Scan to know paper details and
author's profile

Electrical Conduction Mechanisms in Pure and Fe Doped Tio2 Thin Films Prepared by Sol-gel Method for Ics (integrated Circuits) Technology

Davinder Singh & K. K. Saini

ABSTRACT

Sol-gel dip coating was used to obtain undoped and Fe doped TiO_2 thin films deposited on ITO (Indium tin oxide) coated glass substrate. These films were sintered at 500 °C for 1 hour. The particle size decreases with an increase in Fe concentration. The electrical properties were analyzed by Electrometer in the voltage range -30V to +30V. We examined the various conduction mechanisms i.e. Schottky mechanism, Poole-Frenkel mechanism, ohmic and space charge limited current mechanism etc. The dominant conduction mechanism is space charge and Pool-Frenkel conduction mechanism. These conduction mechanisms depend upon the deposition parameters like sintering temperature, nature of substrate, the thickness of films, and amount of dopant.

Keywords: sol-gel, conduction mechanisms, sintering temperature.

Classification: FOR Code: 090699

Language: English

London
Journals Press

LJP Copyright ID: 925662
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural and Formal

Volume 19 | Issue 7 | Compilation 1.0

Electrical Conduction Mechanisms in Pure and Fe Doped Tio2 Thin Films Prepared by Sol-gel Method for Ics (integrated Circuits) Technology

Davinder Singh[α] & K. K. Saini[σ]

ABSTRACT

Sol-gel dip coating was used to obtain undoped and Fe doped TiO_2 thin films deposited on ITO (Indium tin oxide) coated glass substrate. These films were sintered at 500 °C for 1 hour. The particle size decreases with an increase in Fe concentration. The electrical properties were analyzed by Electrometer in the voltage range -30V to +30V. We examined the various conduction mechanisms i.e. Schottky mechanism, Poole-Frenkel mechanism, ohmic and space charge limited current mechanism etc. The dominant conduction mechanism is space charge and Pool-Frenkel conduction mechanism. These conduction mechanisms depend upon the deposition parameters like sintering temperature, nature of substrate, the thickness of films, and amount of dopant.

Keywords: sol-gel, conduction mechanisms, sintering temperature.

Author α: Department of Physics, Pt. JLN Govt. College Faridabad, Haryana, (India). 121002.

σ: Former Chief Scientist, National Physical Laboratory, New Delhi, (India), 110012. Corresponding author Davinder Singh, 35

I. INTRODUCTION

TiO_2 is a material which has a wide range of applications such as self-cleaning of glasses, dye- sensitized solar cells, miniaturization of IC's, degradation of hazardous materials in the environment. These applications depend upon the various properties of TiO_2 such as structural, photo catalytic, optical, electrical, and dielectric.

TiO_2 is electrically insulating with an extremely high resistivity above 10^8 ohm-cm but the sub oxidized TiO_2 with an excess of titanium is an n-type semiconductor with unique properties indicating the defect disorder and O/Ti stochiometry play an important role in the electrical properties of TiO_x [1].

In TiO_2 thin-films the conduction processes are mainly due to hopping i.e. impurity centers while contribution of intrinsic free carriers is negligible event at high temperature. To measure the conduction current through the dielectric film we prepare the MOS structure. Incorporation of metal dopant into TiO_2 changed its electrical conductivity from oxide nonconductor to oxide semiconductor with the desired p (for metal Co, Pd) and n (metal 5th, Pd) type electrical conduction due to the incorporation of metal components.

Yeo et all. Indicated the scaling limits of alternative gate dielectrics based on their direct tunneling characteristics and gate leakage requirements for future CMOS technology [2]. Various conduction mechanisms in TiO_2 thin films have been reported in literature includiong Poole-Frenkel [3-4], Fowler Nordheim [5] Ohmic conduction and space charge limited conductions. [6-10], Schottky Emission [11] Hopping conduction mechanism [12]. The studies of conduction mechanisms of Fe doped TiO_2 is limited. Recently the resistance switching behavior in dielectric films have been extensively studied.

In this work, we aim to examine the presence of various conduction mechanisms in pure as well as Fe doped TiO_2 thin films and to correlate with the processing parameters.

