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SIGNALS OF CHAOS IN THE TRANSIENT CURRENT THROUGH $As_2S_3(Ag)$ and $As_2Se_3(Al)$ THIN FILMS

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Abstract: The transient current through a sample of $As_2S_3(Ag)$ and $As_2Se_3(Al)$ glass substrate has been analyzed in order to study possible chaotic behavior using methodology similar to that in work on polymers [1,2]. Rescaled range analysis (R/S) shows the presence of two regimes of fractal behavior, one of which can be attributed to short time scale relaxation and the other can be attributed to long term chaotic behavior. The mutual information data indicates the necessity of noise reduction using a moving average. Extending the moving average window gives correspondingly large delay times as expected. The indicated delay time starts at 20*s* and grows up to 250*s*. The false nearest neighbor results also indicate a value around 10. A robust increase in the Lyapunov exponent stretching graphs confirm long term chaos; the result is not sensitive to the precise values of the delay time and embedding dimension. Possible relaxation mechanisms [3] in the short time range include parametrizations involving stretched

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exponential relaxation and logarithmic relaxation, the latter suggested by a proposal of Trachenko [4,5].

Keywords: Chaotic Behavior, Lyapunov Exponents, Rescaled Range Analysis.

1. Introduction

The specimens under investigation were prepared as sandwiched metal-glass-metal structures with the glass as the isolating layer. 300 nm thick aluminum electrodes were thermally evaporated at 10^{-6} mbar on microscope glass slides cleaned in a detergent solution. Subsequently, aluminum top contacts were evaporated. The I-V measurement was performed via a programmable picoammeter/voltage source (Keithley, model 487) and a temperature controller (Lake Shore, model 300). The picoammeter and the temperature controller were interfaced to a computer through an interface card that automated data taking, schematically presented in Fig. 1. The picoammeter model 478 used is capable of reading currents in the range 10 fA to 2 mA. It also serves as a DC voltage supply in the range up to 500V.

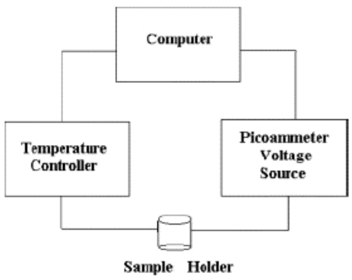


Fig. 1. Schematic of the experimental setup

The data of transient current against time for $As_2S_3(Ag)$ and $As_2Se_3(Al)$ are presented in Fig. 2 and Fig. 3. One horizontal unit represents 30 ms. Examining the graphs, we find that there is an overall relaxation in $As_2Se_3(Al)$ but not in $As_2S_3(Ag)$. However for both materials the data looks more like the behavior of the transient current data for polymer thin films such as PMMA [6] or PEG-Si[2].

