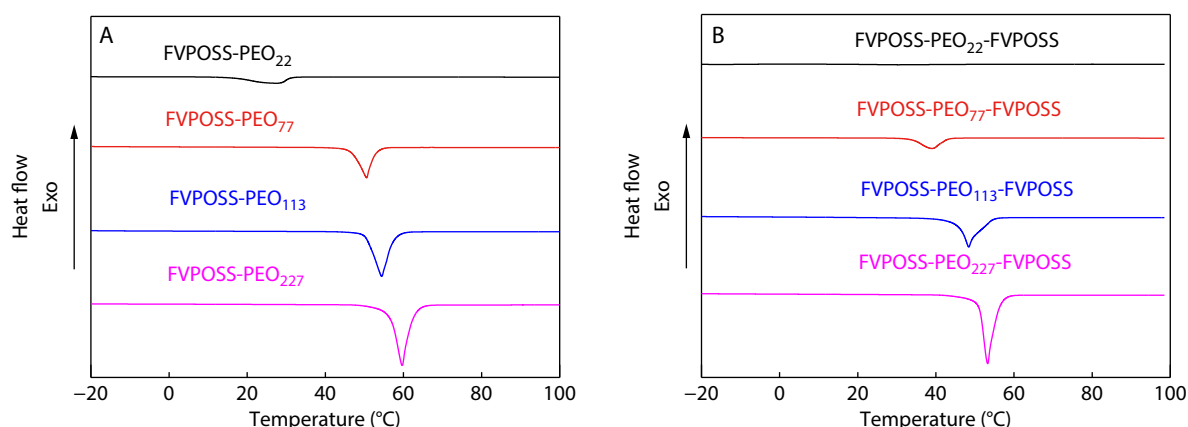


Fig. 8 DSC curves of giant amphiphiles (A) FVPOSS-PEO_n and (B) FVPOSS-PEO_n-FVPOSS with different PEO chain lengths ($n=22, 77, 113$, and 227). (Reproduced with permission from Ref. [61]; Copyright (2020) Elsevier).

melting peaks at 51 and 42°C , respectively, and the large steric hindrance formed by the FVPOSS limits the fractal growth of the PEO chains at the surface of substrate. FVPOSS head restricts PEO chain crystallization. Only PEO chain is long enough, the effect of FVPOSS will become weak, and fractal growth will present. As the crystallinity of PEO segments increases, the width of the branches of fractal pattern will increase (Fig. 7).

POSS Head Number

The fractal growth of giant amphiphiles with one, two, and three FVPOSS heads tethered on one end of PEO₂₂₇ chain is further discussed (Fig. 1). The π -A isotherms are shown in Fig. 9. The curve of FVPOSS-PEO₂₂₇ only exhibits one pseudo plateau and after the pseudo plateau it smoothly increases until

collapse, while the isotherms of (FVPOSS)₂-PEO₂₂₇ and (FVPOSS)₃-PEO₂₂₇ show a complex multi-transition during the compression. The behaviors of these molecules at the air-water interface in each transition pressure were monitored by Brewster angle microscope.^[62] LB films were prepared at the surface pressure of 30 mN/m to investigate the fractal growth behaviors of these giant amphiphiles (Fig. 10). FVPOSS-PEO₂₂₇, (FVPOSS)₂-PEO₂₂₇, (FVPOSS)₃-PEO₂₂₇ all present seaweed-like patterns. As the number of FVPOSS head increases, the size of the branch in fractal pattern will decrease (Fig. 10).

