q-Gaussian Analysis of the Electronic Behavior in $As_2S_3(Ag)$ and $As_2Se_3(Al)$ Thin Films

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Introduction

Complex systems have common charecteristics such as long-range correlations, multi-fractal structure and non-Gaussian behaviors. These systems usually cannot be well described by standard statistical mechanical approaches. Generalized or nonextensive statistical mechanics can provide a better description, which was introduced by Tssalis [1-4]. Generalized distributions are the probability distributions derived by maximazing the Tssalis entropy under appropriate constraints. In the context of q-statistics, q-Gaussian analysis can be used to interpret systems which Show weak chaotic behavior, that is, the systems which have Lyapunov exponents near zero [5].

The complex structure of chalcogenites includes many degrees of freedom and a multi-fractal structure. In this context, we previously analyzed the electronic behavior of $As_2S_3(Ag)$ and $As_2Se_3(Al)$ chalcogenites [6]. In the present work, our data of the transient current through the corresponding glass substrate were examined with q-Gaussian analysis in a similar way as the work on polymers [7]. The fomer analysis of ours points out that there is intermediate dimensional chaos with positive maximal Lyapunov exponents. The behavior of the system possibly correspond to two different regions, one with short range and another with long range correlation.

The aim of the present work is to see the applicability of -statistics to transient current in thin films and to observe if the results of the q-Gaussian analysis show consistency with our previous results, and to obtain possible more details on the electronic properties of $As_2S_3(Ag)$ and $As_2Se_3(Al)$ thin films. Since q-statistics is an analytical tool which is independent from those of chaos theory; the previous results can support or deny the present results of q-Gaussian analysis.

q-Distributions Applicability in Transient Current of $As_2S_3(Ag)$ and $As_2Se_3(Al)$

It is not possible to analyze data which show weak chaoticity with classical statistical mechanical tools. However, nonextensive statistical mechanics is found to be useful for such analysis, as stated in the introduction. $As_2S_3(Ag)$ and $As_2Se_3(Al)$ data can be fitted by a q-Gaussian curve, much better than it would be for a normal Gaussian. The q-Gaussian distribution is defined by the probability density function (PDF)

$$p_{qg}(x) = p_0\left[1-(1-q)\left(\frac{x}{x_0}\right)^2\right]^{\frac{1}{1-q}} \tag{1}$$

for $\left[1-(1-q)\left(\frac{x}{x_0}\right)^2\right] \geq 0$ and otherwise $p_{qg}(x) = 0$. The pdf is normalized when

$$p_0 = \left(\frac{2}{x_0}\right)\frac{\sqrt{\frac{q-1}{\pi}}\,\Gamma\left(\frac{1}{q-1}\right)}{\Gamma\left(\frac{3-q}{2(q-1)}\right)} \tag{2}$$

For the limit case where $q \to 1$ Eq. (1) becomes the standard Gaussian distribution. So, $q \neq 1$ implies the regime where Gaussian statistics does not work.

Rewriting Eq. (1) gives

$$p(x) = A\left[1-\frac{(1-q)x^2}{B}\right]^{\frac{1}{1-q}} \tag{3}$$

where A and B are constants. We calculated the difference of each succesive current value $I(t)$ over the whole measurement span:

$$I(t) = i(t+1) - i(t) \tag{4}$$

Then, $I(t)$ was normalized by subtracting its mean value over time and dividing the result by the standard deviation:

$$\frac{I(t) - < I(t) >}{\sigma(I(t))} \tag{5}$$

The histograms of the data were computed and the distributions were plotted against the normalized $I(t)$. The resulting distributions were fitted to a q-Gaussian curve by picking suitable A and B parameters and also finding a suitable value for q. The PDFs against normalized $I(t)$ can be seen in figures 1 and 2.

In figures 1 and 2, the PDFs of the current magnitude differences (Eq. 4) for the transient current through thin $As_2S_3(Ag)$ and $As_2Se_3(Al)$ films. The curves fitted to a typical q-Gaussian with exponents q=2.5 and q=2.7 respectively. The values obtained from the fits can be seen in Table 1.