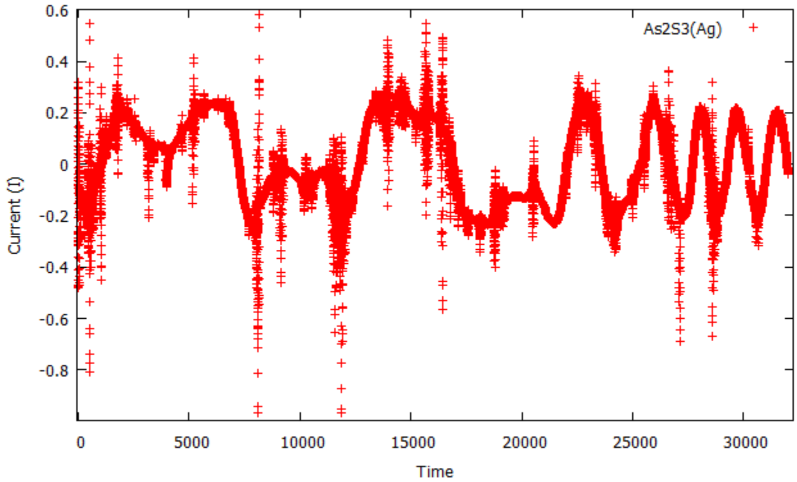


Fig. 2. The data of $As_2S_3(Ag)$

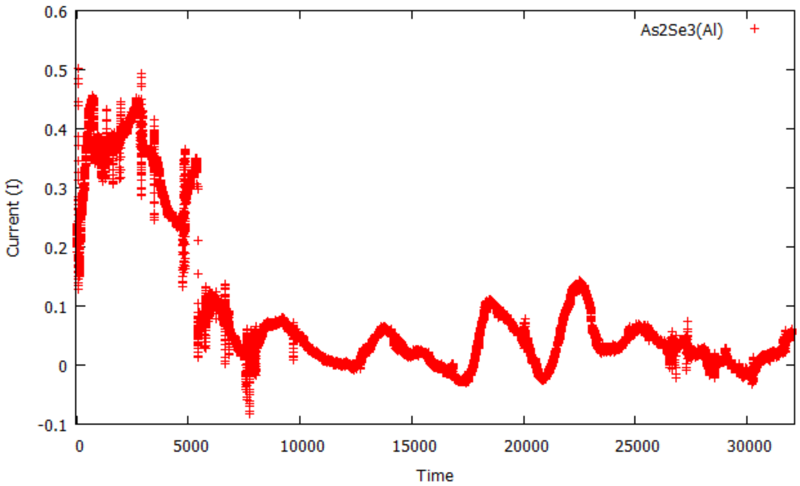


Fig. 3. The data of $As_2Se_3(Al)$

2. Time Series Analysis

Time series analysis is used for analysing the data of $As_2S_3(Ag)$ and $As_2Se_3(Al)$ using TISEAN [7,8] software package. The formulas used are part of the standard literature and are omitted. We observe one dimensional signal in uniform time intervals, x(0), x(T), …, x(nT). In fact the signal x(T) depends on an unknown number of parameters. To determine the number of parameters (dimensionality of the system), we find the meaningful time delay τ and the meaningful embedding dimension to construct time delay vectors. We find the embedding dimension by using the False Nearest Neighbors (FNN) method. We find the delay time by using Mutual Information (MUT) or correlation function (CORR). We calculate the autocorrelation function, which is the Fourier transform of the power spectrum and we present the results in Fig.4.

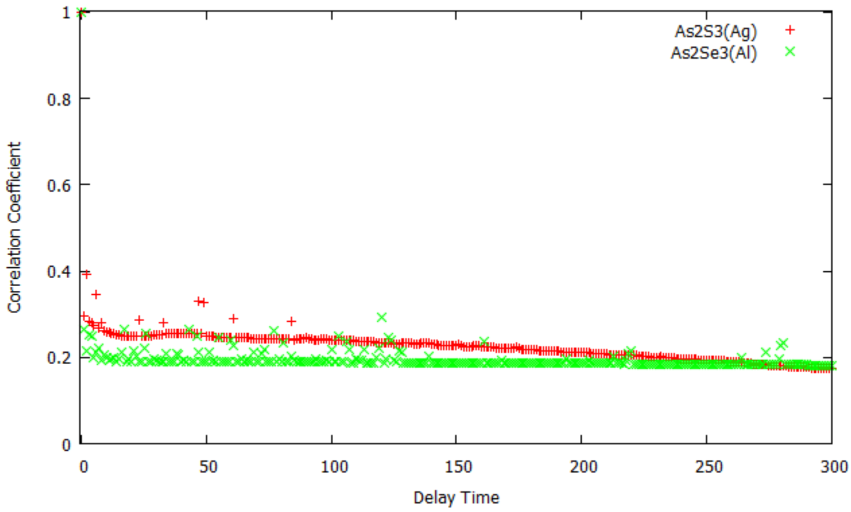


Fig. 4. Correlation coefficient

Another method for obtaining the delay time is to find the first minimum of the mutual information as presented in Fig. 5. We wish to represent a random variable with actual probability distribution p(x) with a code whose average length is H(p). In practice, because of missing information or sampling, we may not know the actual distribution p(x), so that we have to take the distribution to be q(x). In such a situation, we may need a longer code to represent the random variable. This difference in length, D(p(x)||q(x)) is known as the relative entropy. The knowledge that one random variable includes about another random variable is known as mutual information. We can only examine the information that we send to one channel in terms of information output from there. Let x and y be random variables with mutual distribution p(x,y). If variables x and y have distributions p(x) and p(y), the mutual information is the entropy between the mutual distribution and product distribution. If it is chosen to be too small, x(t) and x(t+τ) will be very close to each other and it will be difficult to distinguish them. If it is chosen too large, x(t) and x(t+τ) coordinates will be too far apart, will behave independently and cause loss of information.

