7.1 Conclusion

To summarize, the research objective of this thesis revealed the use of metallic nanoparticles in the realization of bulk heterojunction organic solar cell devices. The plasmonic nanoparticles have been synthesized by using pulsed laser ablation of a bulk target material in a suitable liquid. Gold, silver, and copper nanoparticles were synthesized using a corresponding bulk targets material and dispersed in different solutions. The liquids used are the water soluble polystyrene sulfonate, and the chloroform solutions. However, other solutions were also used in order to investigate the influence of the surfactants on the nanoparticle size distribution. For instance, SDS, SDBS, and SVBS surfactants were investigated. The resulting dispersed nanoparticles have been mixed with a suitable polymer blend in order to gain a nanocomposite matrix for its application in the realization of OSC. To be specific, the synthesized AuNPs, AgNPs and CuNPs in chloroform were mixed with the photoactive blend material P3HT:PCBM and the produced AgNPs and AuNPs in PSS were mixed with PEDOT:PSS blend or used as NPs array between the hole transportation and the active layers. The obtained nanocomposites were employed for the fabrication of OSC devices and the resulting devices have been characterized in terms of power conversion efficiency and other solar cell operational parameters.

The synthesis of nanoparticles through laser ablation has several advantages (surfactant free NPs, fast and easy, further the possibility to disperse the nanoparticles in a suitable solution). However, The polydispersity of the size distribution of the colloidal particles synthesized by this method is revealed to be higher than that obtained by wet chemical precipitation. In this way, the first objective of this thesis was focused on the control and reduction of size distribution of the NPs, and as a result, very narrow size distributions were obtained by using surfactants and by changing the experimental conditions during laser ablation. In fact, it has been demonstrated that many factors affect the final size distribution. For instance, the use of surfactant molecules in the liquid environment has demonstrated that the shape and the length of the surfactants play an important role during the formation of NPs. So, surfactants which exhibit larger head group and longer tail are selected for the formation of small NPs. However, very narrow NPs size distribution has been obtained by using chloroform solution which exhibit a very
7.1 Conclusion

hight molecular polarizability, thus a further parameter. Laser parameters have also been investigated and shown the impact of the laser fluency and repetition rate on the size of the NPs. The use of high laser energy was accompanied by larger NPs, because of the generation of larger fragmentations. However, an increase in the size, which has been observed by changing the repetition rate (from 30 kHz to 125 kHz) is due to the interaction between the small species included in the plum formed by the first laser beam. The properties of the metal target, such as optical absorption, have also been shown to be affecting the quantity of the ablated material and the final properties of the obtained NPs. The ablation of different materials by femtoseconds laser pulses has been compared. An interesting result has been obtained by comparing silver and gold. The two-photon absorption mechanism observed using gold target yields the loss of the laser energy which is absorbed from the generated NPs results in the formation of two population of NPs. However, in the case of silver target a broad size distribution have been obtained compared to gold. On the other hand, a high ablation rate of silver have been observed in comparison to gold NPs; this results can be explained by the lower ablation threshold of silver compared to gold material.

Finally, the incorporation of NPs within the OSC devices have been investigated. A significant improvement in the efficiency of the BHJ OSC devices have been observed when NPs were deposited in the active layer and within the layers. In fact, the use of surfactant-free NPs in the fabrication of plasmonic organic solar cells was effective and it was an interesting route to gain further improvement in this field. The one-step generated NPs via laser ablation have been dispersed in a suitable liquid medium, which is used for the dilution or the preparation of the composite matrix, and the obtained solutions have been used in the fabrication of plasmonic OSCs. An important improvement in the efficiency have been observed when both silver and gold nanoparticles have been imbedded between the active absorption and the hole transportation layers. Best efficiency enhancement has been obtained by large sized 26 nm AgNPs, and 23 nm for AuNPs with an enhancements of 13% and 14%, respectively. The origin of both enhancements is attributed to the shape and size of the laser synthesized nanoparticles in PSS, which present a broad size distribution. Thus the large NPs offer a unique approach towards optimizing the
7.2 Outlook

optical absorption improvement by light scattering and light-harvesting in OPVs. On the other hand, incorporation of very small NPs (<10 nm) in the photoactive blend has been studied. The results indicate that the photocurrent gets apparently enhanced by embedding Ag, Cu, and AuNPs into the active layer, which leads to a maximum improvement in the efficiency by almost 30%. The increase in the $J_{sc}$ was mainly due to the LSPRs effect caused by small diameter nanoparticles produced by laser ablation in chloroform. In this case the best result was obtained by using gold nanoparticles.

7.2. Outlook

The work described in this thesis contributes to the generation and size controlling of metallic nanoparticles via laser ablation in liquid. The generation of NPs via PLAL has shown its success concerning the control of the size of the NPs and the possibility to disperse it in different solutions. In addition, the application of these nanocomposites in the preparation of organic solar cells was also successful. Now, what are the field’s unsolved problems and future challenges?

For their application in OSC, nanoparticles have been synthesised in chloroform solutions, and in the polymer PSS. However, during the preparation of OSCs other solutions are also required. For instance, chlorobenzene and ethanol. So, the synthesis of NPs in these solutions by laser ablation could also help to improve the PCE of solar cells. Oxide nanoparticles like ZnO are also required for the preparation of inverted OSCs, such NPs can also be generated via laser ablation. In addition, alloy of NPs can also easily be generated and controlled via laser ablation and have numerous applications in different fields. For example, Cu-Ag NPs have successfully been generated in chloroform and have shown a high stability (see appendix C).

The addition of NPs to the polymer material or/and other materials have attracted the attention of the researchers for their use in the microelectronic and lighting fields in the last few years. The synthesis of NPs directly in such polymers via laser ablation could highlight their properties. This one-step method is not only easy and fast but also leads to the formation of surfactant free NPs. Such
7.2 Outlook

surfactant free NPs are very important in their application in the biomedicine field.