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Confined Fractal Patterns in Gelatin

Lung-Jieh Yang*, *Member, IEEE,* Chia-Chan Lee, Po-Hung Chen, Chih-Wen Hsu

Abstract— **Fractal patterns are commonly found during the re-crystallization process of over-saturated solution. In this work, the authors initially choose the gelatin aqueous solution, of high weight percentage of 18.2-27.3 wt %, dissolved with excess amount (9 wt %) of a photo-sensitizer agent potassium dichromate ($K_2Cr_2O_7$) and sodium chloride (NaCl) to generate the tree-like, dendrite, fractal micro structures with the feature size of 5-40 μm. They also tried to make the fractal patterns uniformly to some extent according to Feynman's confinement statement. The smaller field for growing fractal gelatin has the survival percentage of 80 %, over the survival percentage of 55 % for the 5000 μm larger case. These fractal patterns are going to develop the application to the fabrication of new chaotic mixers.**

***Index Terms*—gelatin, fractal pattern**

I. Introduction

The re-crystallization is conventionally regarded as an approach to form the micro or nano structures with fractal patterns [1]. The classical domain for the fractal patterns is frequently three-dimensional. Therefore the generated micro patterns are very chaotic and hard to control repetitively [2]. This is also the reason why not many researches about the fractal patterns have been conducted in MEMS area.

Mixing $K_2Cr_2O_7$ inside a gelatin aqueous solution as a photo-sensitizer will make the gelatin solution a negative-toned photoresist. After the photo cross-linking via UV-exposure, the gelatin will be selectively hardened and developed by warm water. The authors have ever used the photo-sensitized gelatin as the strengthened layer to against the stiction problem of parylene free standing structures [3]. Other cross-linking agent, e.g., glutaraldehyde (GA), could be applied to pattern the gelatin and applied to the cell culture field [4]. As the gelatin weight percentage is increased above 18.2 wt %, and after its spin coating process the authors occasionally found the tree-like, dendrite, fractal micro structures in gelatin as Fig. 1 (taken by optical microscope and 3D NanoFocus μSurf RC system). The width the dendrite is 20-40 μm; the maximum height is about 10μm. This salting-out of the gelatin fractal patterns is quite different from other methods of growing fractal patterns [5-10].

*Lung-Jieh Yang is with the Department of Mechanical & Electromechanical Engineering, Tamkang University, Tamsui, 25137 Taiwan (corresponding author to provide phone: +886-932159193; fax: +886-2-26209745; e-mail: Ljyang@mail.tku.edu.tw).
Other coauthors are in their master research with the 1st author.

Since μm-thick gelatin has its micromachining method for making small patterns with the best line resolution of 10 μm in the previous art [3], it inspires the authors to construct a confined domain of gelatin for intrinsically growing fractal patterns inside. The basic idea of making gelatin fractal patterns promisingly is referring to what Feynman has said about the confinement of smaller domain: "*if we go down far enough, all of our devices can be mass produced so that they are absolutely perfect copies of one another*" [11].

II. Experiment and Discussions

A. Verification of Feynman's confinement effect

Two ways inspired by Feynman's confinement statement in this work have been conducted to solve this issue correlated to the uniformity and repetitiveness of fractal micro patterns in gelatin.

The first way is using $K_2Cr_2O_7$ rather than other inorganic salts for defining the area contour of the fractal patterns on the gelatin matrix by photolithographic method. Such a cross-linked gelatin contour with a dimension of several hundreds of μm (at least 10 times larger than the dendrite width) also sets up a limitation area for the fractal micro patterns to develop inside afterwards. An implemented example is shown in Fig. 2.

The second way is to define many gelatin mesas by wafer-dicing on the glass substrate in advance shown in Fig. 3. The dicing depth is only 1/3 of the glass thickness. Theses separated mesas automatically confine the area of spin-coated gelatin as well as the fractal patterns grown inside the gelatin pixels in Fig. 4. Therefore the photolithography in the first way, which may induce toxic issues for biological entities or have the swelling drawback, is not necessary for defining the gelatin matrix.