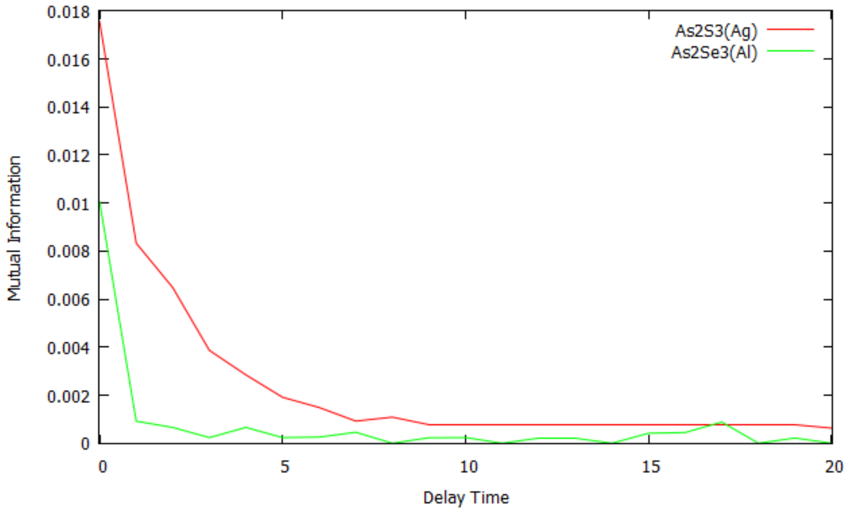


Fig. 5. Mutual information

False nearest neighbors graph (FNN) presented in Fig. 6. is useful for determining the minimal embedding dimension. The purpose is to find points near each other in the embedded space. If the embedding dimension is too small, points that are close in embedded space will appear as false neighbors. If the embedding dimension is too large, we lose statistics and information. By expressing the distance in (d+1) dimensions in terms of the distance in d dimensions, we can calculate the number of neighbors in d and d+1 dimensions, R_{d+1}/R_d . If this ratio is above a critical value, we have false nearest neighbors.

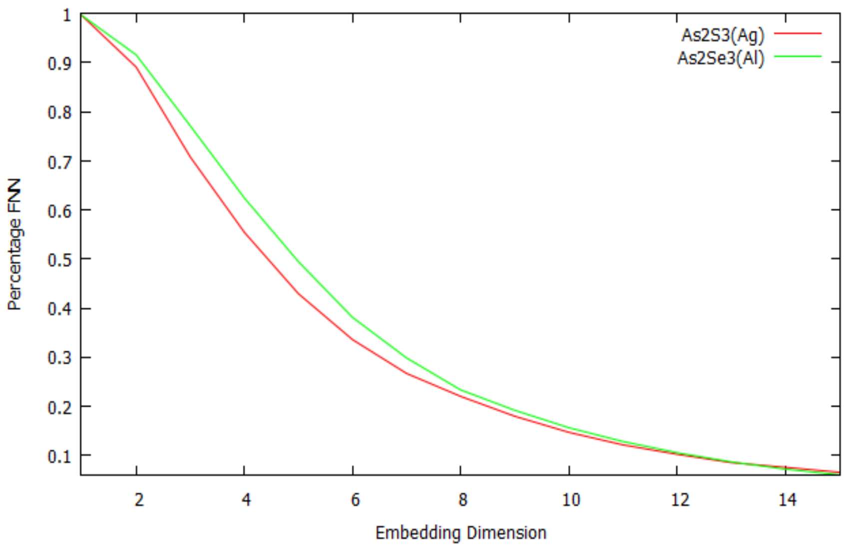
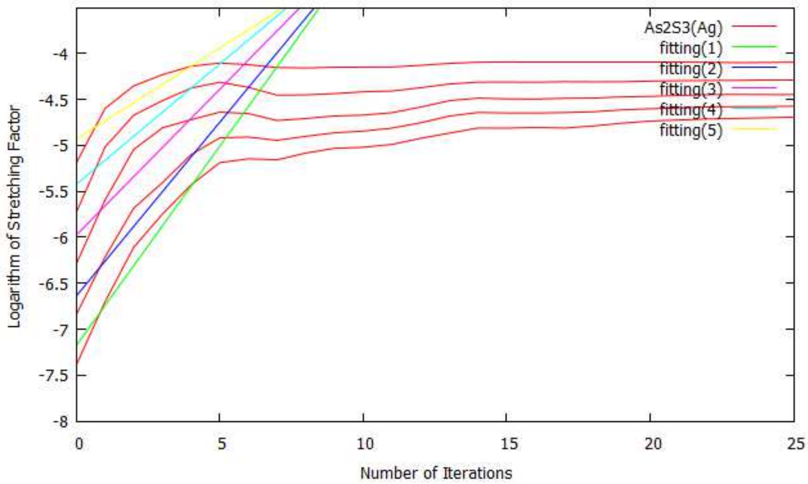


