

1/f NOISE STUDIES ON THIN FILMS OF CADMIUM OXIDE

S. Victor Vedanayakam^{1*}, D. Punyaseshudu²

¹Dept. of Physics, MITS, Madanapalli, A.P., India

²Dept. of Physics, Rayalaseema University, Kurnool, A.P., India

*e-mail: victorvedanayakams@mits.ac.in

Abstract. 1/f noise and nonlinear effects in Cadmium Oxide thin films for different current densities on varying the thickness of the films, at room temperature are studied. The specific dependence of 1/f noise on the thickness of the film, the effect of current densities on 1/f noise for the films of various thicknesses (300 Å to 750 Å) has been investigated. It is noticed that, for a constant current, the thickness of the film leads to an increase of 1/f noise. 1/f noise plays an important role in choosing frequency band in which a device can be effectively used. Cadmium oxide thin films are regarded as a material with many attracting properties such as large energy band gap, good conduction, high transmission coefficient etc. It is specially used in optoelectronic devices.

1. Introduction

Cadmium Oxide (CdO) thin films are having remarkable characteristics. They have found extensive applications in electronic and optical devices. The wide band gap properties of CdO, are of interest particularly for applications such as solar cells and transparent electrodes. Measurements of nonlinear properties are very interesting from the point of the view of optoelectronic and all optical switches. Hence these films are studied in the present work. Using the newly developed measuring system the studies are undertaken and found that the results are matching the theoretical values.

1/f noise plays an important role in choosing frequency band in which a device can be effectively used. As 1/f noise comes from the fluctuations of microscopic entities, it can act as a probe of what is happening physically at the microscopic scale. Characterization of noise with a 1/f like spectrum, and referred to as an excess or flicker noise, provided most important problems in modern radio physics. This noise limits the sensitivity and stability of many radio electronic devices, the requirements to which are enhancing constantly.

These fluctuations reflect many processes at the electron and atom levels and specific features of solid state micro-structure which makes 1/f noise a valuable informative parameter for evaluating the quality of materials and reliability of devices containing semiconductors and integrated micro chips. It is also used to predict the electro migration immunity of thin film metallization in integrated micro chips.

Recently, there has been sharply increasing interest in 1/f noise in thin metal films and other physical systems, which can be accounted for their wide application in different areas of physics and technology, especially in modern micro-electronics which makes high demands of thin films of different materials in manufacturing commutation layers, resistors, and contacts for integrated microcircuits.

1/f noise phenomenon was first studied as an excess low frequency noise in vacuum tubes and later in semiconductor devices. Since the mid-fifties 1/f noise (referred as low frequency noise) has been observed as fluctuations in the physical parameters of the systems.

Characterization of noise with a $1/f$ – like spectrum, also referred to as an excess or flicker noise, provided one of the most important problems in modern radio physics. The reason is that, on the one hand, the nature of these fluctuations remains poorly known although their possible origin has been discussed in scientific literature for many decades. On the other hand, this noise limits the sensitivity and stability of many radio electronic devices, the requirements of which are enhancing constantly.

The study of noise in physical systems is perhaps one of the most selective fields of physical science. The study being fundamental in nature, attracted several investigators emerging from diversified fields. The vast and still expanding literature on the subject of noise had its beginning with “Brownian Movement”. Pollen grains in water were observed to be in motion. These motions were neither due to the currents in the fluid nor from its evaporation, but belonged to the particle itself. Later Einstein showed that Brownian movement arose directly from the incessant and random bombardment of the molecules of the surrounding liquid, and thus the concept of “fluctuations” emerged. These fluctuations are therefore a consequence of the discrete nature of the matter. Such fluctuations are generally referred to as “noise”. It has become a common practice to call the fluctuating component of any measurable quantity as noise.

Van Vliet has given some broad guidelines on how to classify noise phenomena. She defined the terms “characteristic noise phenomena” and “non-characteristic noise phenomena”. Characteristic noise phenomena are those, which are reducible to noise sources, associated with a characteristic time constants of the source. An example for such noise phenomena is the burst noise. Non-characteristic noise phenomena are those fluctuation processes, which are not reducible to noise sources such as quantum $1/f$ noise. In such phenomena, actual representation of the noise as an ‘effect’ is not directly noticed. The earliest noise phenomena discovered were thermal noise due to the thermal motion of the constituent electrons and shot noise due to the corpuscular nature of transport. $1/f$ noise and burst noise are both low frequency noise phenomena.