The weight percentage of the gelatin aqueous solution is 18.2-27.3 wt %; and the amount of $K_2Cr_2O_7$ is 10 wt %. The gelatin solution needs gentle heating up to 50-60 °C and proper mixing. Spin coating is accessed to spread the gelatin film over a glass substrate. The re-crystallization happens no sooner than the completion of spin coating, and proceeds for several minutes or several days corresponding to different weight percentage of the gelatin solution and the ambient humility.

The fractal figures on the photo-patterned gelatin of Fig. 2 (the first way) get seriously blurred for the excuse of gelatin swelling during the water developing stage of photolithography. Therefore, the photolithographic approach for confining the area for the growth of fractal gelatin patterns has so far not been achieved. However, the second way in Fig. 3 shows the more

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clear pictures of the confined fractal micro patterns in Fig. 4. Table 1 shows the percentage of the survived (almost identical) fractal contours on the gelatin squared pixels.

The size of the diced glass blocks of Table 1 or Fig. 4 ranges from 5000 μm down to 500 μm. The smallest chip of 5000 μm for growing fractal gelatin has the survival percentage of 80 %, more than the survival percentage of 55 % for the 5000 μm larger case in Table 1. The better survived percentage of the fractal patterns on the smaller mesas manifested Feynman's confinement statement at the current stage of investigation.

On the other hand, the identical extent or the repetitiveness of the fractal gelatin patterns herein is still in veil. For quantitatively defining the characteristics of fractal gelatin patterns, the authors preliminary proposed computing the fractal dimension values for all the successfully fractal patterns in Fig. 4. The fractal dimension D_b is defined by the box dimension theory [9] as follows:

$$D_b = \lim_{s \to 0} \frac{\ln N(s)}{\ln(\frac{\ell}{s})}$$

where $N(s)$ denotes the box number of the area that covers the fractal patterns in the whole image; s denotes the width of the small box; and ℓ denotes the length of the whole image. Table 1 also summarizes the averaged values and the variation of the fractal dimension for gelatin fractal patterns according to different mesa sizes. The fractal gelatin patterns on the smaller dices at this time do not have the larger value of fractal dimension over the larger dices. Two inferences are possible. It might be due to the inappropriate processing of the fractal images during the calculation of the fractal dimension, or fractal dimension may be no matter with the Feynman's confinement statement. In summary, the good repetitiveness of the fractal gelatin patterns verifying Feynman's confinement statement is not confirmed so far.

B. *Other fractal patterns in NaCl-gelatin collagen matrix*

The authors also chose other non-toxic salts, e.g., sodium chlorine (NaCl), for re-crystallizing the fractal patterns inside gelatin. The weight percentage is 18.2 wt % for gelatin and 9 wt % for NaCl. The fractal patterns in NaCl-gelatin collagen matrix are shown in Fig. 5. After the measurement of surface topology, the maximum height of the pattern is not only changing from 10 μm in the previous case to 2.5μm herein, but the geometry is also changing from the tree-like dendrite to the compound-leaf shape. The line-width of this compound-leaf fractal is 20-40 μm, similar to the tree-like dendrite case of $K_2Cr_2O_7$-gelatin.

The authors identified the fractal patterns as gelatin material by the protease etching on gelatin shown in Fig. 6. After 10 minute etching, the depth difference monitored by AFM for $K_2Cr_2O_7$-gelatin and NaCl-gelatin are 925 nm and 718 nm, respectively.

C. *Correlated pattern transfer technique and applications*

The $K_2Cr_2O_7$-gelatin is toxic and not proper for biomedical applications. The authors coated the gelatin surfaces with parylene and assigned them as the molds for PDMS pattern transfer. The transferred patterns on PDMS are shown in Fig. 7. This technique is useful in adding fractal grooves in the new chaotic micromixer [13] comparable to the prior art [12].

III. Conclusion

Gelatin fractal patterns are grown successfully in a wafer-diced area from 500 to 5000 μm. The better survived percentage according to the smaller fractal patterns agrees with Feynman's confinement statement. The fractal dimensions corresponding to different confinement size are evaluated as well. Other fractal patterns in NaCl-gelatin collagen matrix is also successful made. The toxic issue of $K_2Cr_2O_7$-gelatin is solved by PDMS molding transfer and beneficial to biomedical applications in the future.