II. EXPERIMENTAL

2.1 Preparation of TiO_2 precursor solution

We started with 0.5M titanium butoxide solution in isopropyl alcohol. This solution was partially hydrolyzed by adding a calculated amount of water while using HNO_3 as catalyst for the hydrolization reaction as reported earlier [13]. The mixture was stirred vigorously with a magnetic stirrer till a clear and transparent sol was obtained. Calculated amount of iron acetyl acetonate compound, dissolved in isopropyl alcohol, was added in the TiO_2 solution to obtain iron doped TiO_2 nano-particles. Iron concentration was varied from 2 to 10-mol% in relation to TiO_2 to have different doping levels. All the chemicals used were of AR grade and were used as procured without further purification.

2.2 Preparation of pure TiO_2 and Fe / TiO_2 films

As top Al electrodes were vacuum evaporated on the film to provide electrical contact the bottom electrode being ITO. The thickness of ITO electrode is ~ 500 nm and that of Al electrode is ~ 300 nm. Al was chosen since it has a low work function of 4.2 eV and should provide an ohmic contact with the TiO_2; which has an electron affinity of around 4.0 eV. The value of 4.5 eV for the work function of ITO is larger than that of about an ohmic contact with TiO_2 is expected to surface defects at the metal surface.

Copper wires were connected by Ag on the top electrode of film and on the ITO bottom electrode for electrical measurements. The substrates were dipped in the precursor solution and allowed to settle for two minutes before pulling out at a constant speed to obtain films of 140-160 nm thicknesses. Thin film of TiO_2 that formed on the ITO coated glass substrates were dried in air at room temperature, followed by drying at 100°C for 30 min in an electric oven. The films thus formed were further annealed at 500 °C for 1 h in an electric programmable furnace. The temperature of the furnace was increased at a constant rate of 3°C per minute up to the desired value of 500°C. Iron-doped titania films were prepared from Fe doped precursor solution. Iron acetylacetonate [Fe (acac) $_2$] was used as basic material for doping TiO_2 precursor. Addition of iron acetylacetonate yields more homogeneous distribution of iron for each film [14]. The I-V characteristics were measured with the help of Keithley 617 programmable electrometer in the voltage range from -30V to 30 V. The ITO/TiO_2/Al heterostructure was prepared by depositing the TiO_2 on the commercial ITO coated glass substrate and Al top electrode was fabricated by the vacuum deposition technique.

III. RESULTS AND DISCUSSION

3.1 TEM Studies

TEM images of pure, 6 mol % and 10 mol % iron-doped TiO_2 films taken at accelerating voltage of 160 KeV, are shown in figure1. The inset in figures 1(a), 1(b) and (1c) shows the electron diffraction spectra of the samples. Polycrystalline growth has been identified in all the samples, the crystallites are randomly oriented and so lattice planes, on the substrate surface. TEM studies reveal the existence of both anatase and rutile phases of TiO_2 in the samples.