General properties of $1/f$ noise. In the past $1/f$ noise has been variously called as current noise, excess noise and flicker noise (usually in connection with fluctuations in electronic emission from a thermionic emission from a thermionic cathode), semiconductor noise (before it was appreciated that it also appears in metals and aqueous electrolytes) and contact noise (although it was quite well known that $1/f$ noise is not generally a contact effect). All these names have been dropped recently and only the name $1/f$ noise has been retained. In the various research papers on $1/f$ noise, it has been cautioned by most authors that the name of $1/f$ noise common to all manifestations of the phenomena should not be taken to imply the existence of a common physical mechanism-giving rise to them all.

A remarkable sign of growing interest has been Tokyo Symposium in 1977, which solely dealt with $1/f$ fluctuations. The Fifth International Conference on Noise (Bad Nauheim 1978, Fed. Rep. of Germany) 1978 and subsequent Noise conferences provided ample scope for $1/f$ noise. In the field of noise research, it has been generally experienced that the well-known exception for which the experimental predictions is $1/f$ noise. The main aspects of the $1/f$ noise are (the discussion is centered on device noise and can be extended to any other phenomena) as follows.

(1) Power Spectral Density.

The shape of the power spectral density is of the f^{-1} -type with lying between 0.8 and 1.4. This spectral shape has been observed over a wide range of frequencies from 10^8 Hz to 10^6 Hz or higher.

(2) Amplitude Distribution.

The amplitude distribution of $1/f$ noise is strongly Gaussian. Although considerable deviations from Gaussian distributions have been observed, they are attributed to interference

effects with additional low frequency noise components particularly burst noise.

(3) Stationarity.

A process is said to be statistically stationary when the statistical properties are independent of the epoch in which they are measured. In the 1/f noise literature one comes across statements to the effect that 1/f noise is a stationary fluctuation as well as those saying that it exhibits some degree of non-stationary. In order to clarify the situation, two kinds of noises namely the band limited 1/f noise and low pass filtered 1/f noise have to be studied. The band limited 1/f noise is that for which the power spectral density is defined only for any frequency between the upper and lower angular frequencies of the pass band considered.

(4) Current Dependence.

In homogenous conducting materials, it has been verified that there is a current squared (I^2) dependence of noise, which led to the belief that 1/f noise originates from fluctuations in conductivity. However, in junction devices such as diodes and transistors, the current spectral density is observed to be proportional to I^γ with γ between 1 and 2.

(5) Temperature Dependence.

From the above property since 1/f noise depends on current and current depends on temperature, it is to believe that 1/f noise dependence on temperature. The studies of Horn and Bernard have shown the dependence of 1/f noise in metal films on temperature. According to Handel, in semiconductors, there is certain temperature dependence due to absorption and desorption of gases or water vapor on the surface, due to changes in the concentration of the carriers.

2. Thin films

Thin film science has received tremendous attention in the recent years for their applications in diverse fields such as, electronic industries, military weapon systems, space science, solar energy utilization etc. Thin films are used as optical and superconducting film materials, high memory computer elements, sensors etc.

The thin film properties mainly depend upon the preparative conditions, film structures, and presence of defects, impurities and film thickness. Various physical constants related to the bulk material properties may not often be the same for corresponding films prepared from the bulk. However, with increasing film thickness these tend to assume corresponding bulk values. Numerous applications of films lead to intense studies of these especially to develop and prepare better films with specialized properties for newer compounds or composite materials.

Subsequent developments of the study of thin films revealed that the tailoring of properties is possible by the use of thin film technique. The proper control of compositions and deposition conditions results into tailored micro materials. These materials used in the fields of optics, electrical, optoelectronics and such other applications. Thin film devices and components are preferred over their bulk counterparts, because of compactness, better performance, reliability coupled with less cost of production and low package weight.

Thickness plays an important role in thin films. It is an important parameter, which affects the optical, electrical, structural etc. properties of metals considerably. Reproducible characteristics can be obtained by choosing specific thickness and proper combination of deposition parameters for a particular material.

Cadmium Oxide (CdO) thin films are regarded as a material with many attracting properties such as large energy band gap, good conducting film and high transmission coefficient in visible spectral domain. In recent years, researchers have focused on CdO due to its applications, especially in the field of optoelectronic devices such as solar cells, Phototransistors and diodes, transparent electrodes, gas sensors, etc. These applications of CdO are based on its specific optical and electrical properties. For example, CdO films show a

high ohmic conductivity.

