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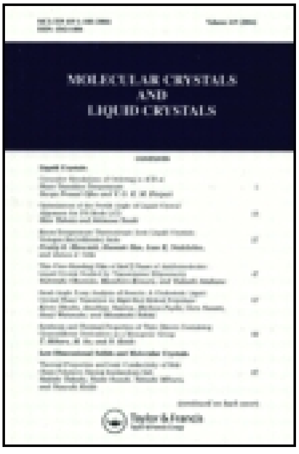

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Fractal Patterns in Burned Hele-Shaw Cells of Liquid Crystals and Oils

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Fractal Patterns in Burned Hele-Shaw Cells of Liquid Crystals and Oils

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Fractal patterns in burned Hele-Shaw cells of nematic MBBA and mineral oil are observed when the DC or AC voltage across the cell increases beyond a threshold value. Each pattern consists of continuous strings etched on the plates, which can be thin and smooth, or thick and wrinkled. The two types may connect to each other in the same string. The overall pattern depends sensitively on the cell thickness, and whether DC or AC is used. Fractal dimensions of some of these patterns are calculated.

Keywords: fractal, dielectric breakdown, Hele-Shaw cell, liquid crystals, pattern formation

INTRODUCTION

Fractals exist in many systems.[1] In liquid crystals they are less studied.[2,3] Diffusion-limited-aggregates-like (DLA-like) fractals are known to exist in dielectric breakdowns.[4] In a liquid crystal cell consisting of two conducting glass plates, short circuit happens when the applied voltage is increased continuously and the cell is burned. One usually just throws it away. Yet, some burned patterns are left behind in the cell and the physics behind them are very interesting. Here, these patterns are studied. Specifically, experiments on the fractal patterns and other interesting nonlinear structures[5] produced in Hele-Shaw cells of simple and complex liquids are presented. The liquids used were either nematic MBBA or oil.

EXPERIMENTAL

The Hele-Shaw cell consists of two transparent glass plates coated with conducting indium tin oxide in the inner surfaces (from Thin Film Device). The spacers used were either Mylar plates or fine glass balls. A DC or AC (frequency 60 Hz) voltage

