Perovskite oxides are multifunctional materials that have been the focus of intense scientific research over the past years. Indeed, some of these display many remarkable and often extreme properties such as high-temperature superconductivity or colossal magnetoresistance. They can even show novel coupling of multiple coexisting states, such as magnetism and superconductivity, or ferroelectricity and ferromagnetism. Together, the perovskite compounds form a rich materials playground for exploring new physical properties and novel device concepts. In this context, new functionalities in an ‘old’ material such as strontium titanate (SrTiO$_3$) continue emerging.

Strontium titanate, in stoichiometric form, is a transparent insulator, of $\sim$3.2 eV band gap, with a great potential for microelectronic applications due to its extremely high bulk dielectric constant ($\sim$300) at room temperature (RT) and even larger at lower temperatures. Recently, SrTiO$_3$ has been epitaxially grown on Si(100) opening the route to devices based on metal-oxide heterostructures such as field effect transistors (FETs) using SrTiO$_3$ as a gate dielectric for new high-density random access memories [1]. This opens up the possibility of FETs with functional gate oxides with ferroelectric, superconducting, or magnetoresistive properties [2]. Moreover, SrTiO$_3$ has interesting and complex electrical, optical and magnetic properties that can be modified by the incorporation of dopants or vacancies. Recently it was found that oxygen vacancies in SrTiO$_3$ induce the emission of blue light by electron–hole recombination at RT [3]. This encouraged the use of SrTiO$_3$ in optoelectronics applications. The short wavelength (430 nm) permits higher density optical storage devices, as is evident in the latest generation of DVD players that are currently emerging.

Ion implantation is a method to incorporate impurity atoms (dopants) into the host material with precise control of the concentration, depth and profile of the dopant. For cases where low elemental solubility hinders doping during growth, ion implantation is an attractive
approach for doping. So far it is poorly exploited in perovskites such as SrTiO$_3$ but, nowadays, it is a routine process in the semiconductor industry for the manufacture of integrated circuits by selective area electrical doping. In this field it has already proven to have outstanding advantages for doping semiconductors such as silicon. The main disadvantage, however, is the implantation damage in the host material due to nuclear collisions between the impinging impurity ions with the host atoms. The problem is often overcome by annealing the lattice damage. The annealing temperature for the activation in compound semiconductors, generally, follows a two-third relationship with respect to the melting point of the material mainly due to the threshold for vacancies mobility [4]. The optimal annealing temperature can be investigated by several nuclear techniques. For example, the local atomic scale Perturbed angular correlation (PAC) technique combined with the lattice structure and composition Rutherford Backscattering/Channeling (RBS/C) technique provide a good understanding of defect annealing upon implantation. PAC is a useful tool providing a better understanding of the interaction between dopants, point defects and impurities and RBS/C is a specially suited technique to evaluate the crystalline quality and composition of the lattice after implantation and to determine the width and defect concentration of the damaged layer in the material.

As previously mentioned, a key aspect in device production is the incorporation of dopants that can alter the electronic, magnetic or optical properties of the host material. SrTiO$_3$ acts as a n-type semiconductor upon substituting Nb$^{5+}$ or Sb$^{5+}$ for Ti$^{4+}$ and as p-type upon substituting by Sc$^{3+}$ or La$^{3+}$ [5]-[6]. The rare-earth elements are also attractive candidates for optical SrTiO$_3$-based applications in the visible region, since these elements exhibit sharp optical emission lines independently of the host material [7]. The incorporation of magnetic transition metals (e.g. Cr, Mn or Fe) aim to produce the so called dilute magnetic semiconductors, which would allow the device to make use not only of the charge of electrons, but also of their spin state [8]. Finally, transition metals when incorporated in SrTiO$_3$ can
change the photocromic properties, or enhance certain properties if used as co-dopants [9]. In all cases, the exact influence of the dopant or impurity on the material properties depend on the lattice site it occupies. Therefore, it is relevant to know the sites of impurities and how the incorporation can be influenced by point defects and external parameters in order to drive them into active sites.