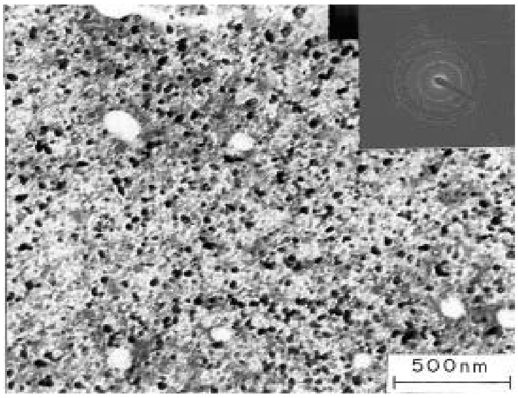

Fig.1: (a) TEM image of Pure TiO$_2$ film

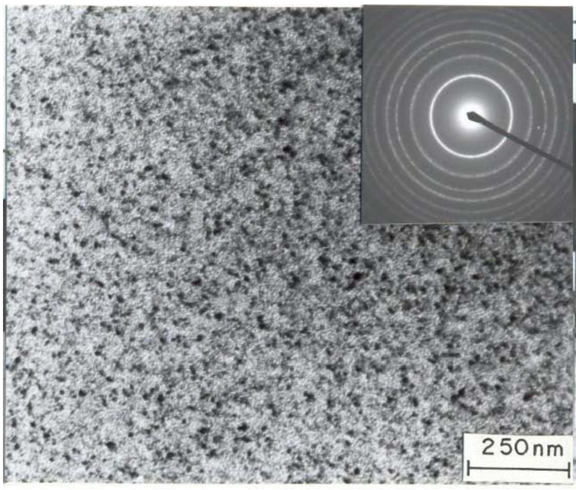

Fig. 1(b): TEM image of 6 Fe/TiO$_2$ Film

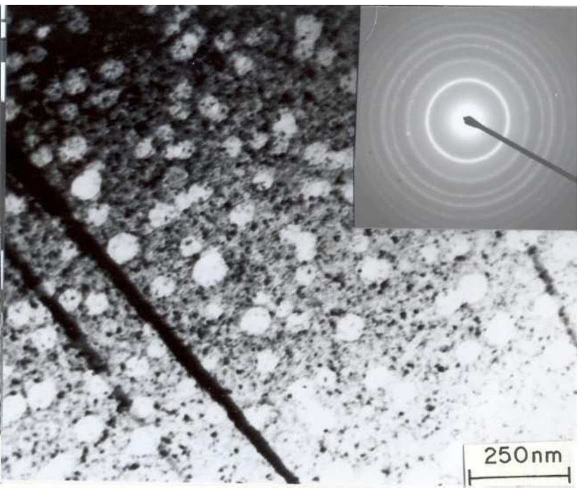

Fig.1 ©: TEM image of 10 Fe/TiO$_2$ Film

Particles are spherical in shape in pure and iron doped TiO$_2$ thin films. The pores of different diameters are present in all the samples. The average diameter of spherical particle is 35 nm in pure TiO$_2$ film, while its value is 20 nm and 17 nm for 6 mol % and 10 mol % iron doped TiO$_2$ films respectively. This indicates a decrease in particle size with increase in Fe doping concentration. The particle size decreased due to change in the surface charge and distance between the particles in the TiO$_2$ solution. Electron diffraction (ED) patterns have been used for phase identification as shown in insets of Fig. number 1(a), 1(b) and 1(c) respectively.

From XPS studies it has been observed that titanium exists in Ti^{+4} state in pure and iron doped TiO$_2$ thin films and in iron doped TiO$_2$ thin films iron exists in Fe^{+3} state as already reported [15].

3.2 Characteristics

There are two types of conduction mechanisms i.e. electrode limited conduction and bulk limited conduction. In electrode limited conduction mechanism the important parameters are effective mass of conduction carriers in the dielectric film while in case of bulk limited conduction mechanism barrier height, relaxation time, density of states, and density of interfacial states.

Schottky emission is a conduction mechanism that if the electrons can obtain enough energy provided by thermal activation of the electrons in the metal will overcome the energy barrier at the metal dielectric interface to go to the dielectric.

As we know well, the Nordheim Fowler (FN) mechanism is associated with tunneling effect of hot carrier, The Schottky (SK) mechanism is associated with the thermionic emission across the metal insulator interface, and the Poole-Frenkel (FP) mechanism is due to the field enhanced thermal excitation of trapped electrons into the conduction band.

Fig. 2 shows the I-V curve of the MOS arrangement (Al/TiO_2/ITO) hetrostructure at room temperature in the voltage range from -30 V to 30 V. I-V curves are ohmic in low field region and non-ohmic in higher field regions for all the samples. It is clear from the graph shown in figs. 2(a) and 2(b) that more than 2 mol % iron doped samples the resistance changes from LRS (Low resistance state) to HRS (high resistance state). In the ohmic region the I-V characteristics should be of the form

$$I = (Aq\mu_p PV)/d$$

Where A is the electrode area, q is the electronic charge, P is the hole current, d is the sample thickness μ_p is the hole mobility.