POSS head would affect crystallization of PEO tail.^[61,63] As the POSS head number increases, the effect to restrict PEO crystallization will strengthen. Here, the polymerization degree of PEO segment is 227 . As the POSS head number increases from 1 to 3 , the crystal melting temperature and crys-

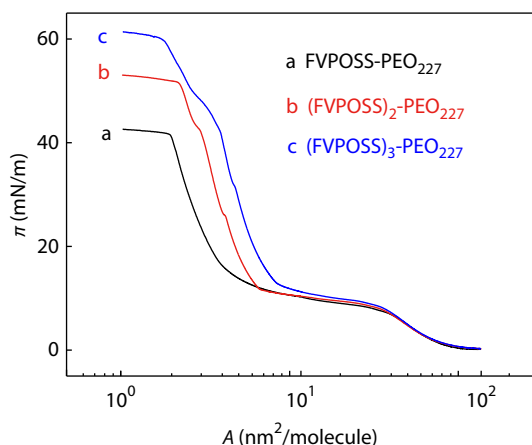


Fig. 9 π - A isotherms of giant amphiphiles FVPOSS-PEO₂₂₇, (FVPOSS)₂-PEO₂₂₇, and (FVPOSS)₃-PEO₂₂₇. (Reproduced with permission from Ref. [62]; Copyright (2021) American Chemical Society).

tallinity both decreases. The morphology difference of the FVPOSS-PEO₂₂₇, (FVPOSS)₂-PEO₂₂₇, (FVPOSS)₃-PEO₂₂₇ in LB films should be related with their crystallization of PEO tails which are affected by the number POSS head.

INFLUENCE OF TRANSFERRING SURFACE PRESSURE

The transferring surface pressure determines the giant surfactant number per unit area transferred from the air-water interface to the solid substrate. Here, we use “bola-form” giant amphiphile FVPOSS-PEO₁₁₃-FVPOSS to discuss the effect of surface pressure on the fractal growth. The AFM images of LB films of FVPOSS-PEO₁₁₃-FVPOSS prepared under different surface pressures are shown in Fig. 11.

At the surface pressure of 15 mN/m, the fractal pattern shows a slender fiber-like morphology and fragmentary leaves due to only small number of giant molecules are transferred onto the substrate. However, when the surface pres-

sure increased to 20 mN/m, it germinates a seaweed-like pattern and a featured fractal leaf. The denser of PEO chains can aggregate together and form an integrated fractal structure, while the size of the main trunk is smaller than the leaves. As the transferring surface pressure elevates, the branches and leaves of fractal morphology becomes crowded and presents the same dimension. The angle between the main trunk and the branch is about 45° at the surface pressure of 25 mN/m, while this angle gradually decreases with the surface pressure increasing.

As more molecules were transferred on the substrate surface, the fractal pattern can occupy more area (Fig. 12A). It occupied only 33% area at surface pressure of 15 mN/m, while it increased to 50% as the surface pressure increased to 20 mN/m; and 70% when the surface pressure increased to 40 mN/m. The increase in surface pressure makes the fractal morphology close to a two-dimensional plane.

The PEO chain is folded in a lamella during crystallization. The thickness (l_n) of PEO lamella is much lower than its contour length (L), and the functional relationship between the two can be $l_n = L/(n + 1)$, where n is the folding number.^[64] The measured height of the fractal pattern should be consisted of FVPOSS and PEO folding chain, therefore, the thickness of PEO folding chain is the height of fractal pattern subtracts the size of FVPOSS. The size of FVPOSS is about 1 nm while the contour length of the homopolymer PEO chain with 113 repeating units is about 31.6 nm.^[65] The height of fractal pattern of FVPOSS-PEO₁₁₃-FVPOSS was measured by AFM. The heights and the folding number of PEO chain are summarized in Fig. 12(B). The heights of pattern are very hard to fit integral folding of PEO chain. During the fractal growth, the PEO tails mainly adopt non-integral folding, which is kinetically favorable.

Fractal dimension (D_f) can quantitatively evaluate the fractal ratio of the pattern. If the fractal morphology is close to a straight line, the D_f value is near to 1; while the fractal morphology is close to a plane, the D_f is near to 2.^[2] According to the box counting theory, the D_f is 1.60 at surface pressure of 15 mN/m, while this value increased to 1.75 as the surface