In this paper the results of investigations are made on CdO films. The $1/f$ noise characterization on film thickness, variation of the current densities is made on CdO thin films of thickness 300 Å, 380 Å, 500 Å, 620 Å, and 750 Å.

3. $1/f$ noise and non-linear studies in CdO thin films

Each device under selected biased condition has its own record in the form of digital data file (which is not provided). When plotted directly they look alike, the differences in magnitudes can be noticed but quantitative measurements can't be made. The spectral power density records are obtained using the digital data records as inputs to the MATLAB programs. These FFT records have the unique signatures of noise produced by the device under test, abbreviated as DUT. These observations are of prime significance, containing crucial information regarding the electrical behavior associated with DUT if analyzed using MATLAB programs.

The raw noise records for different components under the present study are shown in the following figures. These plots represent the noise recorded for one individual device. On observation, the noise recordings look alike on first perusal. Nothing seems to be differentiated between any two plots except the noise magnitudes are different.

The noise patterns similar to shown in Fig. 1 represent 8-bit pulse code amplitude for CdO film of thickness 300 Å. As already pointed out the raw noise records do not convey any meaning. The observation is of prime significance, containing crucial information regarding the electrical behavior associated with DUT if analyzed using the software. The simplest way of translating the noise data into spectral power density form is known as FFT transform of the noise input. The noise patterns shown in Fig. 2 represent the variation of magnitude of FFT with the frequency for different current densities.

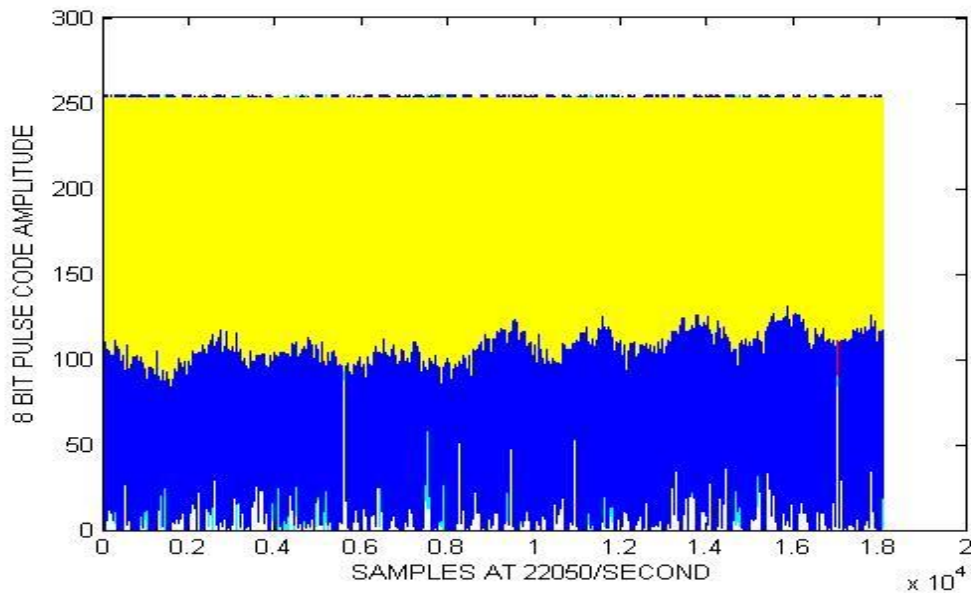


Fig. 1. 8-Bit pulse amplitude of CdO film of thickness 300 Å for different current densities.

Figure 3 is averaged power spectral density record of CdO film of thickness of 300 Å. All graphs are plotted in the standard format of $\log f$ versus \log (spectral power density), after passing the data through the elliptical filter. The elliptical filters are found to be quite suitable for measurements that are recorded randomly. Notch filters were also used in the software to eliminate the stray ac interference.

These graphs convey better information when they are compared for different films of for different conditions for the same DUT. Plotting them on the same graphical presentation compares two or more plots. This is equivalent to superimposing multiple graphs presented on similar scales. To visualize the difference, the graphs are plotted using different colors. A legend to each graph is added for easy explanation. In the present work 1/f noise dependence on different conditions is studied. The 1/f noise plots are carefully compared to achieve the objectivity of 1/f noise studies.