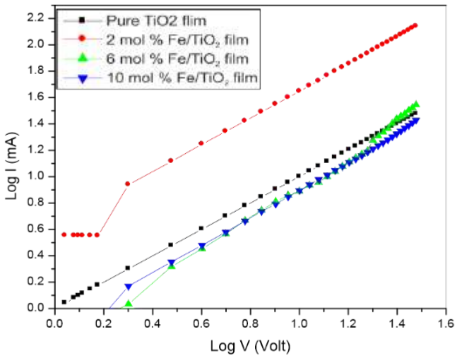

Fig.2: (a) I-V curve

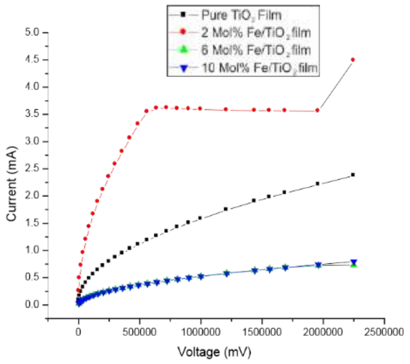

Fig.2. (b): Log I Vs. Log V

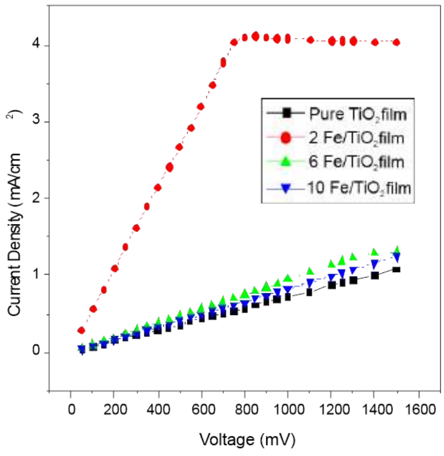

Fig 2(c): J Vs. V

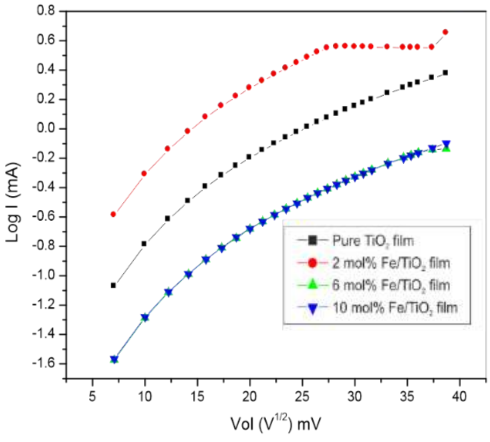

Fig.2: (d) Log I Vs. Log $(V)^{1/2}$

A typical room temperature J-V plots of pure and iron-doped TiO_2 thin films is shown in fig no 2 (c). The plots of 2, 6 and 10-mol % Fe doped TiO_2 films have single region which is non- ohmic. The 2 mol % Fe doped TiO_2 film has two regions. Normally for space charge limited conduction, the slope in the non-ohmic region should equal to or greater than two. The value of slope is greater than 2 for pure TiO_2 film while the value of slopes for Fe doped TiO_2 films is less than 2 which indicates the absence of space charge conduction mechanism in Fe doped TiO_2 films.

The values of slopes are smaller than those of required for space charge limited conduction. Iron acts as an acceptor impurity the dopant elements like Ca and Mg incorporated in TiO_2 matrix act as an electron acceptor and decreases the electrical conductivity [16-17]. The consequence of space charge limited conduction is given by Child's law $I=kV_2$, Where k is constant and is taken equal to one. I and V are the current and voltage respectively.

We examined the presence of formation of Schottky barrier. A Schootky barrier is possible with an n-type semiconductor, if the work function of the metal φ_m is greater than the work function of semiconductor φ_{sc} while it is reverse for a p-type semiconductor ($\varphi_{sc} > \varphi_m$). The work function of TiO_2 is 7.3 eV and the band gap is 3.2 eV. If one treats TiO_2 as wide band gap semiconductor, then depending on the nature of TiO_2 (viz. p-type or n-type), Schottky barrier may or may not be formed. Pure TiO_2 is reported to exhibit n-type conductivity the work function of Al metal electrode is 4.3 eV, which is lower than that of the work function of TiO_2; therefore there is no possibility of Schottky mechanism (electrode limited conduction) in these samples.