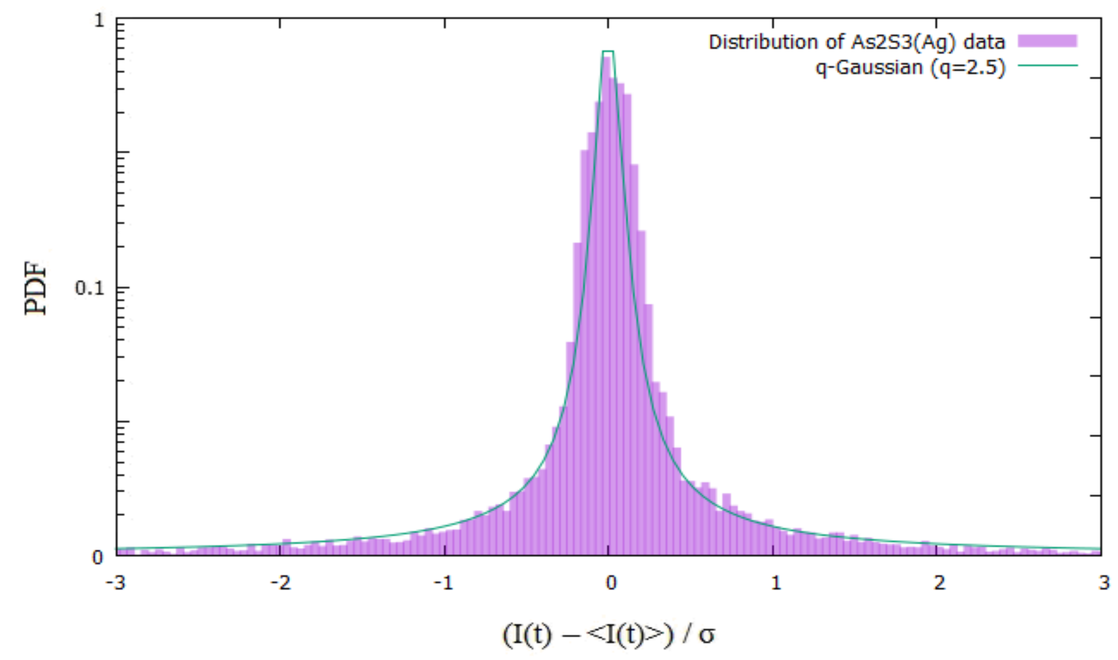

Figure 1. PDF of the current magnitude differences for the transient current through thin $As_2S_3(Ag)$. The curve has been fitted with a q-Gaussian (green line) with an exponent q=2.5.