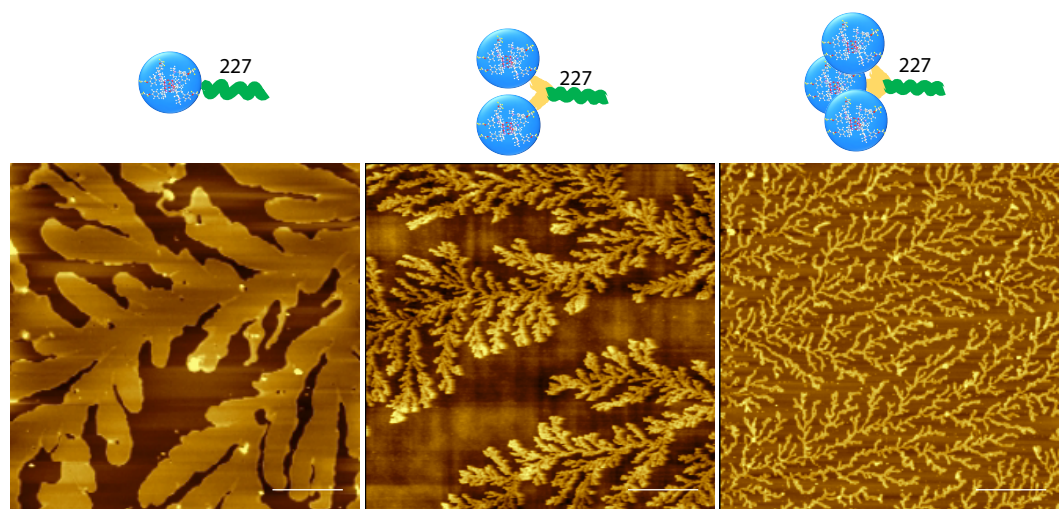


Fig. 10 AFM images of FVPOSS-PEO₂₂₇, (FVPOSS)₂-PEO₂₂₇, and (FVPOSS)₃-PEO₂₂₇ LB films. The films are prepared at 30 mN/m, and the scale bar in the pattern is 2 μ m.