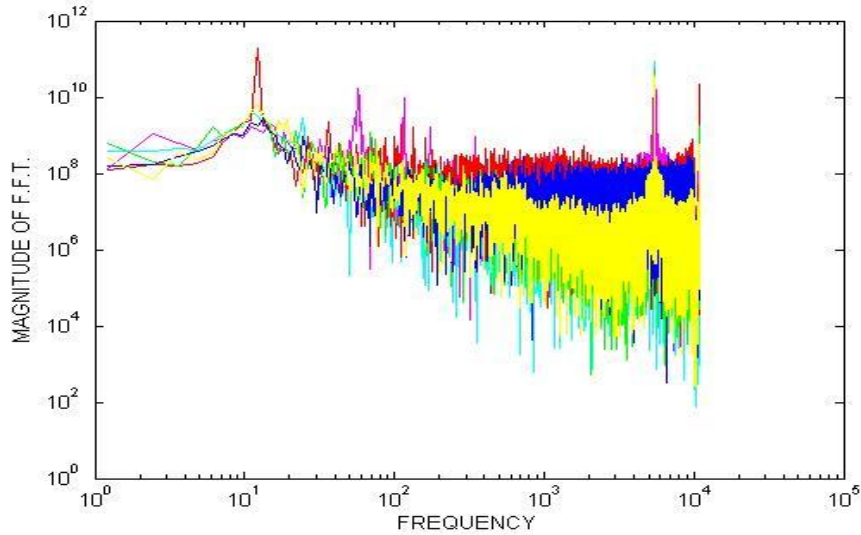


Fig. 2. FFT amplitude of CdO film of thickness 300 Å for different current densities.

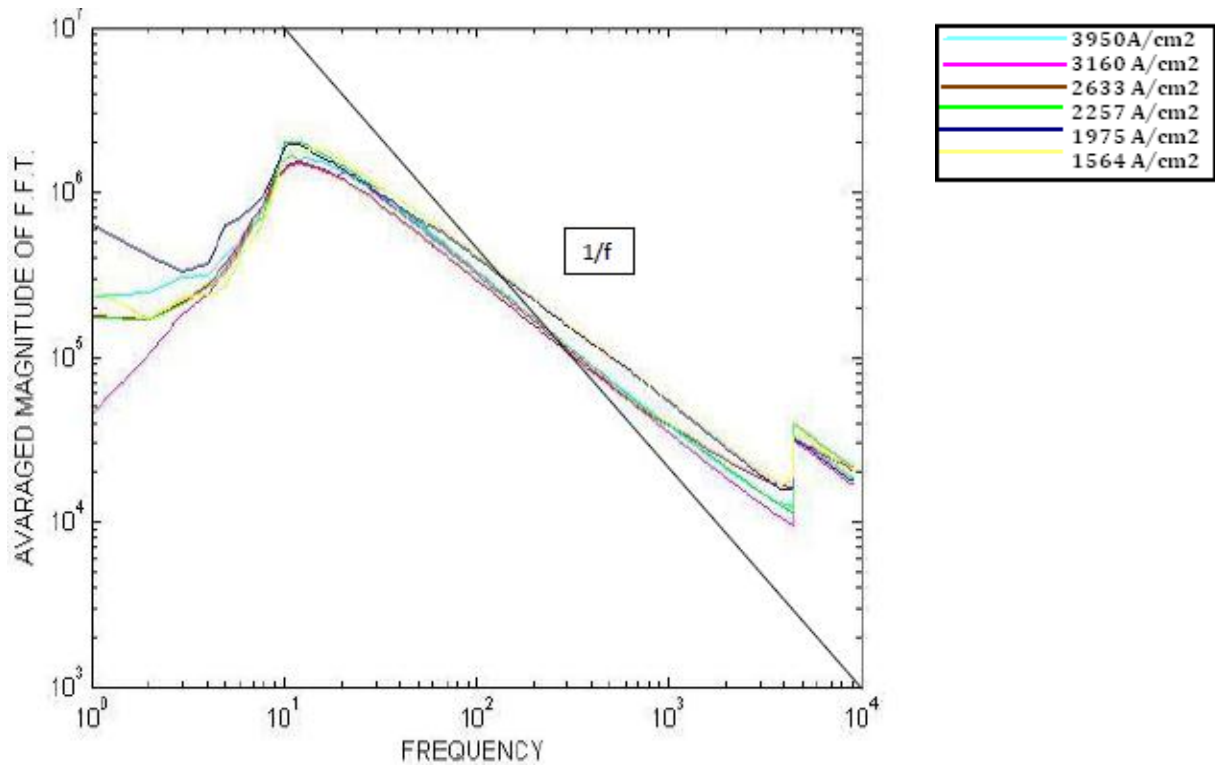


Fig. 3. 1/f noise of 300 Å CdO film at different current densities.