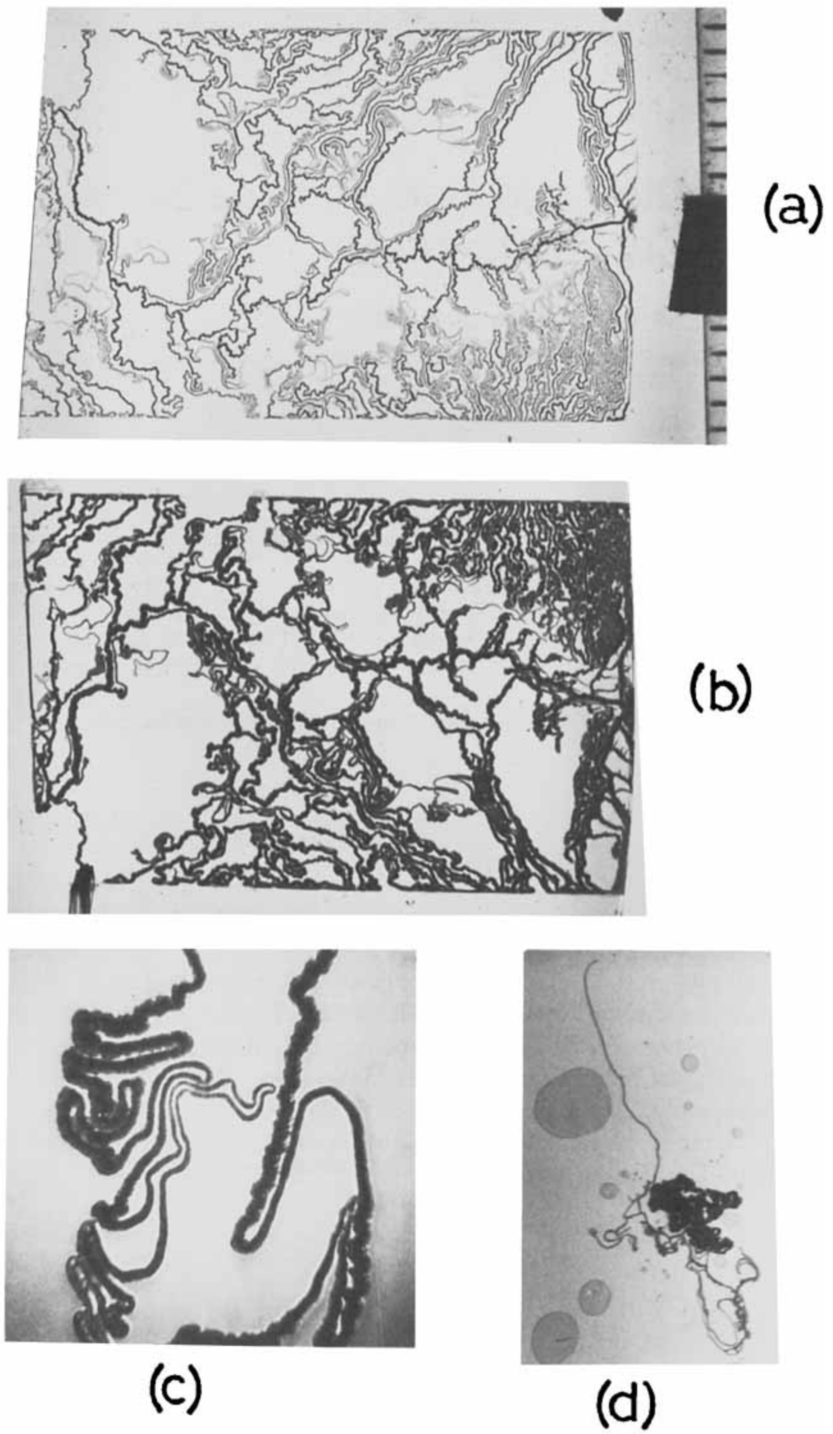

FIGURE 1 Oil. d = 25 μm. (a)–(c) are DC results, and (a) negative-potential plate; (b) positive-potential plate; (c) blow up of (b); (d) AC.

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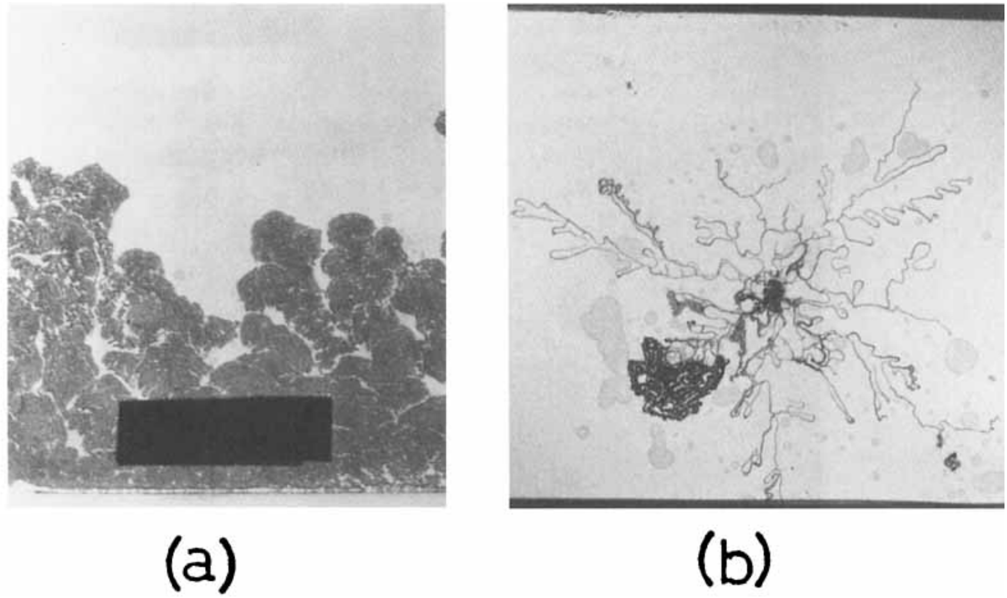


