Chapter 1
Extensive Introduction

1.1 Solar Activity and Magnetic Fields

It is known from observations that solar atmospheres are highly structured, governed by an intricate interplay between magnetic forces, turbulent motions, and heating processes. These interactions are manifested in various signatures of solar activity, like sunspots, bright faculae, flare eruptions, X-ray emissions, coronal transients, wind streams, etc. The key physical parameter behind these various forms of activity phenomena is the magnetic field. The pattern of magnetic fields on the sun appears quite complex, showing up a number of characteristic features: emerged and decayed bipolar magnetic regions, latitude zone of activity, background fields and the magnetic network. But their overall behavior of evolution is remarkably ordered as the solar cycle proceeds. The pattern of solar magnetic fields and of solar activity are generally thought to be caused by some kind of dynamo mechanism operating in the largely unobservable depths of the convective zone (Priest 1982).

The magnetic concentration regions where sunspots and flaring activity occur are called "active regions". Since they correspond to the regions on the sun with the strongest flux concentrations, the magnetic field in active regions is the first to be concerned and taken in routine observations. In the past nearly ninety years a large amount of observational material has been accumulated and on this basis much interesting theoretical research has been performed for revealing the physics of solar flares. Nowadays it is generally accepted that the energy released in solar flares is stored in stressed magnetic fields of active regions. When a magnetic field emerges into the corona as a significantly twisted configuration, it flares to shed energy in order to rapidly seek a metastable state (Low 1996). In the condition of solar atmosphere, as characterized by very high conductivity, an efficient conversion of magnetic energy is assumed to occur by reconnection at spatially localized regions where current sheets form. But such current sheets in the corona are unobservable, reconnection process can be only inferred from the special topology of magnetic configurations, related to the emissions observed in a flare. Consequent-ly, the paradox or even contradict results are sometimes encountered, which make us confusion. Thus for well understanding the energy build up and release mechanism working in active regions, it is significant to make an intensive study of more high-resolution magnetic observations. This is what the present thesis aims at.

1.2 Measurement of Solar Magnetic Fields

Quantitative measurements of solar magnetic fields are made possible by the Zeeman effect, which was discovered in the laboratory in 1896 (Zeeman 1897a,b,c) and was first seen on the sun by Hale (1908) in sunspots. However, magneto-sensitive spectral lines in the visible are almost formed in the photosphere over a height range of 500km, thus

the magnetic fields in the solar atmosphere are allowed to measure, in fact, limited in a fairly finite thick layer. Even so, magnetic observations have contributed to many new discoveries since available, and now are the substantial way to reveal magnetic structures of active regions. So far there have developed many kinds of instruments specially designed and constructed for measurements of the photospheric field. Next we will briefly introduce some of them such as vector magnetographs as the background of this thesis.

The basic principles underlying all vector magnetographs are in essence the same; i.e., the magnetic vector including the longitudinal component ($B_{||}$) and the transverse component ($B_{\perp}$) is determined by the Stokes parameters Q, U and V known from observations. In spite of what difference in construction, any magnetograph consists of a telescope used to form the solar image, a polarization analyzer to select various combination of the Stokes parameters and a spectrograph or a birefringent filter to isolate the radiation within one or two magneto-sensitive spectral lines. Due to the different designs of the last part, the vector magnetographs at present thus contain two categories: some with spectrographs such as photoelectric magnetographs at the Crimean Astrophysical Observatory (Stepanov & Severny 1962), the Okayama Astrophysical Observatory (Makita 1986), and Stokes Polarimeters at the Mees Solar Observatory (MSO) of the University of Hawaii (Mickey 1985) and the Solar Observatory "Einsteinturm" at Potsdam (Staude 1970); the others with birefringent filters such as videomagnetographs (VMGs) at the Big Bear Solar Observatory (BBSO) (Cacciani, Varsik & Zirin 1989), the Marshell Space Flight Center (MSFC) (Hagyard et al. 1982), the Applied Physics Laboratory of the Johns Hopkins University (JHU/APL) (Rust & O'Byrne 1991) and the Huairou Solar Observing Station (HSOS) of Beijing Astronomical Observatory (Ai & Hu 1986).

The two kinds of instruments have their own advantages and disadvantages. The instruments of the first type acquire data by point-to-point scanning, so to obtain a vector magnetogram it costs a long time, while those of the second type performing the same process by CCD camera require only a few minutes and the measured magnetograms have by far higher spatial resolutions than the first category. So the vector magnetographs with monochromatic filters are very favorable for the magnetic observations of flares and some other rapidly changing active features. However, the VMGs have lower spectral resolution due to their filter passband of not enough narrow widths, which inevitably causes the serious distortion on the profiles of the Stokes parameters. Therefore, for precise quantitative studies the vector magnetographs with filters are inferior to those with spectrographs.

In this thesis all vector magnetic data used were observed by the Solar Magnetic Field Telescope (SMFT), a VMG of HSOS; its calibration and data reduction will be described in Chapter 2 and Chapter 3.

1.3 Subjects for the Study of Vector Magnetic Measurements

The emphases of this thesis are concentrated on the study of the features of active regions, because only in these regions observations can provide both the longitudinal and transverse magnetic fields. As shown in recent studies the measurement of transverse fields is particularly important for exploring the physics of the energy build up and release of active regions. Amounts of results have shown that flares prefer to occur in the regions where there appear prominent signatures of non-potentiality inferred from the transverse field, such as angular shear, source field, vertical electric current and force-free factor. And some authors (e.g. Hagyard 1990; Wang et al. 1996) also found the flare-associated

rapid changes of these features. This lends strong support to the assertion that the flare energy comes from the stressed fields. On the other hand, observations of the transverse field provide the additional restrictive conditions for extrapolation models, so which may lead more realistic constructions of the corona field topology.

On the basis of vector magnetic field measurements, we try to investigate the build up mechanism of large-scale current systems in terms of current helicity in Chapter 4, and make efforts to explore the topological properties of an observed field in Chapter 5 and its spatial field configuration with multi-waveband observations in Chapter 6 in order to reveal how free energy stored in active regions can be released in a flare.