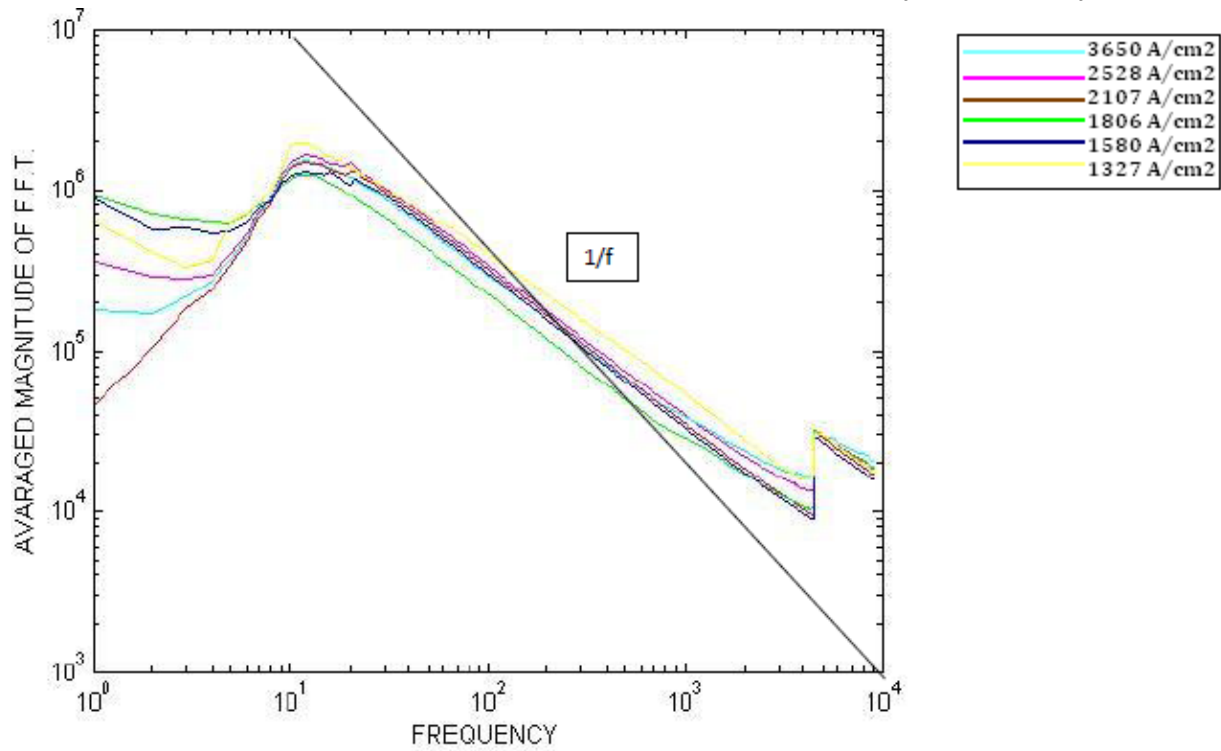


Fig. 4. $1/f$ noise of 380 Å CdO Film at different current densities.

