6.1 Summary of Results

Intense research is currently being pursued in the field of material preparation, characterization and its linear, nonlinear optical properties of nanoparticles by various laboratories, motivated by the fundamental question of how the material properties evolve with size. My doctoral dissertation is an attempt to prepare few new nano materials with cost effective techniques and study its confinement effect through linear and nonlinear optical absorption spectral studies and our goal is to achieve better optical limiters (materials that would act as linear absorption media at low intensities/fluences and limit to a threshold at higher intensities/fluences).

To summarize, we have studied three different classes of nano materials. My doctoral dissertation is focused on the investigation of nonlinear optical materials like oxides (Bi$_{12}$SiO$_{20}$ and Cu$_2$O) and CdS nanomorphologies.

In Chapter 3, we explored the preparation of Bi$_{12}$SiO$_{20}$ nanoparticles in gram scale quantities by using simple chemical solution decomposition (CSD) method. The value of $\beta$ for BSO nanocrystals was found to be four orders of magnitude higher for 6 ns excitation and two orders of magnitude higher for 30 ps excitation when compared to the bulk single crystal data. In addition to the nonlinear absorption (NLA), we observed nonlinear scattering (NLS). We are combining two mechanisms like NLA and NLS making it an attractive candidate for nonlinear optical device applications and enhance its optical limiting performance.

In Chapter 4, we explored the synthesis of Cu$_2$O with different morphologies by changing concentration of NaOH in simple chemical coprecipitation method. Size and shape dependent nonlinear optical absorption
properties at nano and pico second regime at 532nm studied in this chapter. We also observed a strong dependence of the effective nonlinear absorption coefficient with change in the particle size. Effective nonlinear absorption coefficient ($\beta_{\text{eff}}$) values in the case nano-clusters are higher compared to the micro-particles. To the best of our knowledge, this is the first observation of SA and RSA behavior in the case of Cu$_2$O at 532 nm laser excitation.

In Chapter 5, we explored the synthesis of CdS nanomaterials by simple chemical coprecipitation technique and heat treatment allowed us to change the size of the particle and also transform the phase from cubic to hexagonal. We observed enhanced two photon excited luminescence (anti-Stokes luminescence) in case of 600 ºC heat treated CdS powder samples due to complete transformation of hexagonal phase.

6.2 Future Prospects
There are several interesting directions for future work in the areas of the research presented in this thesis. One can manipulate properties by changing particles size or doping with transition metal ions in semiconductor nanocrystals. Fe doped BSO single crystals shows enhanced limiting performance compare to their pure BSO single crystals. But there is a contradiction about occupation site of Fe in BSO. It may occupy either Bi site or Si site.

Doping Fe in BSO nano crystals is a challenging task and identification its occupation site it is rather difficult. It is also possible to enhance nonlinear optical properties by doping in BSO nanocrystals. One can dope transition metal ions like Fe in Cu$_2$O and with different (lower or higher) amounts one can tune its linear and nonlinear optical properties. With lower doping Fe will go into the lattice site of Cu$_2$O and at higher dopings it sits on the surface of Cu$_2$O. One can also tune linear and nonlinear optical properties of Cu$_2$O by Ag doping.
Summary and future perspective

One can tune or enhance upconversion or anti-Stoke luminescence of CdS by doping with transition metal ion or doping with rare earth ions. This type of materials may be useful in enhancing the solar cell efficiency. Novel devices have emerged based on near-infrared to visible upconversion materials and they include lasers, infrared quantum counters, photo detectors, temperature sensors, biological labeling, solid-state color displays and security coding data storage.

We believe that the novel developments in the field of nanomaterials presented in this thesis and the extension of these ideas into further avenues will show a way for further exciting research in near future.
Research publications:

(Thesis related publications)

1. **H. Sekhar** and D. Narayana Rao “Stokes and anti-Stokes luminescence in heat treated CdS nanopowders” *(Accepted, J. Physical Chemistry C)*


Not included in the thesis


2. **H. Sekhar** and D. Narayana Rao “Preparation, structural and linear optical properties of Zinc Sillenite (Bi$_{12.66}$Zn$_{0.33}$O$_{19.33}$) Nanocrystals” (Accepted *Journal of Materials Science: Materials in Electronics*)

luminescence in heat treated rare earth doped CdMnS nano powders” 
(Accepted, J. Alloys and Compounds)

4. **H. Sekhar** and D. Narayana Rao, “Preparation and characterization of heat treated Zn doped CdS powders and it’s Up and down conversion luminescence” (Minor Revision, Science of Advanced Materials)

5. **H. Sekhar** and D. Narayana Rao, “Tuning linear optical properties by Fe doping in cuprous oxide” (Manuscript under preparation)

6. **H. Sekhar** and D. Narayana Rao, “Tuning linear optical properties by Ag doping in cuprous oxide” (Manuscript under preparation)

(Co-authored publications not included in the dissertation)


National and International Conferences


2. P. Harshavardhan Reddy, H. Sekhar and D. Narayana Rao “Picosecond nonlinear optical properties of cuprous oxide with different nano-morphologies” NLS-2013 (*Poster Presentation*, Accepted)


4. H. Sekhar and D. Narayana Rao, “Preparation, structural and linear optical properties of Zn doped CdS nanopowders” (ICMST-2012) (at St. Thomas College, Pala) (*Oral*)