References

[1] A. Mersmann, *Crystallization Technology Handbook*, 1st ed., New York, Marcel Dekker, Chap. 1, pp. 48-56, 1995.

[2] S. Busch, H. Dolhaine, A. DuChesne, S. Heinz, O. Hochrein, F. Laeri, O. Podebrad, U. Vietze, T. Weiland, and R. Kniep, "Biomimetic morphogenesis of fluorapatite-gelatin composites: fractal growth, the question of intrinsic electric fields, core/shell assemblies, hollow spheres and reorganization of denatured collagen," *Eur. J. Inorg. Chem.*, vol. 10, pp. 1643-1653, 1999.

[3] L. J. Yang, W. Z. Lin, T. J. Yao, and Y. C. Tai, "Photo-patternable gelatin as protection layers in surface micromachinings," *Sensors and Actuators A: Physical*, vol. 103(1-2), pp. 284-290, 2003.

[4] L. J. Yang and Y. C. Ou, "The micro patterning of glutaraldehyde (GA)-crosslinked gelatin and its application to cell-culture," *Lab on a Chip*, vol. 5(9), pp. 979-984, 2005.

[5] Y. Yin. T. Zhang, F. Yang, and X. Qui, "Geometric conditions for fractal super carbon nanotubes with strict self-similarities," *Chaos, Solitons and Fractals*, vol. 37, pp. 1257-1266, 2008.

[6] S. Balakrishnan, Y. K. Gunko, T. S. Perova, R. A. Moore, M. Venkatesan, A. P. Douvalis, and P. Bourke, "Dendrite-like self-assembly of magnetite nanoparticles on porous silicon," *Small*, vol. 2(7), pp. 864-869, 2006.

[7] H. Firoozm and, B. S. Murray, E. Dickinson, "Fractal-type particle gel formed from gelatin + starch solution," *Langmuir*, vol. 23, pp. 4646-4650, 2007.

[8] I. Lee, J.S. Ahn, and T. R. Hendricks, "Patterned and controlled polyelectrolyte fractal growth and aggregations," *Langmuir*, vol. 20, pp. 2478-2483, 2004.

[9] Y. Q. Hu, Y. P. Zhao, and T. X. Yu, "Fractal pattern formation in anodic bonding of Pyrex glass/Al/Si," *Int. J. Nonlinear Sci. & Num. Simul.*, vol. 9(4), pp. 315-322, 2008.

[10] L. Kebbabi and A. Beroual, "Fractal analysis of creeping discharge patterns propagating at solid/liquid interfaces: influence of the nature and geometry of solid insulators," *J. Physics D: Applied Physics*, vol. 39(1), pp. 177-183, 2005.

[11] R. Feynman, "There's plenty of room at the bottom," *J. MEMS*, vol. 1(1), pp. 60-66, 1992.

[12] A. D. Strook, S. K. W. Dertinger, A. Ajadari, I. Mezic, H. A. Stone, and G. M. Whitesides, "Chaotic mixer for microchannels," *Science*, vol. 295, pp. 647-651, 2002.

[13] A.-F. Kao, L.-J. Yang, and F.-W. Yeh, "Fractal grooves applied to passive micro-mixers," Proc. of the 6th IEEE-NEMS conference, Feb. 20-23, 2011, Kaohsiung, Taiwan, 2011.

Table 1 the percentage of the survived (almost identical) fractal contours on the gelatin squared pixels and the corresponding fractal dimension.