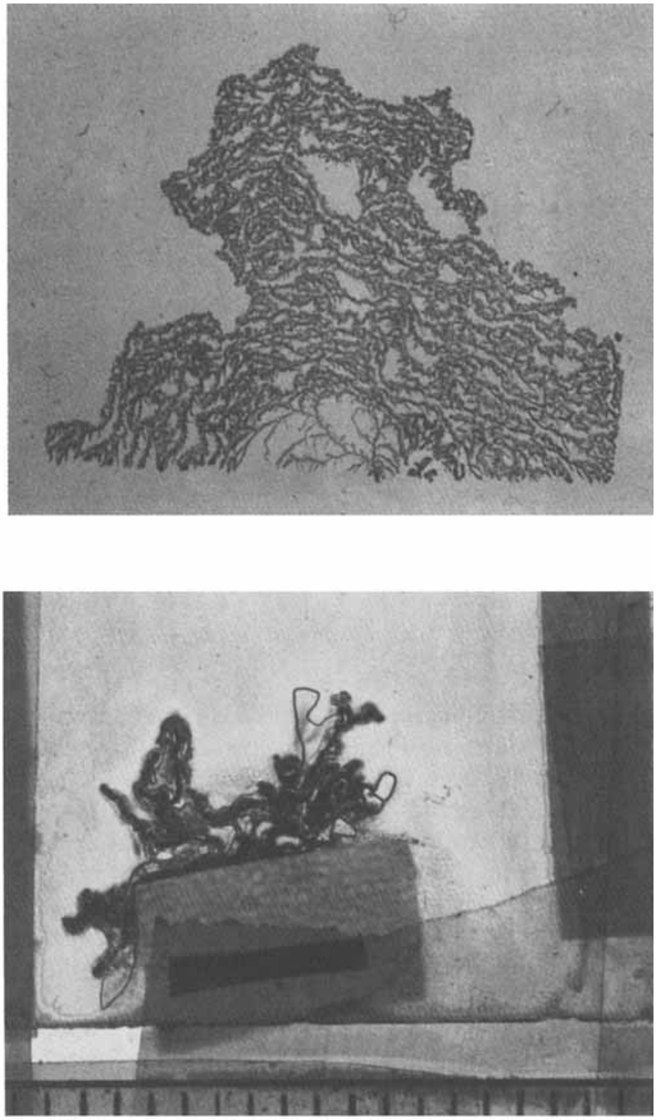
FIGURE 2 Oil. d = 20 μm. (a) DC. (b) AC.

was applied across the cell. Mineral oil (NDC 0003-0559-33 from E. R. Squibb & Sons) or nematic MBBA was introduced into the cell without surface treatment.

The experiments were carried out at room temperature. The voltage V was increased slowly until a threshold V_c was reached (Figure 7a) and the cell was "burned". The burning process was almost instantaneous as appeared to the eye. The burning may start from the edge or near the center of the cell. The pattern may cover the whole cell or just a small part of it. The burned cell was then photographed with or without the use of an optical microscope, and sometimes with the use of crossed polarizers. (The voltage was turned off immediately after burning.)

Some of our burned patterns are presented in Figures 1–5. Mylar spacers at the edges of the cell are used in Figures 1–4; glass balls mixed with the nematic is used as spacers in Figure 5. (i) All the patterns are made up of continuous strings recorded on the two glass plates. There are two types, viz., thin smooth ones and thick wrinkling ones, which may appear in the same string (Figure 1c). (ii) In Figures 1a and 1b the strings left on the positive-potential plate is about three times thicker than those on the negative-potential plate. (iii) The width of the smooth strings w increases with cell thickness d (Figure 7b). (iv) The overall pattern depends sensitively on d, and the use of DC or AC. (v) All these patterns are fractals of dimension D between 1 and 2. The string itself is also a fractal line with dimension between 0 and 1.[1] The fractal dimension of Figure 2b is 1.125 (Figure 6).

(vi) Sometimes the liquid is gone in some regions in which the pattern is formed (Figures 4a and 4b). A very interesting pattern consisting of nematic filaments of constant width separated by thin lines of air is shown in Figure 4c. It is a *static* equilibrium structure (with zero voltage across the cell plates).



(a)

(b)

FIGURE 3 Nematic MBBA. d = 25 μm. (a) DC. (b) AC.