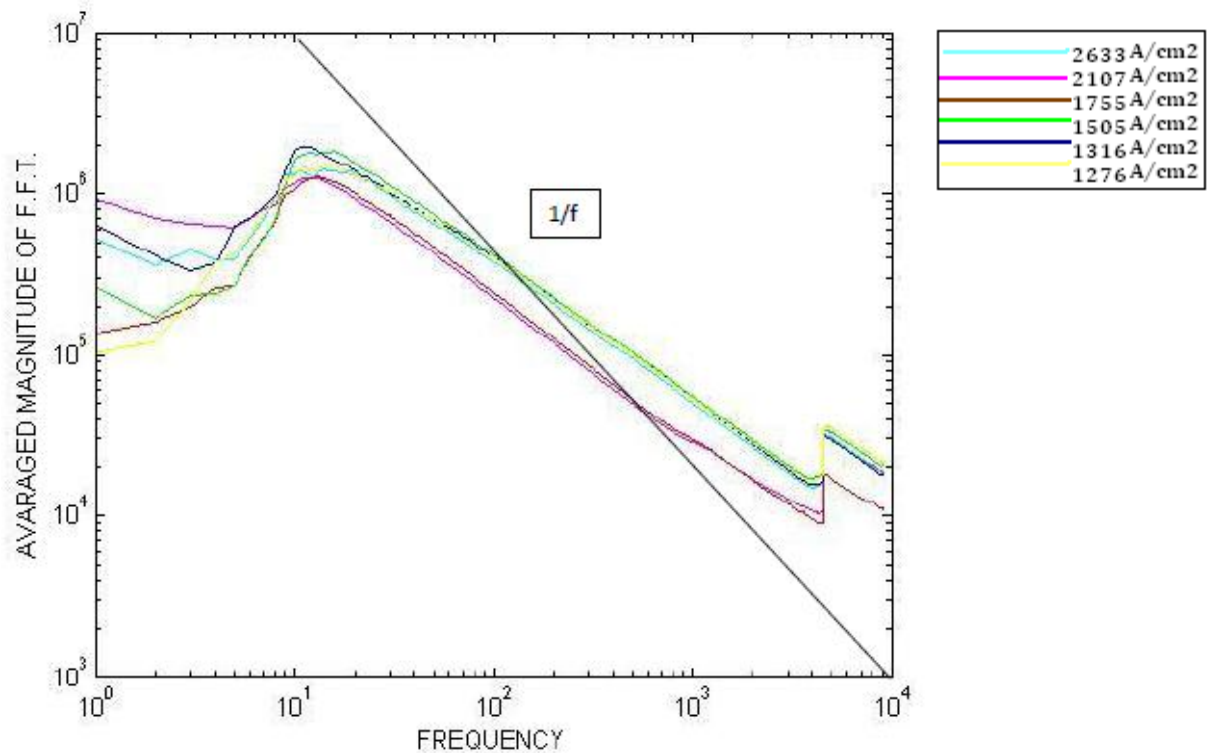


Fig. 5. $1/f$ noise of 500 Å CdO film at different current densities.

4. Tabulation of $1/f$ noise in CdO thin films

For strict $1/f$ noise compliance, a linear dependence of frequency versus FFT is expected. That is, FFT decreases with frequency, proportional to f^γ , where $\gamma = -1$ for a strict $1/f$ noise

compliance. In this work the 1/f line for every FFT plot is included and also the value of γ evaluated.

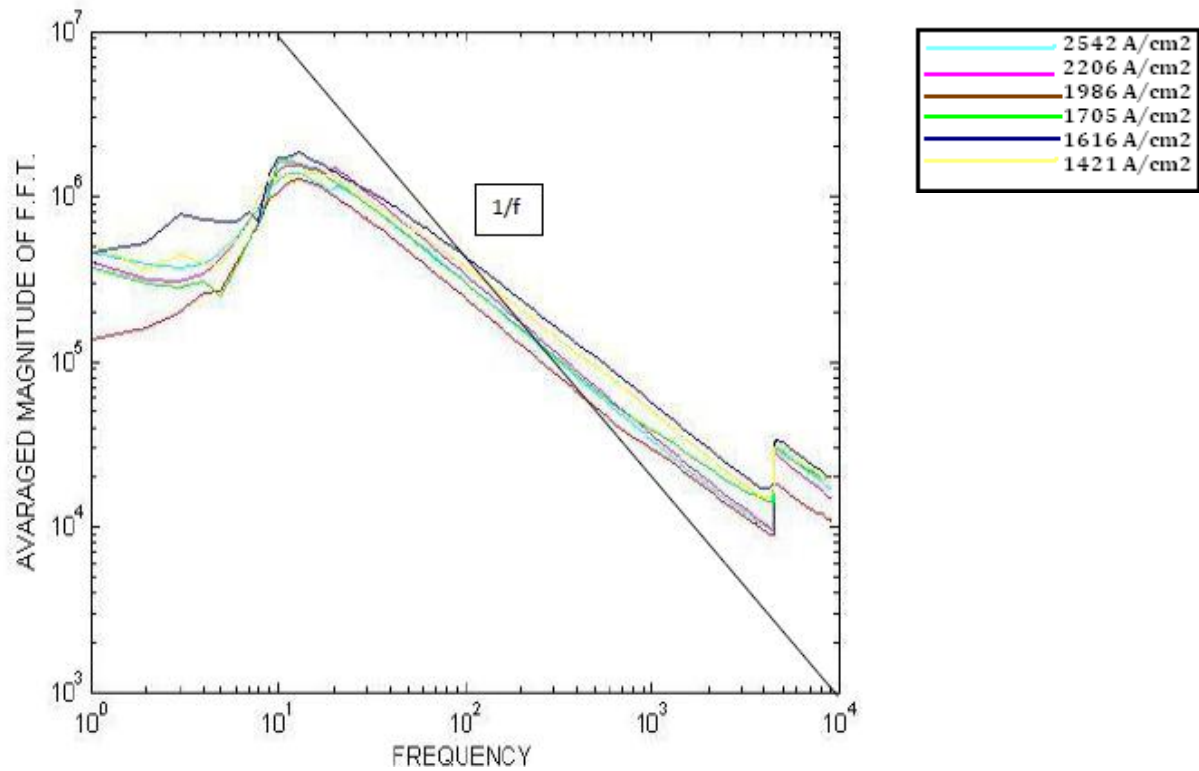


Fig. 6. 1/f noise of 620 Å CdO film at different current densities.