In this thesis, a systematic study of lattice site location of impurities in SrTiO$_3$, as a function of annealing temperature, has been performed by means of electron Emission channelling (EC). These experiments use position-sensitive detectors read out by an external trigger based methodology, originally developed for particle detection in high energy physics, then to X-ray medical applications that, with some modifications, turned out to be successfully adapted to electron detection with energies down to 40 keV. These detection systems suffer from resolution-efficiency trade-off inherent to low energy electron detection and are characterized by slow data readout speed. In this context, an alternative readout methodology has been proposed and developed, in order to overcome these limitations and to extend the range of available isotopes for the EC technique. The usefulness of the new detector readout system has been revealed by preliminary lattice site location studies performed in ZnO and GaN with two short-lived isotopes $^{56}\text{Mn}(2.6 \text{ h})$ and $^{61}\text{Co} (1.6 \text{ h})$ in June 2007, never possible to do before. EC experiments with short-lived isotopes also required the development of a new mechanical setup for on-line experiments at the ISOLDE-CERN facility. This setup fulfils the requirements of on-line experiments with the new, fast position-sensitive readout system suitable for implanting and measuring at the same time.

In this context, this manuscript deals with the effort to provide additional insight on the lattice site location of electrical, magnetic and optical dopants in SrTiO$_3$. It aims at a better understanding of the interaction between dopants, point defects and impurities.
In parallel to the materials science work, a research and development project has been followed with the scope of enlarging the number of available isotopes for EC experiments in SrTiO$_3$ and other materials of fundamental and technological interest.

The thesis is structured in eight chapters briefly summarized as follows:

**Strontium titanate:** It describes the relevant aspects of SrTiO$_3$ to understand the subsequent chapters of this thesis. The *flame fusion Vernuil* growth method is referred and the SrTiO$_3$ doping problematic is also discussed.

**Sample preparation and characterization:** A brief overview of experimental setups and of the techniques used for sample preparation and characterization are given. Ion implantation with subsequent thermal annealing is referred as a sample preparation method and RBS/C, PIXE, SQUID, PAC and EC techniques as characterization methods. Because most of these techniques took place at ITN and ISOLDE-CERN, these facilities will be both presented.

**Implantation induced damage in SrTiO$_3$:** The main characteristics of defect accumulation in SrTiO$_3$ implanted with $^{59}$Fe, $^{89}$Sr, $^{111}$Ag and $^{111m}$Cd ions, and subsequent removal by thermal annealing, are investigated by means of RBS/C, EC and PAC nuclear techniques. The influence of temperature, impurity type and fluence in the crystalline quality, impurity substitutionality and point defects recovery of virgin SrTiO$_3$ samples are discussed. Further studies on this last topic were performed in 2%Nb-doped SrTiO$_3$ samples and the results are discussed in section 4.1.3.

**Lattice location of impurities in SrTiO$_3$:** This chapter presents and discusses results of lattice site location of implanted Ag$^+$, Cd$^{2+}$, Sn$^{4+}$, Yb$^{3+}$ and Fe$^{2+}$, $^{3+}$ ions in SrTiO$_3$ as a function of annealing temperature. The influence of fluence on lattice location studies of implanted Fe in SrTiO$_3$ is also discussed. Magnetic characterization studies, based on the measurement of the magnetic dipole moment as a function of temperature, applied field and fluence, complement...
the previous study. In this context, subsequent impurity search on the samples was also performed by means of particle induced X-ray emission (PIXE) spectroscopy.

**EC experimental developments:** This chapter summarizes the technical progress performed in the new EC experimental setup and the VME-based position-sensitive detection system. The properties of each of the new readout system constituents and their role in the data collection will be thoroughly discussed. The usefulness of the system has been revealed by tests with gamma and electron sources. Preliminary lattice site location studies performed on ZnO and GaN with $^{56}$Mn and $^{61}$Co isotopes are presented.

**Conclusions and perspectives:** A general conclusion of this thesis is presented and the perspectives for future scientific and technical research work are highlighted.

**Appendix A:** Presents the curriculum vitae and lists the scientific articles published.

**References**