DISCUSSIONS

We believe that the mechanism behind these burned patterns is dielectric breakdown of the liquid. In spite of its practical importance, dielectric breakdown is a process not very well understood.[6] In the usual experiments the dielectric breakdown tracks are photographed at a distance and the photographs are studied. In contrast, in our experiments here, for the first time, the construction of the cell allows these burned tracks to be recorded on the surfaces of the glass plates, and

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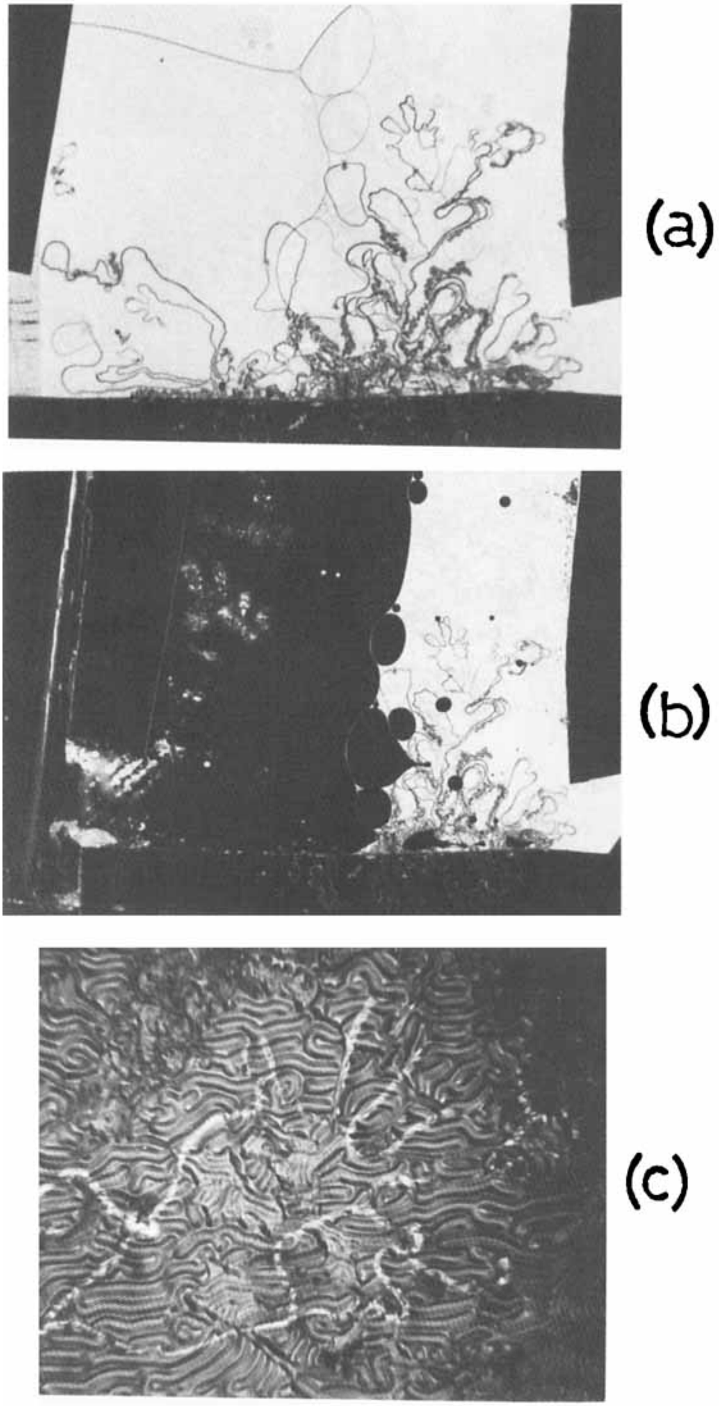

FIGURE 4 Nematic MBBA. d = 13 μm. AC. (a) Without polarizers. (b) With crossed polarizers; the dark areas contain air but no nematics. (c) Blow up of (b).

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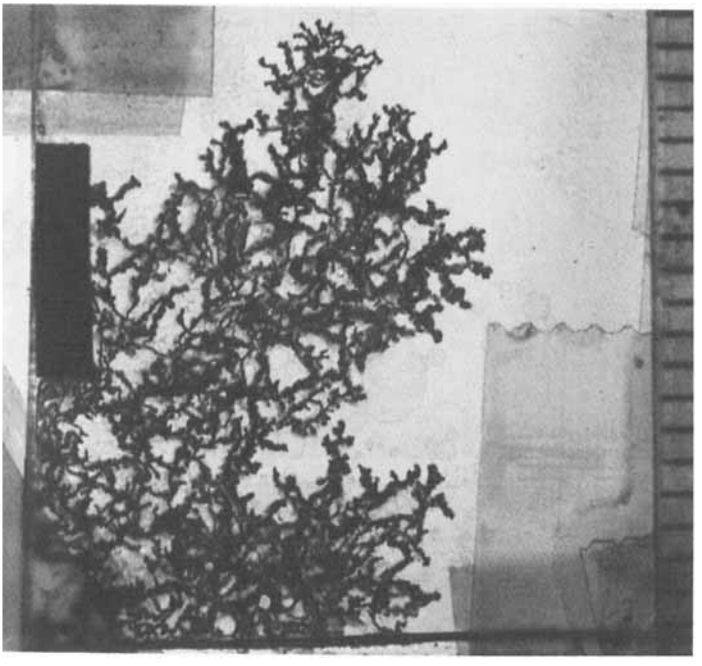

FIGURE 5 Nematic MBBA. d = 5 μm. AC.

