Chapter 6

Conclusions and Future Aspects

General conclusions and future aspects of the work entitled in the thesis becomes the main subject of this chapter
The five chapters presented in the thesis describe the synthesis of nanofluid and the utility of thermal lens (TL) effect in the characterization of pure nanofluids and dye-doped nanofluids.

One of the main contributions in the thesis is about the interactions between plasmons and dye molecules. TL technique has been successfully employed to study the resonant energy transfer (RET) process in nanoparticle–dye mixture. The donor-acceptor pair in the RET process is the xanthene dye, Rh 6G, and the Ag NP respectively. The dye–NP distance is evaluated by varying the concentrations of Ag NPs and it is found to decrease with an increase in the NP concentration in the mixture. The Ag nanoparticle acts as a fluorescence quencher in NP–dye mixture and the quenching of fluorescence follows the Stern–Volmer relation. The distance dependent energy transfer efficiency showed that dye–NP mixture follows the $R^{-3}$ dependence, where $R$ is the dye–NP distance. The $R^{-4}$ dependence of the energy transfer efficiency indicates that Nanomaterial Surface Energy Transfer (NSET) is more appropriate to explain the energy transfer between Rh 6G and Ag nanoparticle. Additionally the complementary nature of both steady state fluorescence spectroscopy and TL spectroscopy are also shown by comparing the energy transfer efficiencies calculated using both techniques.

Another important topic covered is the study of TL and fluorescence measurement of Ag nanofluid alone and then evaluate the quantum yield of laser dye - Rh 6G in the presence of Ag nanofluid. Rh 6G is preferred since it readily adsorbs to silver and is detectable at nanomolar concentrations and below. Moreover Rh 6G is a common laser dye used for testing SERS (Surface Enhanced Raman Spectroscopy) activity on colloidal silver. Also the absolute values of fluorescence quantum yield (FQY) of laser dyes are
necessary for the calculation of thresholds of laser action and hence studied the effect of nanoparticles on the FQY of Rh 6G. The fluorescence quantum efficiency of fluorophore can be tuned by varying the size of NPs. Analysis of the results clearly indicates that the particle size and the spectral overlap between the emission spectra of Rhodamine 6G and absorption spectra of the silver nanoparticles determine the quantum yield value of dye-nanoparticle mixture. The enhancement of absorbance and spectral width of the absorption spectrum of the nanoparticle and consequently more efficient spectral overlap enables more efficient nonradiative energy transfer between the nanoparticle and dye molecule which reflected in corresponding thermal lens as well as static fluorescence signal. FQY of Rh 6G has also been tuned by varying the concentration of NPs.

By varying the parameters such as concentration and size of Ag NP, the thermal characterization (thermal diffusivity) of heat transfer fluid (water) in presence of nanoparticles has been done. Thermal diffusivity of organic solvents in the presence and absence of NPs are also analyzed. Effect of laser dye (Rh 6G) on the thermal diffusivity of silver nanofluid is also explained.

**Future Scope**

We have used chemically synthesized silver nanofluids by reduction method for the characterizations described in the previous chapters. But it is better, in future, to use biologically synthesized nanofluids. Recent reports suggest that biologically synthesized nanoparticles exercise numerous advantages over the chemically synthesized ones. The nanoparticles synthesized from microbes are exceptionally stable and the stability is likely to be due to capping with proteins secreted by the microbe. Using metal-accumulating
microorganisms as a tool for the production of nanoparticles and their assembly for the construction of new advanced materials is a completely new technological approach. The concentration of silver nitrate does have a role in size dependent synthesis of the particles. It is speculated that particle size and shape are dependent on various conditions, such as the culture supernatant, nanoparticle type and reaction temperature and reaction mixture composition. This is because silver nitrate forms a coat on growing particles, thereby preventing their aggregation and thus, yielding particles of nanoscale size. This shows that silver ions, by their dispersive action, have a role in controlling the growth of AgNPs. The increase in size of the particles does increase the toxicity of the particles. The synthesis and assembly of nanoparticles would benefit from the development of clean, nontoxic and environmentally acceptable “green chemistry” procedures, probably involving organisms ranging from bacteria to fungi and even plants.

Ag NPs have found practical applications in health and daily life such as better drug delivery methods, chemical deposition for environmental pollution cleanup, medical imaging as well as military purposes. Ag NPs play important role in enhancing the Raman scattering and thus to provide important contribution towards sensing and bio-medical applications.

Resonant energy transfer systems consisting of organic dye molecules and noble metal nanoparticles will have great importance in biophotonics as well as in material science. Future work in energy transfer will explore the new possibilities available to study protein interactions. The energy transfer study in dye-nanoparticle system opens up possibilities for future studies on novel nanocomposite systems, particularly in biological applications. Significantly extending the range of optical based methods in molecular rulers is an important leap for biophysicists. Optical-based
distance measurements are essential for tracking biomolecular conformational changes, drug delivery and cell biology. The power of optical based molecular rulers is the ability to measure subtle changes in structure following an event, particularly in biological systems. For instance, measuring larger distances is desirable for diverse applications including nucleo-protein assemblies involving DNA duplexes where large-scale conformational changes are seen. So the NSET approach described in the present case of AgNP-Rh 6G system provides a basis for achieving the distances to deconvolute such a complex and important interactions mentioned above. The observation of energy transfer between a dipole and a metal nanosurface provides a new paradigm for design of optical based molecular ruler strategies at distances more than double the distances achievable using traditional dipole-dipole Coulombic energy transfer based FRET methods.

Manipulation of the characteristics of laser dyes using metal nanoparticles is one of the rapidly growing areas in nanotechnology due to their promising applications in diverse fields, ranging from biomedical imaging to green energy. The quantum yield study by incorporating nanoparticles in laser dyes helps in improving laser performance and in future it has great impact in many optical applications. Also the nanoparticle size dependent quantum yield of the dye molecule can be exploited to develop future biological sensors. The decrease in quantum yield of Rh 6G is expected to have a very important consequence in enhancing Raman scattering which is an important spectrochemical tool that provides information on molecular structures.

Development of efficient heat transfer fluids with higher thermal diffusivity is warranted to raise the effectiveness of heat transfer process and to
reduce the cost and size of concerned components and machines. Thermal characterization of silver nanofluid (high thermal diffusivity value greater than water) described in the present thesis reveals the relevance of nanofluid in many heat transfer applications. This study has also great importance since thermal properties of nanofluids are especially interesting due to their variety of applications that range from photothermal therapy and radiofrequency hyperthermia to next-generation thermo-fluids. Also the colloidal suspensions formed with nanoparticles and organic solvents can be used as antibacterial medical treatments in photo-thermal therapy and in cooling systems among others. Effect of Rh 6G on the thermal diffusivity of silver nanofluid has much importance since this study will be useful in designing heat transfer nanofluids which will particularly find applications in random lasing.