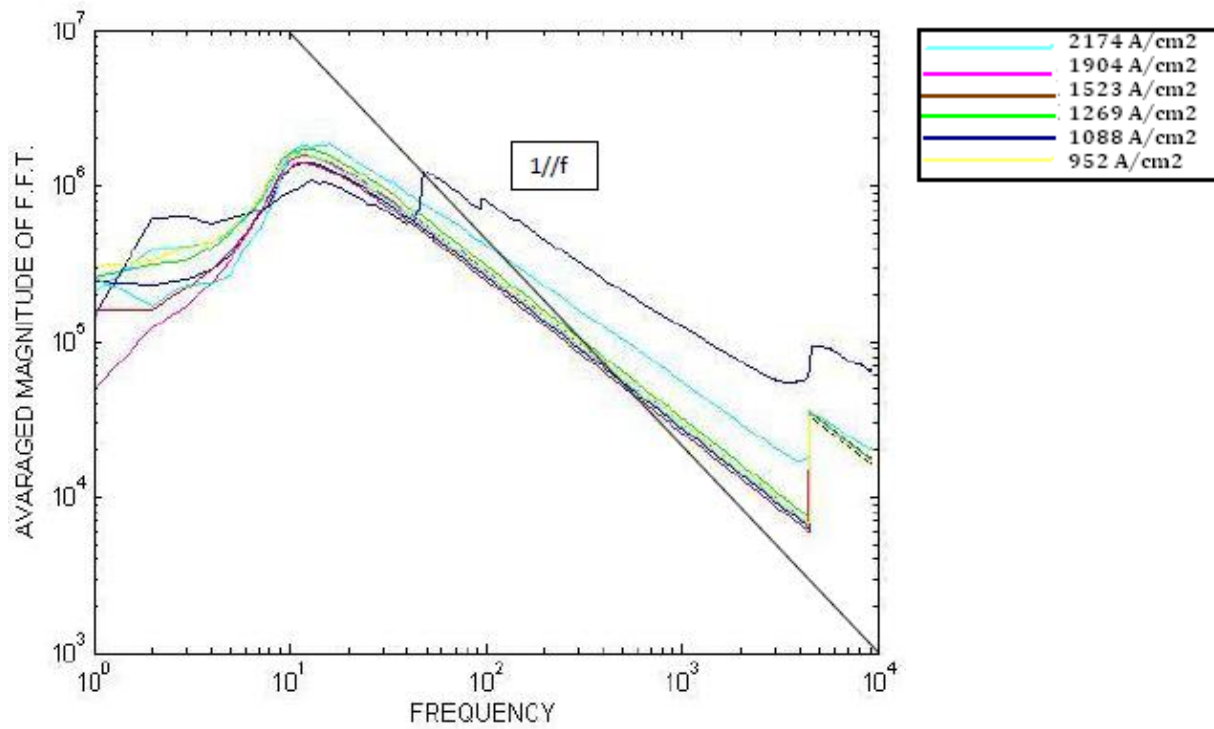


Fig. 7. 1/f noise of 750 Å CdO film at different current densities.

As current density is increased the power γ also tends to increase. It would be quite interesting to check the linearity of γ as a function of current density. The observed values of $-\gamma$ are plotted as a function of current density for different thickness of CdO films. The $-\gamma$ values are appearing to approach the theoretical value of unity for lower currents as visualized in literature. It has not been possible to study the films of thickness below 300\AA since the measurements on these films were quite unreliable due to very large fluctuations. It has been observed that literature values of $-\gamma$ are higher than the present values.

It can be observed that the slopes are not uniform throughout the frequency region of study. The slopes are slightly higher than the mean slopes in the low frequency region, below 1 KHz. The slopes are lower than the mean value in the upper region 1 KHz to 10 KHz. The slopes are tabulated.

Table 1. γ - Values derived from the figure for various frequency regions in 300\AA CdO film.