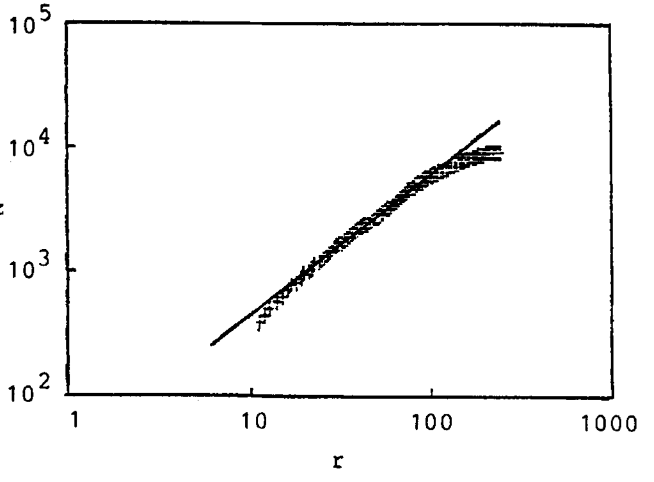

FIGURE 6 Dependence of N, the number of pixels within a radius r, on r. The data is obtained from the scan of Figure 2 (b) with the dense part near the left lower corner removed. The slope of the straight line is 1.125, the fractal dimension D.

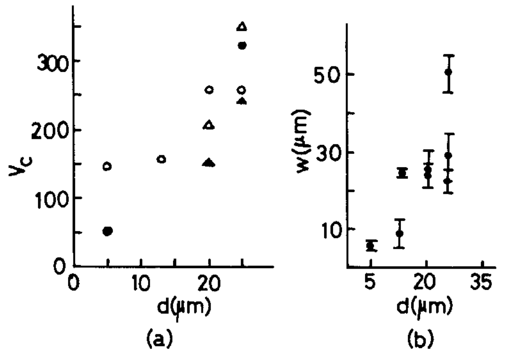

FIGURE 7 (a) Dependence of threshod voltage V_c (in volts) on cell thickness d. ●: MBBA, DC. ○: MBBA, AC. ▲: oil, DC. △: oil, AC. (b) Dependence of width of the smooth strings w on d.

the tracks themselves could then be studied later. The Hele-Shaw cell does provide a new method in studying dielectric breakdown of liquids. More work in experiment and theory is needed. So, next time, when you have a liquid crystal cell burned do not throw it away; study it yourself or send it to us.

Acknowledgment

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References

1. J. Feder, *Fractals* (Plenum, New York, 1988); T. Vicsek, *Fractal Growth Phenomena* (World Scientific, Teaneck, 1989); L. Lam, *Nonlinear Physics for Beginners* (World Scientific, Teaneck, 1991).
2. L. Lam, *Unsolved Nonlinear Problems in Liquid Crystals*, in Nonlinear and Chaotic Phenomena, edited by W. Rozmus and J. A. Tuszynski (World Scientific, Teaneck, 1991).
3. L. Lam *et al.*, *Liq. Cryst.*, **5**, 1813 (1989); C. Baehr, M. Ebert, G. Frick and J. H. Wendorff, *Liq. Cryst.*, **7**, 601 (1990); M. Nakagawa *et al.*, *Mol. Cryst. Liq. Cryst.*, **195**, 15 (1991).
4. L. Niemeyer, L. Pietronero and H. J. Wiesmann, *Phys. Rev. Lett.*, **52**, 1033 (1984).
5. See, e.g., *Nonlinear Structures in Physical Systems*, edited by L. Lam and H. C. Morris (Springer, New York, 1990).
6. I. Adamczewski, *Ionization, Conductivity and Breakdown in Dielectric Liquids* (Taylor and Francis, London, 1969); T. J. Gallagher, *Simple Dielectric Liquids* (Clarendon, Oxford, 1975).

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