1. INTRODUCTION

So-called stimuli-responsive or smart hydrogels are able to change reversibly and reproducibly their volume by more than one order of magnitude even due to very small alterations of certain environmental parameters. Their volume change is the largest known for solid state materials. Furthermore, the sensitivities of hydrogels towards physical parameters, e.g. temperature, and chemical or biochemical species are very manifold. Therefore, an enormous importance for many technological and scientific applications was expected [1]. Some applications of smart hydrogels are already commercialized. The window Cloud Gel™ from Suntek, Albuquerque, N. M. can regulate the quantity of sun light, which travels through the glass of a window. The company Gel Sciences/GelMed, Bedford Mass., introduced SmartGel™, which is a self-adapting shoe inlet. The most important applications of smart hydrogels are currently drug delivery systems. For example, OROS™ and PULSINCAP™ are systems allowing drug release in special parts of gastrointestinal tract. The characteristic pH values of the different sections are used as control parameter. However, the developments in hydrogel-based technology are currently focused on microfluidic applications, because much problems in microfluidics can be solved exploiting the special properties of smart hydrogels. A first impression of the excellent features of this technology gives the Hydrogel Micro Valve purchased by GeSiM mbH, Großkranzn, Germany, which is an electronically controllable hydrogel based microvalve. This chapter gives an overview of the current developments of hydrogel-based devices in microfluidics.
The story of smart hydrogels starts in 1948. Kuhn et al. [2, 3] reported that a clew of polymer molecule based on poly(acrylic acid) shows a discontinuous and very strong expansion as a function of pH value of the surrounding solvent. Simultaneously, this behavior could be observed by Kuhn [4, 5], Katchalsky [6], and Breitenbach [7] in macroscopic systems, i.e. hydrogels. These ionic gels are the first smart hydrogels reported.

In the sixties Dušek and Patterson discussed the existence of a discontinuous phase transition in neutral gels [8, 9, 10]. However, it takes more than ten years until Tanaka verified the volume phase transition behavior of such gels [11].

The huge and reversible volume change transitions of such hydrogels inspired many research groups to develop a lot of spectacular examples. The best known demonstrators are the “gel fishes” [12, 13], the “artificial elbow” [14], the “gel hand” [13], and the rotary “gel motor” [15, 16]. More application oriented developments such as sensors and separation systems were already discussed early. For example, early in the eighties Osada suggested and developed hydrogel based separation membranes, which are able to automatically influence the liquid flow due to changes in the pore size controlled by sugar and protein contents. Osada called this system “chemomechanical” or “chemical” valve [17, 18]. About fifteen years later, the pore size based membrane principle sensitive to temperature was described by Peters et al. as a separation device called “thermal gate” or “thermal valve” [19]. However, the membrane principle does not allow the control large liquid flows. Achieving this feature, other principles must be considered. A macrovalve to control flows in the milliliter and liter range based on hydrogel particles was developed [20]. Based on this chemomechanical valve, the automatic response towards temperature, pH value, and contents of organic solvents in aqueous solutions was demonstrated. Nearly simultaneously, the excellent scaling properties of hydrogels were demonstrated by a pH-sensitive microvalve by Beebe [21]. This step was very important, because a hydrogel based technology allows the development of on-chip integrated key elements used in micro total analysis systems (µTAS) such as microvalves, microsensors, fluidic drives, and other equipment. Currently, the microfluidics can be described as the driving force to develop hydrogel-based technologies. At present, two important microfluidic developments must be emphasized. In 2001, Siegel et al. presented a glucose-sensitive microvalve, as the first application sensitive towards organic or biological materials [22, 23]. On the same conference, an electronically controllable microvalve was presented [22, 24].

The development of hydrogel-based microsensors starts in 2002. In this year, Peppas et al. introduced a pH sensor based on a cantilever whose deflection was optically determined [25]. More useful as the optical detection is the resistance measurement due to mechanical deformation of a membrane, which was used as transducer principle for a glucose sensor by Han et al. [26] and a pH sensor by Günther et al. [27]. Optical Bragg grating sensors were also described for detection of salt contents [28] and pH value [29]. A microgravimetric pH sensor is also known [30]. However, the hydrogel-based microtechnology still in the beginning. Further microfluidic applications of hydrogels are developing. In the next two years on-chip integrated elements such as fluidic drives, storage systems, reactors, manipulation systems (clamps, dispensers etc), micro high performance liquid chromatography (µHPLC), and others are expected to be described.

In the following, the physical and chemical background of smart hydrogels, their sensor and actuator properties, most used fabrication technologies, realized applications and their operational behavior will be discussed.