Pixel dimension (micron)	5000	1000	500
Percentage of survived patterns (%)	55.0	74.7	80.2
Fractal dimension (average ± variation %)	1.966±1 %	1.956±1 %	1.823±3 %

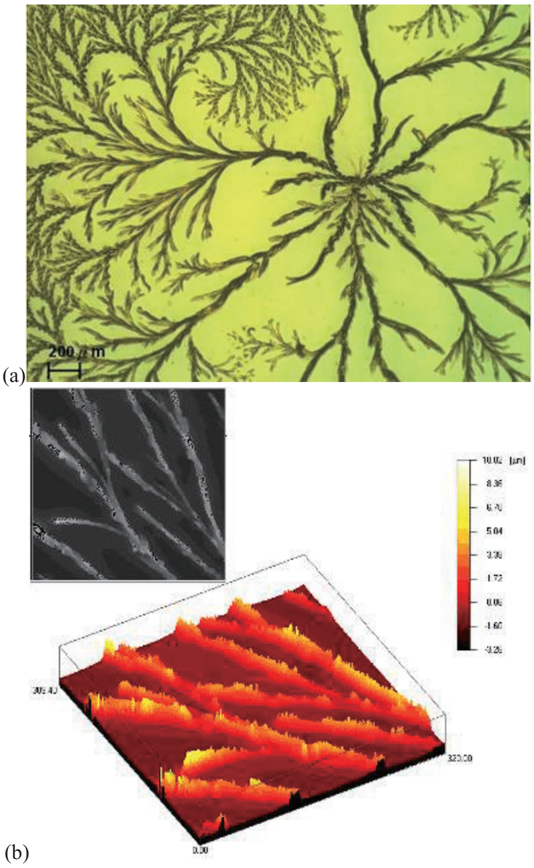

Figure 1. Classical fractal micro patterns in the 9 wt % $K_2Cr_2O_7$-18.2 wt % gelatin collagen matrix; the maximum height of the pattern is 10μm: (a)optical microscopic photo; (b)3D morphology (NanoFocus μSurf RC, Germany).

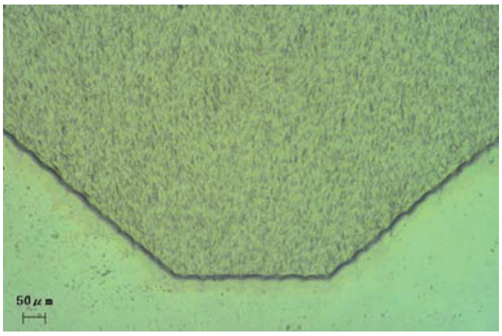

Fig. 2. The "blurred" fractal patterns on the trapezoidal photo-patterned gelatin surface.

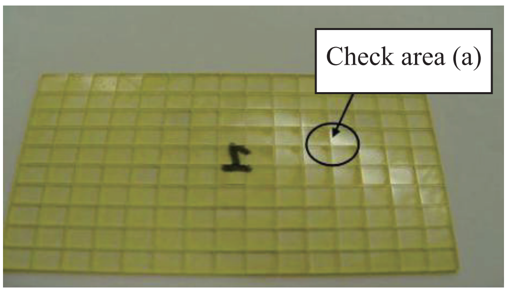

Fig. 3. The fractal patterns on the squared mesas of a glass substrate (75 mm × 50 mm) after dicing process and the re-crystallization; the pixel dimension is 5000μm in this case.

