Summary

The combination of new chemotherapies and surgical treatments has dramatically improved the survival rates of people affected by cancer over the last decades. However, these successes are not evenly distributed among the various types of cancer; in particular, little progress has been made in the treatment liver and pancreas tumors.

The Ph.D. activity aimed to contribute by proposing an innovative all-fiber optic applicator with embedded sensing capabilities for the Laser Ablation (LA) treatment of liver and pancreas tumors.

LA is one of the so-called minimally invasive tumor therapies – the others being radio-frequency (RFA) and microwave (MWA) ablation – that rely on the local increase of the temperature above cytotoxic levels to induce the necrosis of malignant cells. In particular, LA exploits the temperature increase due to the tissue absorption of a high power laser beam, usually at near-infrared wavelengths. These hyper-thermal therapies constitute an alternative to more traditional surgical resection and are particularly attractive because of their reduced post-operative discomfort since they can be performed through percutaneous needles and affect only a limited body zone. Although LA has already demonstrated several advantages over competing procedures, its diffusion is still limited. One of the main reasons is the lack of a proper treatment protocol to be used first for planning and then to monitor as it progresses. A first step towards the definition of such procedure is the real-time monitoring of the temperature reached by the tissue under treatment so that it is possible to ensure reaching the proper cytotoxic level while avoiding damages to the surrounding healthy tissue.

In this framework, the Ph.D. activity explored the feasibility of a new type of applicator for LA that embeds Fiber Bragg Gratings (FBGs) as temperature sensors. FBGs were selected because being all-fiber-based are entirely compatible with the laser radiation and present several advantages with respect to other fiber optic sensors due to their technological maturity and widespread use in different fields of engineering.

In a first phase, several commercial FBGs were encapsulated in different embodiments to reduce the effect due to strain cross-sensitivity and characterized in uniform temperature conditions in order to find their sensitivity. Then, the errors

due to their use with a real temperature distribution in simulated operative conditions have been thoroughly analyzed. Indeed, even if FBGs are commonly employed for several applications, no detailed studies of their response and errors in presence of non-uniform temperature distributions, which are typical of LA, were present in the literature. Numerical models to simulate the sensors readings in presence of steep temperature gradients have been developed and the results have been experimentally confirmed with dedicated setups. The effect of the sensor position, length, and embodiment in the temperature distribution estimation have been quantified for different sensor configurations.

Then, the work has focused on the development of a new applicator to simultaneously deliver a high power laser beam with a suitable pattern to match the tumor size and sense the temperature. This has required studying an appropriate fiber surface modification to allow also the lateral irradiation. Using a double-cladding specialty fiber, it has been possible to write several FBG sensors in the inner core for temperature mapping and use the inner cladding to guide the beam for LA. The irradiation pattern and the integrated sensors response have been characterized in phantoms to allow reproducible test conditions and then validated using ex-vivo porcine liver. Finally, the realized applicator has been tested in in-vivo animal cases, obtaining preliminary results on the clinical validity of the proposed approach.