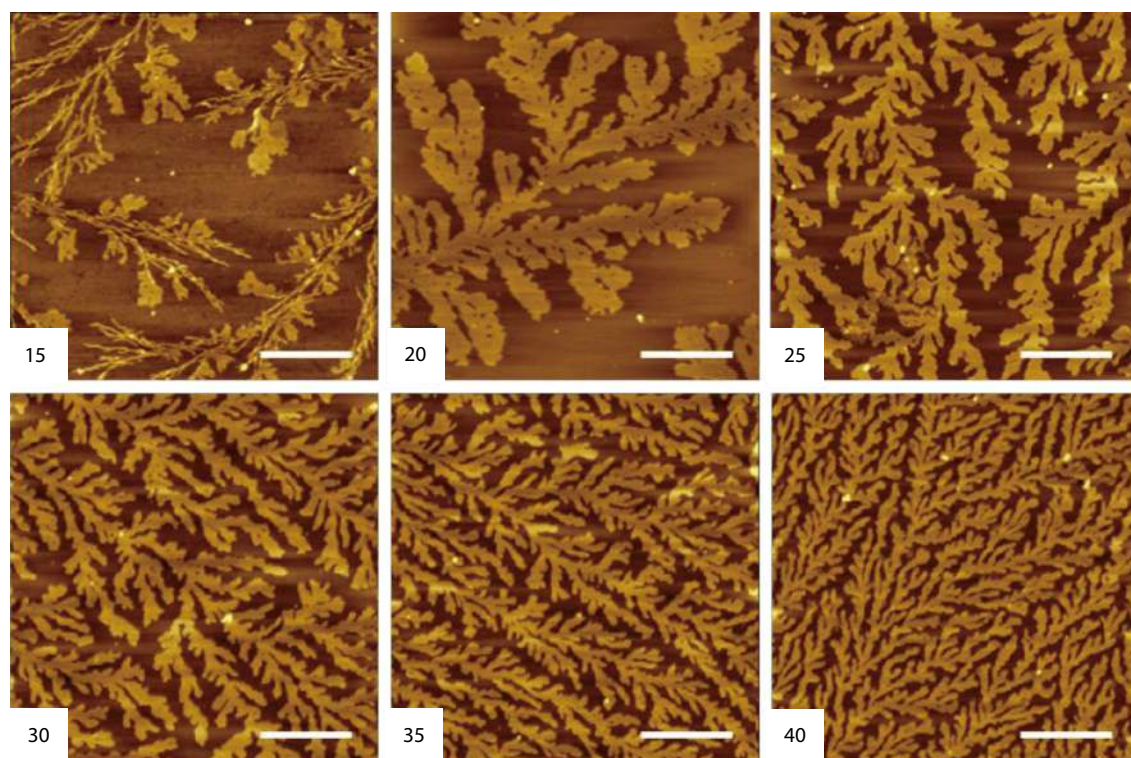


Fig. 11 LB films morphologies of giant amphiphile FVPOSS-PEO₁₁₃-FVPOSS prepared at the surface pressure of 15, 20, 25, 30, 35, and 40 mN/m. The scale bar in the pattern is 2 μ m. (Reproduced with permission from Ref. [61]; Copyright (2020) Elsevier).

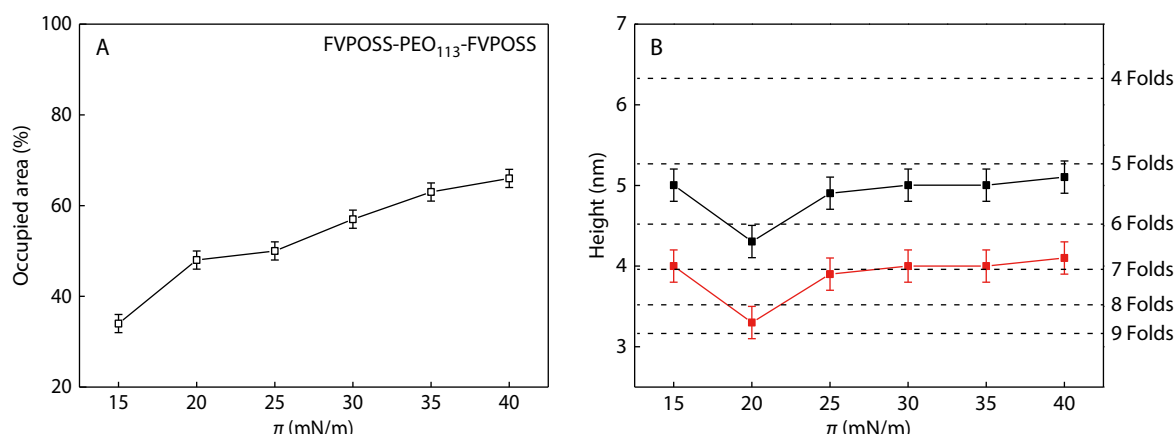


Fig. 12 (A) The occupied area and (B) the pattern height of the fractal morphology as a function of transferring surface pressure. (Reproduced with permission from Ref. [61]; Copyright (2020) Elsevier).

pressure increased to and above 20 mN/m.^[61]

OTHER FRACTAL GROWTH PATTERNS IN LANGMUIR AND LB FILMS

Fractal growth in LB films is rarely reported. Compared with LB films, Langmuir film is relatively easy. If the hydrophobic parts have crystallization capacity, the fractal patterns will probably present. However, for LB films, the crystallization should happen after the transferring, and it means that hydrophilic parts have capacity to crystallize or the species combined with hydrophilic domain can crystallize. Here, we provide the examples to demonstrate the basic rules for fractal growth patterns in

Langmuir and LB films.

Talapatra *et al.* found that potassium chloride (KCl) would form fractal growth pattern in LB film of hemoglobin.^[66] Hemoglobin was spread on surface of KCl solution, and then transferred to solid substrate to prepare LB films. Accordingly, KCl was introduced in LB film. As the time evolution, the growth of KCl crystal is changing from linear to fractal-like structures in LB film of hemoglobin (Fig. 13). Cl⁻ and K⁺ are small inorganic molecules, which are easy diffusion and aggregation for crystallization. But the hemoglobin formed monolayer has some limitation on the over aggregation of Cl⁻ and K⁺, which induced the fractal growth.