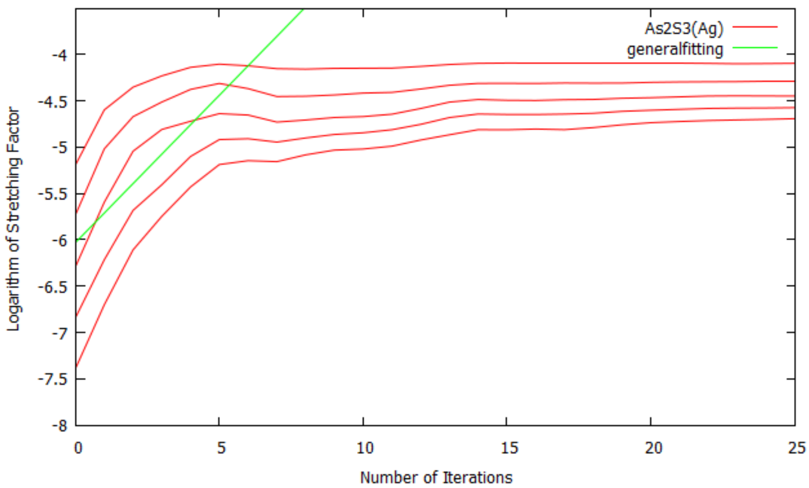
Fig. 6. False nearest neighbors

The largest lyapunov exponent presented in Fig.7 is usually used as an indicator of chaos. This is obtained by calculating the quantity

$$S(\Delta n) = \frac{1}{N}\sum_{n0=1}^{N} \ln\left[\frac{1}{|U(S_{n0})|}\sum_{S_n \in \Upsilon(S_{n0})} \left|\left[S_{n0+\Delta n} - S_{n+\Delta n}\right]\right|\right] \qquad (1)$$

S_{n0} is our reference point, U is a hypersphere of distance ε to this point. If ε is too small, we can not find a sufficient number of points, if it is too large, a periodic component may be missed. For a few ε values, calculating the number of points in the hypersphere S(Δn), plotting it against Δn gives the largest Lyapunov Exponent. A positive slope implies a positive Lyapunov Exponent.