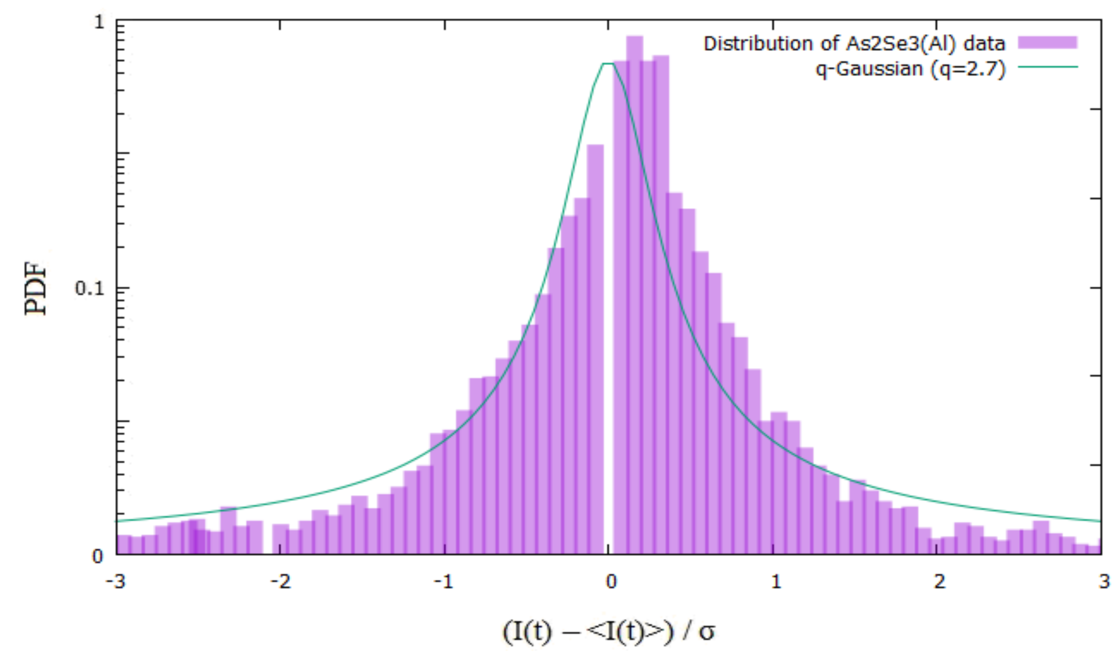

Figure 2. PDF of the current magnitude differences for the transient current through thin $As_2Se_3(Al)$. The curve has been fitted with a q-Gaussian (green line) with an exponent q=2.7.

	A	B	q
$As_2S_3(Ag)$	886.1	53.8	2.5
$As_2Se_3(Al)$	277.1	6.7	2.7

Table 1. A, B and q parameter values of the fitted q-Gaussian function.

Conclusion

In this work, to get more information about the behavior of transient current through $As_2S_3(Ag)$ and $As_2Se_3(Al)$ samples, we have analyzed our data by using q-statistics. We observed a behavior different from a Gaussian one. The curves are peaked and they have long tails. Thus, we obtained non-Gaussian probability density functions. exponents are greater than 1 as we expected, where at q=1 the q-Gaussian recovers the normal Gaussian. All results imply that there is a chaotic behavior. The complex structure of the sample thin films may support a number of conduction mechanisms that are acting simultaneously and affecting each other so that the current fluctuations bring forth a q-Gaussian shape of the PDFs. Different q values can be considered as a measure of the degree of correlation. There is a small difference between q values for $As_2S_3(Ag)$ and $As_2Se_3(Al)$ samples, and this shows that there seems to be a weaker interatomic attractions in $As_2S_3(Ag)$ than it is in $As_2Se_3(Al)$.

In conclusion, we saw the applicability of q-statistics to transient current in thin films in our study and we observed how the results of q-Gaussian analysis show consistency with the first results. Moreover, we saw that the transient current behavior of $As_2S_3(Ag)$ and $As_2Se_3(Al)$ films manifest chaotic behavior which is weak. 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 modeling and show that the behaviors are comparable.

References

1. C. Tsallis. Possible generalization of Boltzmann-Gibbs statistics. Journal of Statistical Physics, 52, 1-2: 479-487, 1988.
2. C. Tsallis, R. S. Mendes and A. R. Plastino, Physica A – Statistical Mechanics and its Applications, 261, 534, 1998.
3. C. Tsallis, Brazilian Journal of Physics, 39, 337, 2009.
4. C. Tsallis. Introduction to Nonextensive Statistical Mechanics: Approaching a Complex World, Springer, New York, 2009.
5. G. Miritello, A. Pluchino, and A. Rapisarda. Central Limit behavior in the Kuramoto model at the 'Edge of Chaos'. Journal of Physics A, 388: 4818-4826, 2009.
6. Hacinliyan et al., Signals of Chaos in the Transient Current Through As2S3(Ag) and As2Se3(Al) Thin Films, Chaotic Modeling and Simulation (CMSIM) 4: 591-599, 2013.
7. G. C. Yalçın, Y. Skarlatos, and K. G. Akdeniz. q-Gaussian Analysis in Complex Polymers. In: Proceedings of the Conference in Honor of Murray Gell-Mann's 80th Birthday Quantum Mechanics, Elementary Particles, Quantum Cosmology and Complexity, World Scientific Publishing, Singapore, 669-672, ISBN: 978-981-4335-60-7, 2010.

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