Li *et al.* reported a tree-like fractal pattern of Cadmium sulf-

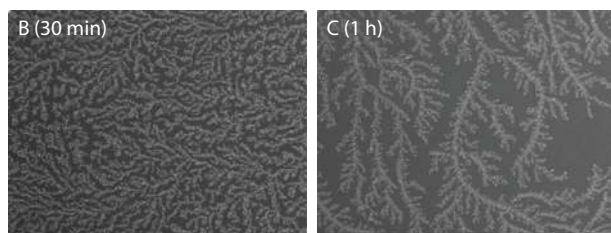


Fig. 13 Fractal growth of KCl crystals in hemoglobin LB film. (Reproduced with permission from Ref. [66]; Copyright (2012) Elsevier).

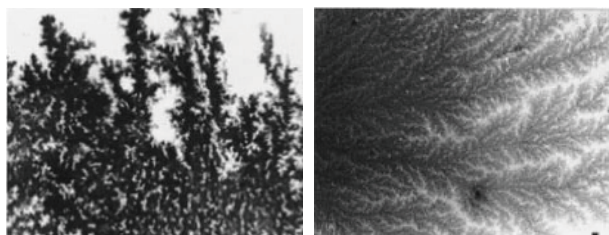


Fig. 14 Tree-like fractal pattern of CdS nanoparticles using the amphiphilic oligomer (polymaleic acid with octadecanol ester) as matrix. (Reproduced with permission from Ref. [23]; Copyright (1998) American Chemical Society).

ide (CdS) in LB film of amphiphilic oligomer (octadecyl polymaleate) and stearic acid (Fig. 14).^[23] Octadecyl polymaleate and stearic acid were dissolved in chloroform and spread on the subphase which containing cadmium chloride (CdCl_2) and sodium bicarbonate (NaHCO_3). The stabilized Langmuir monolayer was transferred on the copper grid substrate, and then the monolayer reacted with hydrogen sulfide (H_2S). After reacting with H_2S , CdS nanoparticles were grown and formed a fractal morphology. The morphology of fractal pattern can be controlled by changing the ratio of carboxylic groups and hydrocarbon chains, the degree polymerization of amphiphilic molecules, and the surface pressure.

Esker *et al.* found a fractal growth in Langmuir film of poly(ϵ -caprolactone) (PCL) and poly(*t*-butyl acrylate) (PtBA) blend.^[67] The PCL/PtBA blend system was dissolved in chloroform and spread onto the surface of water. As the surface compressing, the fractal pattern presented. PCL is semi-crystallization polymer while PtBA is amorphous polymer. In Langmuir film, the diffusion of PCL is limited by PtBA, and during the surface compression, PCL crystallization shows fractal pattern (Fig. 15).

Min *et al.* reported a fractal pattern of lipid in Langmuir monolayer.^[68] The mixture chloroform solution of imidazole surfactant (limits the diffusion of lipid molecules), and fluorescent probe (for observation) were spread on the water surface. When the imidazole surfactant was compressed to liquid condensed (LC) and liquid expanded (LE) co-existence state, fractal pattern was generated as time elapsed (Fig. 16).

SUMMARY AND PERSPECTIVE

The basic mechanism of the fractal-growth phenomenon is considered as “diffusion-limited aggregation”. There should be diffusion capacity, limitation condition, and driving force for aggregation in the whole system. Giant amphiphiles

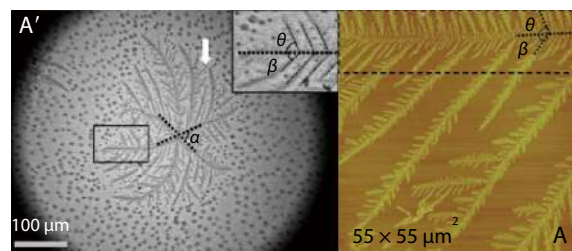


Fig. 15 Fractal patterns of PCL in Langmuir monolayer (Reproduced with permission from Ref. [67]; Copyright (2007) Wiley Periodicals, Inc.).