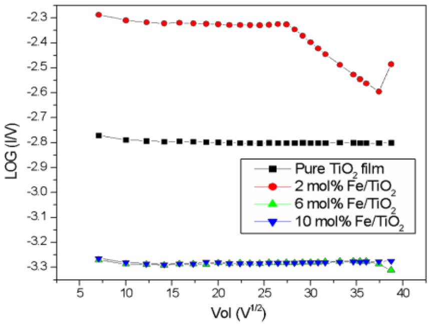

Fig.2. (e) Log I/V Vs $V^{1/2}$

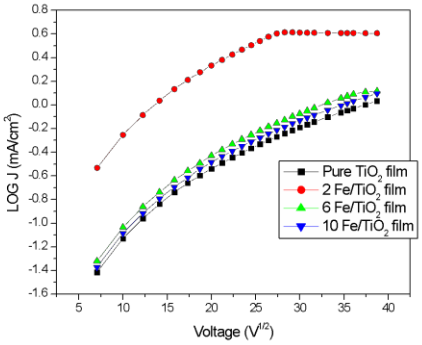

Fig.2. (f): Log J Vs $(V)^{1/2}$

A plot of log I/V Vs $V_{1/2}$ and log J Vs $V^{1/2}$ yielded approximately straight lines as shown in figs 2(e) and 2(f). These confirm that the conduction mechanism is due to Poole-Frenkel. Highest value of leakage current density is in the case of 2 mol % iron doped TiO_2 films. The presence of Pool-Frenkel conduction mechanism is due to the high density of traps due to this it generally occurs in thin film materials having high value of dielectric constant. In Pool Frenkel effect electrons are trapped in the localized states and due to random thermal fluctuations they will get enough energy to get out of localized state and move to the conduction band. PF emission is dependent on the concentration of trap centers (N_t) and donor centres (N_d). (1) When Nt< Nd then conduction mechanism is normal Pool- Frenkel emission, (2) When $N_t=N_d$ then PF mechanism is called the modified PF conduction mechanism or anomalous PF effect. In such a case the slope of PF the slope is of plot is reduced by half and equal to the slope of Schottky plot. The effect of different electrode materials on the conduction characteristics is a valuable means.

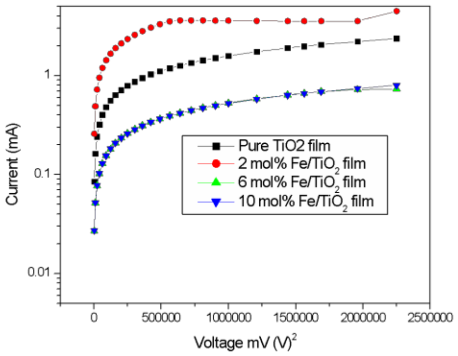

Fig. 2: (g) I Vs. $(V)^2$

The authors have suggested that this nonlinearity originates from a transition from field emission to thermionic emission as the applied field decreases [18]. The roughness of the films can be a factor to influence the electron transport in the junction interface of the MOSFET. With metal ion doping surface roughness of the films increases as already reported [19].

There is asymmetry of the electrical properties when the top and bottom electrodes are made of different metals. Different metals lead to different work functions and therefore results in different metal-dielectric interface. Since different types of conduction mechanisms can give rise to non linear characteristics, one can first explain observed non linearity in terms of Richardson.

Schottky or Pool-Fenkel type of conduction mechanisms. Schottky emission occurs due to thermal activation of electron over the metal oxide interface barrier because of lowering of barrier height due to the applied field. The Poole-Frenkel effect is similar to the Schottky effect except that it is applied to the thermal transfer of electrons from traps into the conduction band of the insulator. In both the cases Log I Vs. $V^{1/2}$characteristics are expected to be linear in nature as shown in fig. 2 (g).

In thin-films, transport mechanisms of charge carriers is strongly influenced by particle size and which depends on the deposition parameters [20]. In order to obtain larger grains with a small number of grain boundaries, then the effect will be the decrease of carrier scattering and finally on increase in electrical conductivity.

IV. CONCLUSION

Pure and Fe doped TiO_2 thin-films were prepared by sol-gel dip-coating method. The study of conduction mechanism through dielectric films is of great importance to the success of integrated circuits and development of switching devices and is more advantageous in comparison to conventional materials such as SiO_2. The dominant conduction mechanisms are Space charge limited conduction in pure TiO_2 and Pool-Frenkel conduction mechanism in pure and Fe doped TiO_2 films. These conduction mechanisms are strongly dependent on the processing parameters and in general conduction mechanisms in dielectric films may be influenced by the following factors i.e. temperature, electric field, device structure, film thickness and deposition method,

ACKNOWLEDGMENT

We are thankful to Director NPL, New Delhi (India) for providing Research facilities.

