IMPEDANCE OF A DETERMINISTIC
3-D FRACTAL ELECTRODE

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The impedance of fractal electrodes has been the subject of several theoretical investigations [1]. However few well-characterized experiments have been carried out so far [2, 3].
In the present work, we study the impedance of an engineered fractal electrode, with a fractal dimension equal to 3, supplied by Amalgamated Research Inc. [4], shown in figure 1. The smaller cut-off length, l, is of the order of 3 mm and the total size L (larger cut-off) is 4.5 cm. It is a prefractal of generation 3. Its surface was metallized by a Ni-P layer, electrolessly deposited, which provides a uniform thickness [5].
The impedance of this electrode was investigated, at the corrosion potential, in solutions of boric acid/sodium borate, in which nickel and nickel phosphorus alloys are self-passive [6]. The electrodes may then be considered as ideally polarizable in these solutions. The resistivity of the solutions was varied by dilution from 190 to 4200 Ωcm. The behavior of the ramified electrode was compared to that of a small branch of total area 2 cm^2, which is used here as a calibrating reference.

RESULTS

The impedance of the reference exhibits two frequency domains (Fig.2, curve 1). In the low-frequency domain ($f<f_1$), the electrode exhibits power-law dependence on frequency with an exponent of order 0.85. In the high-frequency domain ($f>f_1$), it shows also a power-law with an exponent close to 0.55. The transition frequency, f_1, scales as the reciprocal of the solution resistivity (Fig. 3, curve 1). The length associated with the crossover, $\Lambda = 1/\rho\gamma\omega_2$ [2] (ρ is the solution resistivity and γ is the double-layer capacitance of order $10\mu Fcm^{-2}$) is approximately equal to 5 mm. This is of the same order as the perimeter of a typical 2-D planar cut of the surface of the reference.
The fractal electrode exhibits three frequency domains (Fig. 2, curve 2). This behavior, showing three frequency domains, is typical of 2D-fractal electrodes [1]. At low frequency ($f<f_2$), the response is similar to that of the reference electrode apart from the amplitude. The exponent is close to 0.8. In this range ($f<f_2$), the responses of both electrodes correspond to their developed surface area. The measured fractal area is found to be about 100 times larger than that of the reference (ca 200 cm^2). This value corresponds approximately to the geometrical area of the fractal electrode. The length associated with the crossover f_2, $\Lambda = 1/\rho\gamma\omega_2$ is approximately equal to 20cm. This is of the same order as the perimeter of a typical 2-D planar cut of the electrode surface [2].
In the high-frequency domain ($f>f_3$), the response of the fractal electrode shows a power law of exponent 0.8. Fig. 2 shows that the crossover frequency f_3 corresponds to a length Λ of approximately 4 mm which is of the order of the smaller cut-off l. Note that f_1 and f_3 behave similarly with the solution resistivity (Fig. 3, curve 1).
In the medium-frequency range ($f_2<f<f_3$), the weaker slope is characteristic of the response of a fractal electrode.
In conclusion the 3-D fractal electrode behaves in first approximation in the same way as generally accepted for 2D fractal systems. Further studies are in progress to better characterize its behavior.

REFERENCES

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Figure 1: Image of a tridimensional fractal structure studied here. The electrode used in our experiments is of generation 3 while the picture shown below corresponds to generation 4.

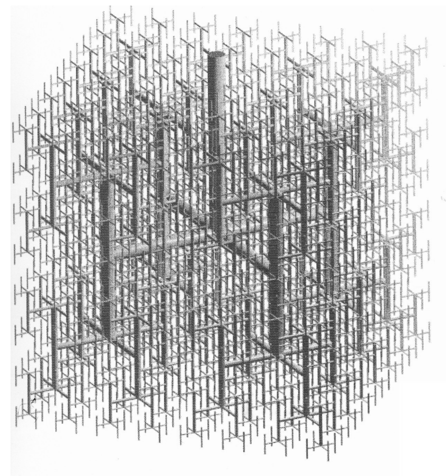

Figure 2 : Frequency dependence of the imaginary part of the impedance

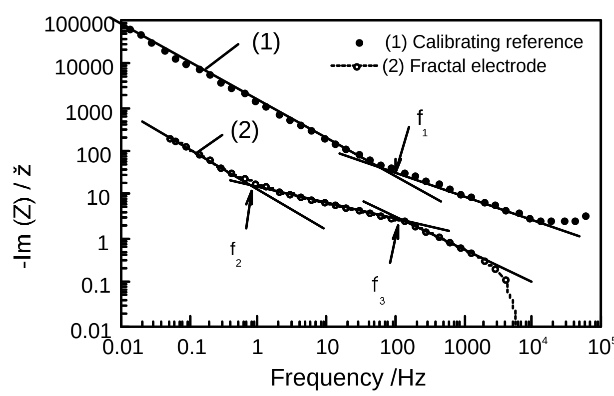

Figure 3 : Crossover frequencies as a function of the solution resistivity