Chapter 8
Conclusions and Scope for Future Work

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8.1. Conclusion

The aim of the present work was to investigate the influence of the MnO, Nb_2O_5, and ZrO_2 (with Cr_2O_3) doping on the structure and the electrical response of ZnO–V_2O_5 based varistors ceramics were using XRD, SEM with EDS, I-V characterisation and AC impedance spectroscopy.

The following conclusion has been drawn from this investigation.

- All the samples of MnO, Nb_2O_5 and ZrO_2 (along with Cr_2O_3) doped ZnO-V_2O_5 varistor ceramics were successfully prepared via solid state reaction at sintering temperature 850 °C, 900 °C & 950 °C.
  - The microstructure of the Nb_2O_5 doped ZnO–V_2O_5 varistors consisted of ZnO grain as the primary phase and $Zn_3(VO_4)_2$ as the minor secondary phases, which acts as liquid-phase sintering promoter and has a significant effect on the sintered density. The average grain size of the ZnO–V_2O_5 system sintered at 850 to 950°C was found to be in range of 3.8 to 16.6 µm, which depend upon the amount of Nb_2O_5 doping. The 0.10 mol% Nb doped ZnO–V_2O_5 sample sintered at 900°C exhibited the most optimum grain size of 7.0µm.
  - EDS spectra of ZnO grain boundary show V and Nb segregation in the samples. Among all of the samples, the 0.50 mol% Nb_2O_5 doped ZnO–V_2O_5 sample sintered at 900°C was found to have the highest values of total resistance.
  - The 0.10 mol% Nb_2O_5 doped ZnO–V_2O_5 system sintered at 900°C exhibited the highest nonlinear coefficient of 7.1, the highest breakdown field value of 281.5 V/mm, the lowest leakage current density of J_L = 310.577 µA/cm^2, the έ (1kHz) = 719 and the lowest tan δ (1kHz) = 0.079 among all of the samples.

- Ea values below 150°C for 0.10 mol% Nb-doped samples sintered at 900°C were found to be 0.485 and 0.445 eV for the R_1 (high frequency) and R_2 (low frequency) grain boundary regions, respectively.
- Conclusively, among all of the Nb_2O_5 doped $ZnO–V_2O_5$ samples, it was found that the 0.10 mol% Nb_2O_5 doped 99.40 mol% ZnO – 0.50 mol% V_2O_5 samples sintered at 900°C is a candidate material for use in chip varistors.

- All the samples of MnO doped $ZnO–V_2O_5–Nb_2O_5$ varistor ceramics were successfully prepared via solid state reaction at sintering temperature 850 °C, 900 °C & 950 °C.
  - The microstructure of the MnO doped $ZnO–V_2O_5–Nb_2O_5$ varistors consisted of ZnO grain as the primary phase, ZnV_2O_4 and $Zn_3(VO_4)_2$ as the major secondary phases, in which $Zn_3(VO_4)_2$ acts as liquid-phase sintering promoter and has a significant effect on the sintered density.
  - The average grain size of the MnO doped $ZnO–V_2O_5–Nb_2O_5$ system sintered from 850 to 950°C was found to be in range of 5.2 to 18.5 μm, which increases or decreases upon the amount of MnO addition. The MnO doped $ZnO–V_2O_5$- Nb_2O_5 sample sintered at 900°C exhibited the most optimum grain size of 8.4 μm.
  - EDS spectra of ZnO grain boundary show V, Nb and Mn segregation in the samples.
  - The 2.50 mol% MnO doped $ZnO–V_2O_5–Nb_2O_5$ system sintered at 900°C exhibited the highest nonlinear coefficient of 28.1, the highest breakdown field value of 572.6 V/mm, the lowest leakage current density of J_L = 51.204 μA/cm^2, the ε' (1KHz) = 312.1 and the tan δ(1KHz) = 0.152 among all of the samples.
  - Among all of the samples, the 0.00 mol% MnO doped $ZnO–V_2O_5–Nb_2O_5$ sample sintered at 850 °C was found to have the highest values of total resistance of 370 MΩ.
  - Ea values below 200 °C for 2.50 mol% MnO doped $ZnO–V_2O_5–Nb_2O_5$ samples sintered at 900 °C were found to be 0.614 and 0.680 eV for the

R_1 (high frequency) and R_2 (low frequency) grain boundary regions, respectively.

- Conclusively, among all of the MnO doped $ZnO–V_2O_5–Nb_2O_5$ samples, it was found that the 2.50 mol% MnO doped 96.90 mol% ZnO – 0.50 mol% V_2O_5 – 0.10 mol% Nb_2O_5 samples sintered at 900 °C is a candidate material for use in chip varistors.

❖ All the samples of ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ varistor ceramics were successfully prepared via solid state reaction at sintering temperature 850 °C, 900 °C & 950 °C.

- The microstructure of the ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ varistors consisted of ZnO grain as the primary phase, $ZnCr_2O_4$ and $Zn_3(VO_4)_2$ as the major secondary phases, in which $Zn_3(VO_4)_2$ acts as liquid-phase sintering promoter and has a significant effect on the sintered density.
- The average grain size of the ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ system sintered from 850 to 950°C was found to be in range of 1.0 to 4.5 μm, which depend upon the amount of ZrO_2 addition.
- Addition of ZrO_2 along with Cr_2O_3 to the binary $ZnO–V_2O_5$- system controlled the abnormal ZnO grain growth and produced a more uniform microstructure. The ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ sample sintered at 900°C exhibited the most optimum grain size.
- EDS spectra of ZnO grain boundary show V, Cr and Zr segregation in the samples.
- Among all of ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ samples, the 1.00 mol% ZrO_2-doped sample sintered at 900 °C was found to have the highest values of total resistance of 120 MΩ.
- The 1.00 mol% ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ sample sintered at 900 °C exhibited the highest nonlinear coefficient of 19.5, the highest breakdown field value of 662.2 V/mm, the lowest leakage current density of J_L = 120.1 μA/cm^2, the ε' (1KHz) = 218 and the tan δ(1KHz) = 0.293 among all of the samples.

- Ea values for 1.00 mol% ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ samples sintered at 900 °C were found to be 0.758 and 0.732 eV for the R_1 (high frequency) and R_2 (low frequency) grain boundary regions, respectively.
- Conclusively, among all of the ZrO_2 doped $ZnO–V_2O_5–Cr_2O_3$ samples, it was found that the 1.00 mol% ZrO_2 doped 95.50 mol% ZnO – 0.50 mol% V_2O_5 – 3.00 mol% Cr_2O_3 samples sintered at 900 °C is a potential material for use in chip varistors.

Conclusively, among all of the samples, it was found that the 2.50 mol% MnO doped 96.90 mol% ZnO – 0.50 mol% V_2O_5 – 0.10 mol% Nb_2O_5 samples sintered at 900°C is a candidate material for use in chip varistors.

8.2. Scope for the Future Work

On the basis of above investigations there is an ample amount of scope for further research work for the development of $ZnO–V_2O_5$ varistor ceramics

- Synthesis of few more specimens can be done using different dopants such as Antimony Trioxide and some rare earth oxide etc.
- Lightening testing of the same specimens can be carried out by applying artificial lightening surges.
- HR-TEM equipped with EELS and STEM analysis of these samples will be useful to know the exact composition and morphology of the secondary phases present at the grain boundary and triple points.