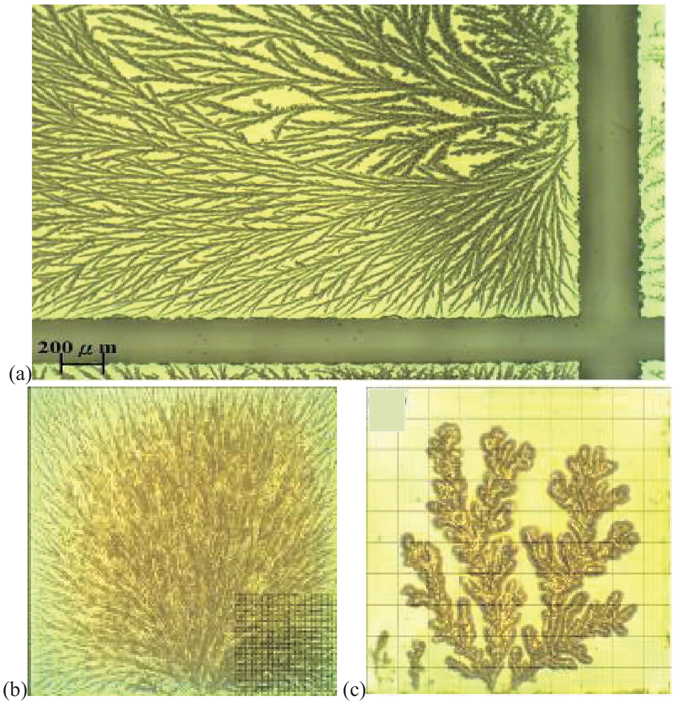

Fig. 4. The separated mesas automatically confine the area of spin-coated gelatin as well as the fractal patterns grown inside the gelatin pixels of different mesa size: (a)5000μm;(b)1000μm;(c)500μm.

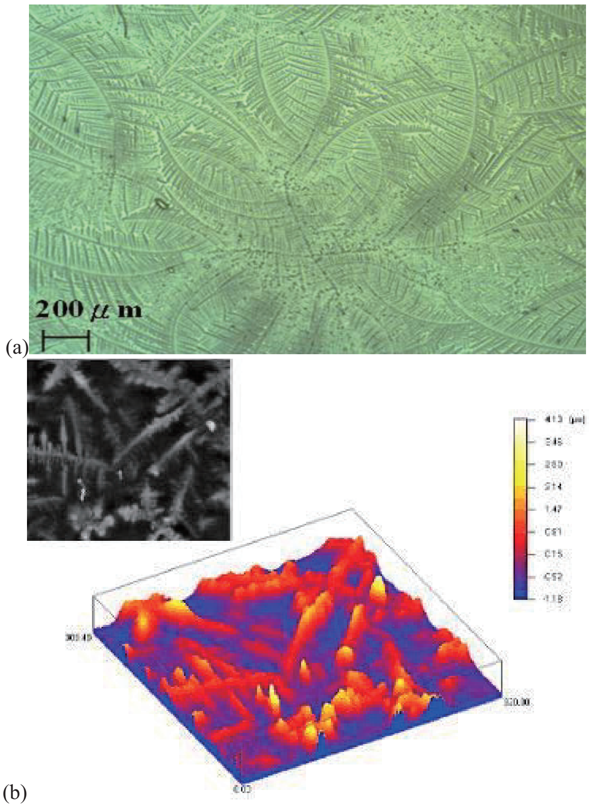

Fig. 5. the fractal patterns in 18.2 wt % gelatin dissolved with 9 wt % of non-toxic sodium-chlorine; the maximum height of the pattern is 2.5 μ m; the fractal pattern is changing from the tree-like dendrite to the compound-leaf shape: (a)optical microscopic photo; (b)3D morphology (NanoFocus μSurf RC, Germany).

