10.1 Introduction

As mentioned in the preface, the main purpose of the present work has been to carry out a systematic study to obtain single crystals of copper tungstate. From a wide variety of techniques to grow single crystals, flux method was taken recourse to, essentially because it would avoid detrimental consequences of high temperatures on the properties and utility of the products. In order to
understand fully the potentiality of CuWO$_4$ single crystals, attention was concentrated in studying their important properties such as dielectric, electrochemical, optical, etc. The systematic studies thus carried out have been described and discussed in the preceding chapters. Finally, in the present chapter the author intends to arrive at certain general conclusions drawn from the studies carried out and a scope for future work.

10.2 Conclusions from the flux growth of CuWO$_4$

Indirect flux reaction technique is found to be quite versatile (chapter 2) for growing large and more perfect crystals of CuWO$_4$. Crystal morphology, size and quality are found to be sensitive to environmental variables such as temperature, cooling rate, soak period, etc. After optimizing appropriate growth parameters, one can obtain the desired morphology and quality of the grown crystals. The microstructures of the habit faces bear good correlation with growth conditions and so one can derive the latter from study of the former. The commonly observed dendrites on the as-grown faces have been the result of rapid growth through faster cooling.

The crystallization kinetics data lead one to
conclude that both diffusion and surface reaction processes are involved in controlling the rate of growth. In the present case, the growth of the longer side (b-axis) of the axinite type crystal is diffusion rate controlled up to an extent of more than 62% in the temperature range of 800 to 850°C. One is inclined to believe that the final crystal size and the number are much dependent on the temperature of crystallization.

10.3 Conclusions from the characteristic properties

With a view to understanding the defect chemistry of the crystalline solids, their electrical conduction has been studied. The migration of defects in the oxide sublattice probably contributes to the conductivity in the intrinsic region, while the extrinsic conduction has been attributed to the occlusion of impurities in the growing matrix.

From the nature of variations of the dielectric constant of CuWO₄ with frequency and temperature we have been able to deduce the effective polarizations involved. The large value of dielectric constant at low frequency coupled with the observed low loss factor indirectly shows the low concentration of impurities and defects in
the crystal. This shows the merit of the growth technique to yield good crystals.

Chapter 7 has been devoted to the optical characterization of CuWO$_4$ single crystals. The crystals exhibit both indirect and direct band-to-band transitions, and the phonon involved in the indirect band-to-band transitions are predominantly the internal vibrations of the sublattice constituted by the tungstate (WO$_4$) ions.

The electrochemical characterization described in chapter 8 reveals the materials under examination to be n-type semiconductors. It is successfully demonstrated that a photoelectrochemical solar cell can be fabricated using n-type CuWO$_4$ single crystals. The use of CuWO$_4$ single crystals as anode works successfully well for the photoelectrolysis of water.

10.4 Scope for future work

A great deal of work on a number of aspects still remains and deserves further investigation to add certainly something to the existing knowledge of the most fascinating branch of material science, namely crystal
growth and characterization.

The studies carried out in better growth conditions i.e. very low cooling rates, using properly programmed temperature controllers, are expected to give better quality and also larger size of the crystals. A lot of work on the growth, by doping with rare-earths, including mixed matrices with other compounds of the same family can be carried out. The consequent changes in the properties would open challenging fields for further research work.

We expect that the conversion efficiency which is low at present, can be much improved upon to some extent, since there is much room to raise the quality of CuWO₄ electrode. The work can thus be extended to the fabrication of more efficient photoelectrochemical solar cells using rare-earth doped materials.