Current Density	Bellow 1 KHz Frequency	Between 1 KHz and 10 KHz	Averaged for the full range
3950 A/cm ²	-0.549	-0.431	-0.500
3160 A/cm ²	-0.570	-0.460	-0.516
2633 A/cm ²	-0.568	-0.481	-0.524
2257 A/cm ²	-0.627	-0.491	-0.567
1975 A/cm ²	-0.674	-0.539	-0.617
1564 A/cm ²	-0.709	-0.576	-0.632

Table 2. γ - Values derived from the figure for various frequency regions in 380\AA CdO film.

Current Density	Bellow 1 KHz Frequency	Between 1 KHz and 10 KHz	Averaged for the full range
3650 A/cm ²	-0.616	-0.512	-0.560
2528 A/cm ²	-0.625	-0.502	-0.570
2107 A/cm ²	-0.642	-0.492	-0.580
1806 A/cm ²	-0.670	-0.537	-0.620
1580 A/cm ²	-0.726	-0.599	-0.670
1327 A/cm ²	-0.769	-0.621	-0.740

Table 3. γ - Values derived from the figure for various frequency regions in 500\AA CdO film.

Current Density	Bellow 1 KHz Frequency	Between 1 KHz and 10 KHz	Averaged for the full range
2633 A/cm ²	-0.627	-0.573	-0.600
2107 A/cm ²	-0.642	-0.578	-0.610
1755 A/cm ²	-0.686	-0.614	-0.650
1505 A/cm ²	-0.721	-0.679	-0.700
1316 A/cm ²	-0.768	-0.726	-0.747
1276 A/cm ²	-0.792	-0.743	-0.767

Table 4. γ - Values derived from the figure for various frequency regions in 620 Å CdO film.

Current Density	Bellow 1 KHz Frequency	Between 1 KHz and 10 KHz	Averaged for the full range
2542 A/cm ²	-0.647	-0.594	-0.621
2206 A/cm ²	-0.662	-0.622	-0.642
1986 A/cm ²	-0.696	-0.616	-0.656
1705 A/cm ²	-0.744	-0.656	-0.700
1616 A/cm ²	-0.784	-0.752	-0.768
1421 A/cm ²	-0.798	-0.768	-0.783

Table5. γ - Values derived from the figure for various frequency regions in 750 Å CdO film.

Current Density	Bellow 1 KHz Frequency	Between 1 KHz and 10 KHz	Averaged for the full range
2174 A/cm ²	-0.712	-0.694	-0.703
1904 A/cm ²	-0.756	-0.720	-0.738
1523 A/cm ²	-0.789	-0.733	-0.761
1269 A/cm ²	-0.811	-0.741	-0.771
1088 A/cm ²	-0.826	-0.784	-0.805
952 A/cm ²	-0.853	-0.811	-0.832

Table 6. Average slopes of various 1/f graphs at the specific current density in CdO films.

S. No	Figure number	Description	Color of graph	Thickness	Average slope γ
1	Fig. 5.14	10 mA through CdO films of different thickness.	Magenta	300 Å	-0.605
			Cyan	380 Å	-0.668
			Red	500 Å	-0.744
			Green	620 Å	-0.827
			Blue	750 Å	-0.914
2	Fig. 5.15	15 mA through CdO films of different thickness.	Magenta	300 Å	-0.526
			Cyan	380 Å	-0.574
			Red	500 Å	-0.655
			Green	620 Å	-0.778
			Blue	750 Å	-0.873
3	Fig. 5.16	20 mA through CdO films of different thickness.	Magenta	300 Å	-0.500
			Cyan	380 Å	-0.560
			Red	500 Å	-0.600
			Green	620 Å	-0.742
			Blue	750 Å	-0.812

4. Results and conclusions

The results of present study on $1/f$ noise of CdO are very interesting.

1. The γ value appears to decrease with increase in thickness and seem to tend to 1 at higher thickness. The γ value also appears to settle down to -0.5 for lower thickness.

2. In similar manner $1/f$ plots of the five samples at constant currents of 10 mA, 20 mA and 30 mA. The $-\gamma$ values are evaluated and plotted, the behavior is almost similar to that presented in the case of current densities.

3. It is observed that, for a given film, the $-\gamma$ values decrease and appear to tend to minus one for diminishing currents or current densities.

4. It is noticed that for a constant current, decreasing the thickness of the film leads to an increase of the γ value in CdO films.

5. In these films the magnitude of noise is increasing while γ is decreasing with increasing current density.

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