**Introduction**

Singular optics is an already well recognized and rapidly developing branch of modern optics dealing with singularities such as (i) caustics in geometrical optics, (ii) edge, screw and mixed dislocations in scalar wave optics and (iii) L–line, C-point and disclinations in vector wave optics [1-4]. In scalar wave optics, the singularities that deal with optical beams with helical wavefront are known as optical vortices (OVs). At the vortex core the amplitude vanishes and hence the phase becomes indeterminate (singular). Laguerre-Gaussian (LG\textsubscript{n}) and higher-order Bessel-Gaussian (BG)-J\textsubscript{n}(kr); n ≥1 beams are some of the well known examples of beams carrying OVs. The seminal paper by Nye and Berry titled “Dislocations in wave trains” introduced the phase singularities in analogy with defects in crystals as a new class of objects in electromagnetic wave theory [5]. Further, Berry concluded that the phase singularities are the most remarkable features of the wavefronts [1]. This concept was expanded subsequently by Nye and Hajnal to include vectorial (polarization) singularities such as C-point, L-line and disclinations in paraxial electromagnetic waves [2, 6-11]. The C-point is where the field is circularly polarized making the azimuth of the polarization ellipse indeterminate. The L-line is where the field is linearly polarized and consequently the handedness of the polarization ellipse is undefined and it also separates the regions of opposite handedness of polarization and disclinations are points where one of the components of the transverse field is an instantaneous zero [2, 6].

Allen et.al., [12] demonstrated that optical beams with helical wavefront also carry Orbital Angular Momentum (OAM) which kick-started the widespread research activity in the area of beams and photons with optical angular momentum which includes both spin (circular polarization) and orbital
momentum (helical phase) beyond its generation and characterization to include a wide variety of applications [13, 14]. More recently, Bekshaev and Soskin associated OAM with polarization singularities as well (C-point) [14, 15].

There are different methods available to generate OV beams in the laboratory [16-18]. The most commonly used are the computer-generated hologram (CGH) and spatial light modulator (SLM). In the CGH method, OVs with arbitrary topological charge are first simulated in computer and subsequently printed on a transparent substrate, whereas in the case of SLM by applying voltage to the pixels, beams with different topological charges are generated. A Gaussian beam transmitted or reflected by these optical elements will generate a beam with embedded OV. The beams generated using these methods are scalar beams, meaning that the polarization across the beam cross section is uniform.

Beams with spatially inhomogeneous polarization such as radial (TM$_{01}$) and azimuthal (TE$_{01}$) field orientations are the well known examples of vector beams. These beams are also known as cylindrical vector (CV) beams due to their cylindrical symmetry in polarization and have enabled several applications due to their unusual polarization characteristics [19, 20]. There are different methods to generate these vector beams, the most commonly used method is the interferometric technique, based on interfering two linear orthogonally polarized Hermite-Gaussian HG$_{10}$ and HG$_{01}$ modes either inside or outside a cavity.

An optically isotropic and inhomogeneous medium such as an optical fiber is a simple and inexpensive method to generate beams with both spatially inhomogeneous polarization (vector) and vortex beams. This is possible as both the vector and vortex modes are the eigen modes of the fiber in linear and
Introduction

circular polarization basis [21-26]. Zel’dovich et.al., [27], reported first the presence of vortices in the fiber radiation field which they studied theoretically and experimentally using fork interference pattern in the scattered laser field and subsequently suggested filtration method to isolate a single pure screw dislocation [28]. Volyar and Fadeyeva revealed that the optical vortices are the guiding modes of the fiber and described their properties [29, 30]. In the recent years pure vector modes of the fiber are generated using two-mode optical fiber by coupling the Gaussian beam or the externally generated Laguerre-Gaussian (LG) beam [31-33].

In this thesis, we present a controllable generation of different combinations of optical vector-vortex (VV) beams from a two-mode step-index fiber. The VV beams are generated by coupling the input Gaussian beam from a He-Ne laser as skew-offset beam. The output beams are characterized for both the vector and vortex behavior using different techniques such as analyzer rotation, interferometric method, complex Stokes parameter method and the state of polarization (SOP) map at each point in the output beam cross section. The skew-offset launch with respect to the fiber axis enables us to flip between the positive and negative helical phase structures and controllable generation of output beam with two C-points with same topological charge and isolated C-point with different topological charges.

Organization of the Thesis
The thesis is organized as follows: in the first chapter we introduce the necessary mathematical background for the fiber modes in different basis such as vector, LP and circular vortex modes. The appearance of vector singularities in the fiber modes is also introduced in this chapter. In the second chapter we
Introduction

present our experimental results on the generation of vector-vortex beams and the switching between the different VV modes. Also presented are our results on the effect of the fiber length and the NA of the input lens on the excitation of these modes. In the third chapter we introduce polarization singularities in paraxial waves, their characterization methods and our experimental results on the wavelength dependence of polarization singularities. In the fourth chapter we present our results on the generation of isolated polarization singularities and the switching between the different topological charges of the C-point. In the fifth chapter we present two applications of optical vortex beams with embedded polarization singularities including the demonstration of rotational Doppler-effect and the characterization of Dove prism using the well defined polarization singularities. Finally, in the sixth chapter we summarize the results obtained and suggest some future scope of the present work.