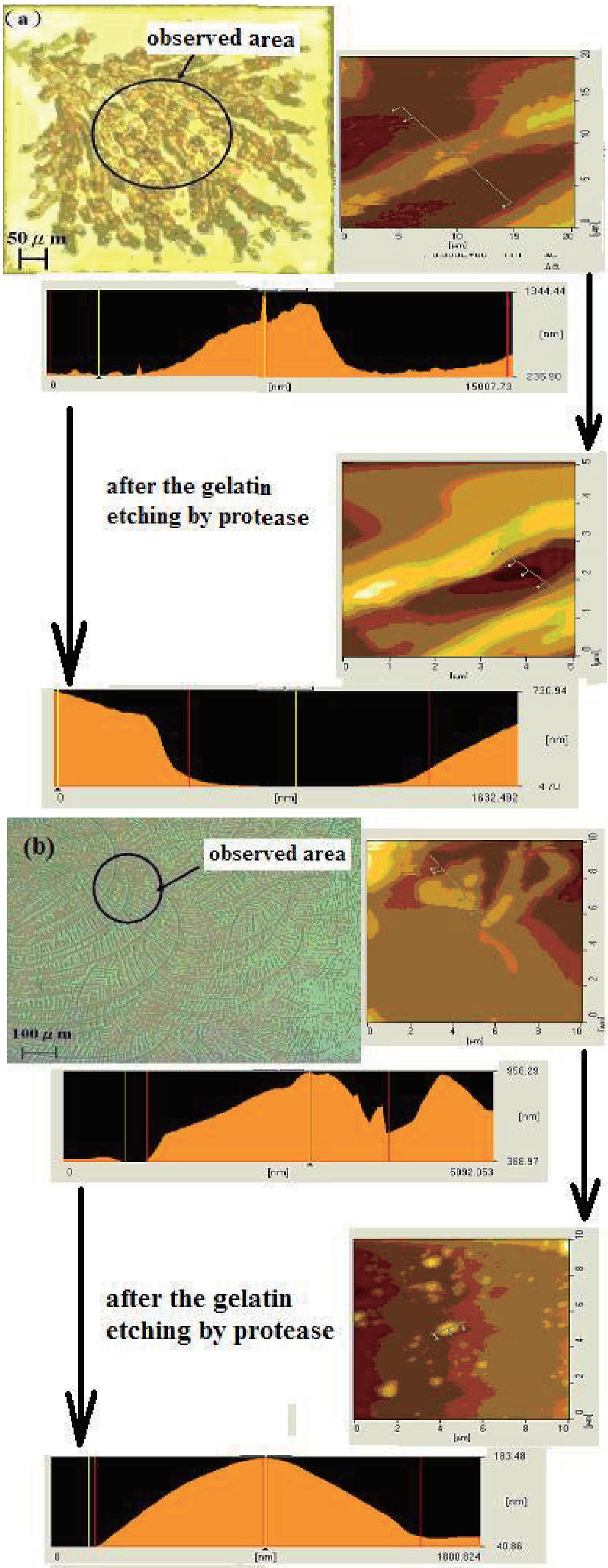

Fig. 6. The AFM images of the fractal gelatin patterns subject to the etching of protease: (a)$K_2Cr_2O_7$-gelatin case; (b)NaCl-gelatin case. The fractal depth difference monitored by AFM for $K_2Cr_2O_7$-gelatin and NaCl-gelatin are 925 nm and 718 nm, respectively.

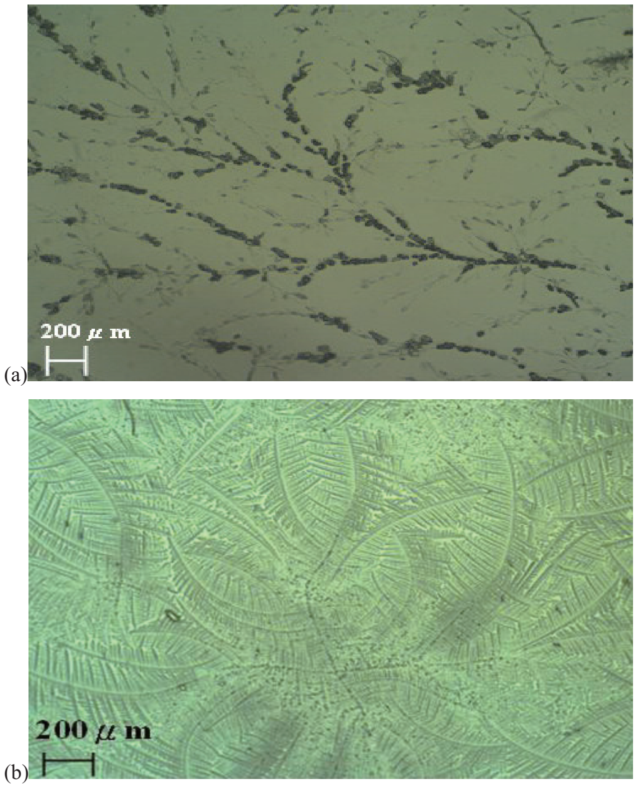

Fig. 7. The PDMS copies with the fractal patterns transferred from the gelatin mold plates: (a)$K_2Cr_2O_7$-gelatin case; (b)NaCl-gelatin case.