Chapter 6

Overall conclusion and future prospects

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6.1 Conclusions

- γ-Fe_2O_3 nanoflowers via microwave-assisted polyol process and $MnFe_2O_4$ nanoflowers as well as Fe_3O_4 mesoporous nanoparticles utilizing solvothermal reaction have been successful synthesised in the current work.

- The formation of single phases in the above-mentioned nanostructures were confirmed from X-ray as well as electron diffraction patterns. Further, lattice parameter and crystallite size of the samples were determined from the XRD patterns.

- Nonetheless, the Mössbauer spectroscopy helped in determining the ionic state of Fe-ions in respective samples which assisted the X-ray and electron diffraction patterns analysis.

- Varying the concentration of NaOAc during synthesis allowed to tune the size and crystallinity of γ-Fe_2O_3 nanoflowers, while solvent played an important role in the synthesis of Fe_3O_4 mesoporous nanoparticles. The TEM helped in realizing the nanoflower morphology of γ-Fe_2O_3 and $MnFe_2O_4$, and mesoporous structure of Fe_3O_4 nanoparticles.

- All the samples showed good magnetic properties (close to bulk magnetic values) and soft ferrimagnetic nature at room temperature (RT). The FC curve indicated the presence of dipolar interactions in all the samples and was effective right from RT to lowest measuring temperature in Fe_3O_4 mesoporous nanoparticles, which readily formed one-dimensional chain like arrangements.

- The Zeta potential measurements indicated the formation of stable ferrofluids for these samples which is essential for biomedical applications, i.e., MFH and PTT.
- Amongst all, the γ-Fe_2O_3 nanoflowers (sample S17) demonstrated the best heating performance during MFH and a high ILP value of 15.21 ±0.34 nHm^2kg^{-1} was noticed for this sample. This value is almost 3 times higher than the previous reported values for Fe_3O_4 nanoflowers. While the ILP values obtained for $MnFe_2O_4$ nanoflowers and Fe_3O_4 mesoporous nanoparticles are in line with previous reported values.
- Excitingly, all magnetic samples demonstrated outstanding heating performance when irradiated with a NIR-laser for PTT. The therapeutic temperature was achievable even at a concentration of as low as 0.1 mg/mL for samples with NIR laser (808 nm) of 0.66 Wcm^{-2} power density. In fact, with Fe_3O_4 mesoporous nanoparticles this temperature was achievable even at lower power density. The highest SLP values achieved were 2400, 3860 and 8400 Wg^{-1} for γ-Fe_2O_3, $MnFe_2O_4$ and Fe_3O_4 samples, respectively.
- Better absorbance, limited radiative emission (or higher non-radiative relaxations), and high NIR photo counts (indicative of defect sites at tetrahedral position of spinel structure) are some of the reasons responsible for high heating behaviour of these samples and in particular for Fe_3O_4 mesoporous nanoparticles.
- The in-vitro studies carried out with Fe_3O_4 mesoporous nanoparticles recommend that the material could easily internalise in the cells. A high rate of cells death was noticed during PTT even at a concentration as low as 0.25 mg/mL for an exposure time of only 5 min.

6.2 Future scope

Based on the present results, the following suggestions could be made for future work:

- Since the study of heating ability of iron oxide based nanoparticles under NIR laser irradiation is in entry stage, further assessment of heating behaviour can be performed varying the structure and composition in order to enhance the performance.
- Effect of combined effect of AC magnetic field and NIR laser on heating performance of these materials could produce interesting results, for e.g., better heating at lower concentration and is highly recommended to explore.
- A detailed in-vitro studies with different cancerous cells could provide better understanding of the performance of these materials.
- In-vivo studies with these magnetic materials could be performed to find their suitability for bio applications.