REFERENCES

1. Young Feng, Mahua Wang Yunlong Wang, Shihu Wang and Cheng Fang Fu, Advances in Condensed Matter Physics, 2013.
2. Y. C. Yeo, J. J. King, C. Hu, Applied Physics Letters, Vol 81, (2002), 2091.
3. W. Yang, J. Marino, A. Monson, C.A. Wolden, Semiconductor Science technology, 21,(2006), 1573.
4. M. K. Lee, J. J. Huang, T. S. Wu, Semiconductor Science Technology, 20, (2005), 519, M. C. Sekhar, P. Kondaiah, G. M. Rao, S. V. J. Chandra, S. Uthaana, Superlattices micros- tructure, 62, (2013), 68.
5. Aksoy, Y. Cagliari, Journal of alloys Compounds, 613, (2014), 330,
6. A Bengi, U. Aydemir, S. Altindal, Y. Ozen, S. Ozilek, Journal of alloys compounds, 505, (2010), 1395.
7. D. Mardare, G. I Rusu, Journal of Non-Crystalline Solids, 356, (2010), 1395.
8. S. Keeem, H. Y. Jeong, S. Y. Choi, Applied Physics Letters, 97, (2010), 033508, 9. L. E. Yu, S. Kim, M. K. Ryu, S. Y. Choi, IEEE 29 (2008), 331.
10. M. C. Sekhar, P. Kondaiah, G. M. Rao, S. V. J. Chandra, S. Uthaana, Superlattices micros- tructure, 62, (2013), 68.
11. H. Wobkenberg, T. IshwaraJ. Nelson, D.D.C. Bradley, S. A. Haque, T. D.
12. Anthapolous, Applied Physics Letters, 96, (2010), 082116.
13. S. D. Sharma, Davinder Singh, K. K. Saini, C. Kant, V. Sharma, S. C. Jain,
14. C.P.Sharma; Applied Catalysis A, 314 (2006), 40.
15. J. A. Navio, Gerardo Colon, M. Macias, M. I. Litter; Applied Catalysis A; General, **177**, (1999), 111.
16. Davinder Singh, Alka Goyal, Neenu Saini, International Journal of Scientific Research in Physics and Applied sciences, Vol 7, (2019), 35-41.
17. A.R. Bally, E. N. Korobeini Kova, P. E. Schmid, F. Levy, F. Bussy, Journal of Physics D: Applied Physics, Vol 31.
18. Mantas Scriubas, Kristina Bockute, Darious Virbukas, Giedrius Laukaitis, Procedia Engineering 98, (2014), 133-138.
19. E. L. Murphy and R. H. Jr. Good, Phys. Rev. 102, (1956), 1464-1473.
20. Marshal Dhayal, S.D. Sharma, Chander Kant, K.K. Saini, S.C. Jain; Journal of Surface Science, 602, (2008), 1149.
21. l. Maisel, R. Glang (Eds.) Handbook of thin film technology, Mc Graw-Hill, New York, 1970.

London Journal Press Membership

For Authors, subscribers, Boards and organizations

London Journals Press membership is an elite community of scholars, researchers, scientists, professionals and institutions associated with all the major disciplines.
London Journals Press memberships are for individuals, research institutions, and universities. Authors, subscribers, Editorial Board members, Advisory Board members, and organizations are all part of member network.

Read more and apply for membership here:
https://journalspress.com/journals/membership

For Authors

For Institutions

For Subscribers

Author Membership provide access to scientific innovation, next generation tools, access to conferences/seminars /symposiums/webinars, networking opportunities, and privileged benefits.
Authors may submit research manuscript or paper without being an existing member of LJP. Once a non-member author submits a research paper he/she becomes a part of "Provisional Author Membership".

Society flourish when two institutions come together." Organizations, research institutes, and universities can join LJP Subscription membership or privileged "Fellow Membership" membership facilitating researchers to publish their work with us, become peer reviewers and join us on Advisory Board.

Subscribe to distinguished STM (scientific, technical, and medical) publisher. Subscription membership is available for individuals universities and institutions (print & online). Subscribers can access journals from our libraries, published in different formats like Printed Hardcopy, Interactive PDFs, EPUBs, eBooks, indexable documents and the author managed dynamic live web page articles, LaTeX, PDFs etc.