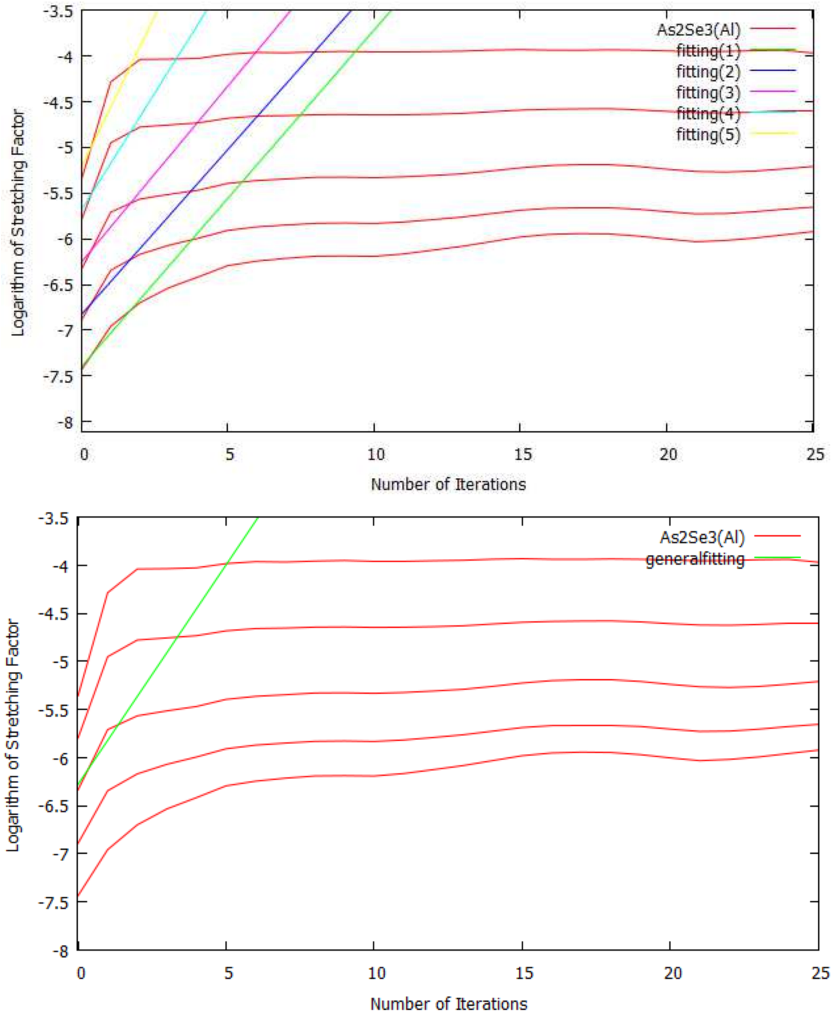


Fig. 7. Largest Lyapunov exponents

Thin Films	Lyapunov Exponent (slope)
$As_2S_3(Ag)$	0.317
$As_2Se_3(Al)$	0.456

3. Hurst (R/S) Analysis

The Hurst exponent is calculated using the standard approach and as presented in Fig. 8 it is a numerical approach to the predictability of a time series. If the Hurst exponent (H) is close to 0.5, the process is a random walk. (Brownian motion) A Hurst exponent (H) in the range $0 < H < 0.5$ implies non random behavior in the time series. A Hurst exponent (H) in the range $0.5 < H < 1$ implies a time series with long range, continuous evolution.

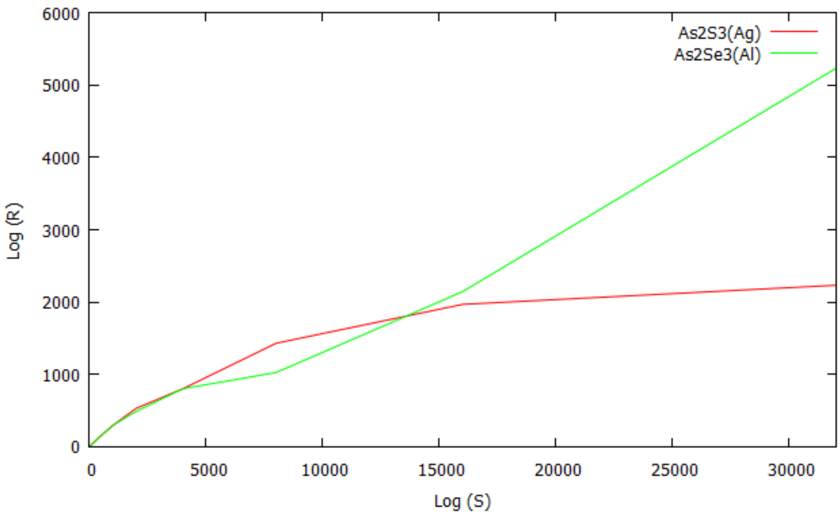


Fig. 8. Hurst Analysis

4. Conclusions

The complex structure of chalcogenites suggests many degrees of freedom and a multi-fractal structure. The transient current through the samples of $As_2S_3(Ag)$ and $As_2Se_3(Al)$ glass substrates has been analyzed in order to study possible chaotic behavior similar to that in our work on polymers. The conductivity mechanism measured by the time dependent behavior of transient current was analyzed by nonlinear considerations such as time series analysis, maximal Lyapunov exponent, Hurst (R/S) analysis. Intermediate dimensional chaos with positive maximal Lyapunov exponents was observed. The behaviors of the system with possibly two different regions, one with short range and another with long range correlation were seen by comparing the correlation coefficient and mutual information. As suggested by studies of other amorphous materials with irregular behavior, the use of nonlinear methods for analyzing the conductivity mechanisms in such materials seems crucial in modelling and show that the behaviors are comparable.

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