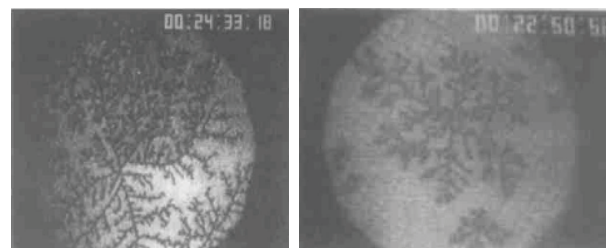


Fig. 16 Fractal patterns of lipid in Langmuir monolayer (Reproduced with permission from Ref. [68]; Copyright (2002) Journal of Synthetic Crystals).

composed of modified POSS heads and PEO tails show fractal growth patterns in the LB film. When these giant amphiphiles are transferred to a solid substrate, water molecules are also entrapped with PEO segments, hence the PEO segments have enough mobility and diffusion capacity. PEO is a semi-crystallization polymer and the melting temperature is about 60 °C, which provides a driving force for aggregation. The LB films of amphiphilic block copolymer PS-*b*-PEO mainly present surface micellar morphologies (Fig. 17). When PS-*b*-PEO is compressed on the water surface, the hydrophobic PS segment

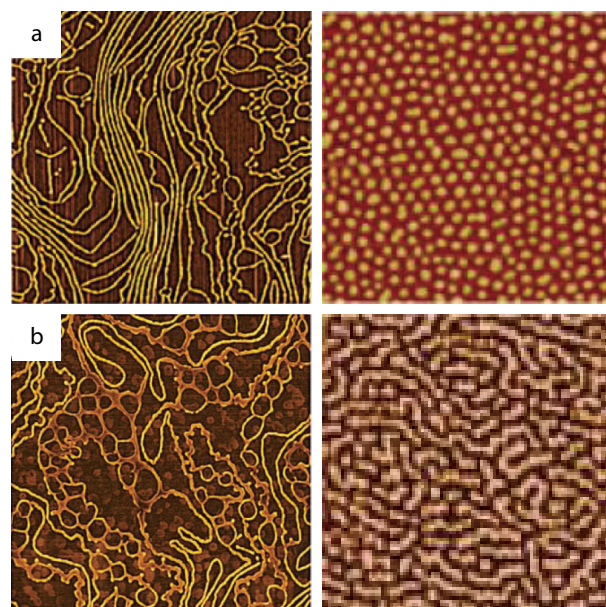


Fig. 17 Morphologies of LB films of PS-*b*-PEO block polymer. (Reproduced with permission from Refs. [69, 70]; Copyright (2005, 2006) American Chemical Society).

will vitrify and form surface micelles.^[69–71] The glass transition temperature (T_g) of PS is about 100 °C. The micellar morphology will keep when transferred to a solid substrate. LB films system can also be used as substrate or matrix for inorganic salts, oxides, and sulfides to realize the fractal growth patterns. In Langmuir monolayer, the fractal growth pattern will also present if the molecular systems meet the requirement of “diffusion-limited aggregation” mechanism.

Fractal is a gift of nature. Many fractal structures seem disordered; however, they present interesting dilation symmetry, self-similarity, or self-affinity through mathematical analysis. Various materials used by human society, such as paper, glue, cement, gel, rock, and so on, have structural attributes of the fractal.^[72] The classic processes, such as random walk and percolation threshold, are described by fractal tools. In this review, we summarized our findings of fractal structures of giant amphiphiles in LB films and illustrated the molecular mechanism of their fractal patterns. How to precisely control fractal structures and more directly correlate fractal structures with material properties, is still a great challenge in material science, and more efforts are needed. Fractal will be a basic material design structure both in low-dimension and three-dimension (3D) bulk for future advanced applications.

BIOGRAPHY

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NOTES

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This work was financially supported by the Research Fund Program of Guangdong Provincial Key Laboratory of Function and Intelligent Hybrid Materials and Devices (No. 2019B121203003). Authors thank Prof. W. B. Zhang at Peking University for his valuable discussion and suggestions.

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