Chapter 1

Introduction and Background

This chapter gives an overview of the research work carried out in the field of electrowetting on dielectrics (EWOD). The historical development since Lippmann’s electrocapillarity to the latest electrowetting on dielectric process is discussed in brief. Some of the important issues in electrowetting (EW) such as contact angle (CA) saturation and asymmetry in EW response are presented. The various applications of EW ranging from liquid lenses to droplet motion in digital microfluidic devices are also discussed. The related theoretical background and some basic aspects of EW are also explained. Finally motivation of the present work is presented.
1.1 Introduction

The wetting and spreading of liquid on solid or on liquid surface is a key parameter in most of natural and industrial processes. Some of these processes are water transport in plants, lubrication of human joints, washing, coating, printing, calming a troubled sea surface, indirect recovery of oil, spreading of insecticide etc.¹⁻⁵ There are numerous methods of controlling the wetting property that involves modification in surface chemistry and/or surface roughness.¹,²,⁶ This altered wetting is long lasting. However in many practical applications dynamic control on wetting is necessary. The controlled wetting on dielectric surfaces in the presence of external electric field became very popular because of its simplicity and potential applications in several commercial processes and in the study of basic sciences. The phenomenon is known as electrowetting on dielectric (EWOD) or electrowetting (EW).⁶,⁷

The modern EW process has its roots in classic experiment on electrocapillarity by Lippmann in 1875.⁸ The present form of EW has been derived from electrocapillarity work. Lippmann showed that the height of mercury column in contact with diluted electrolyte in fine capillary tube is a function of potential across the interface. This is essentially due to formation of electrical double-layer (EDL) at mercury-electrolyte interface by separations of ions. He developed many applications of this phenomenon.⁸ However, the work by Lippmann and other followers did not attract much attention because of electrolytic decomposition of water upon applying moderate voltage across the interface. In 1990 this phenomenon was revisited in a new form wherein a thin dielectric layer is used at the interface to separate conducting liquid from metal electrode.⁹ Generally polymer based insulator is used as an insulating layer that plays a dual role of hindering direct contact of liquid to the electrode and providing a smooth surface with less contact angle hysteresis (CAH).⁹,¹⁰ After this modification by Berge⁹ there has been a rapid development in this field consequently giving applications in many strategic technologies and in basic studies on ‘Science of Wetting’.

1.2 Theoretical background

Before going to elementary theory of EW process, some basics about wetting phenomenon like contact angle and contact angle hysteresis are discussed.
1.2.1 Contact angle

When a liquid drop is brought in contact with a solid surface, there is a spreading of drop so that the free energy of the system is minimized. Eventually the drop attains minimum energy state which is schematically shown in figure 1.1. Here, a tiny liquid droplet, less than a few mm size on solid surface is shown. This shape of the droplet can be fully approximated as a spherical cap if the size is less than the capillary length \( l_c = \sqrt{\frac{\gamma_{LV}}{\rho g}} \) (\( \gamma_{LV} \) is surface tension of liquid with respect to air, \( \rho \) is density of liquid and \( g \) is acceleration due to gravity).\(^6,11,12\) Beyond this size one gets a gravity-flattened droplet. The boundary of the sessile drop placed on solid surface makes a definite angle with it. The angle between tangent to the liquid surface at Triple Contact Line (TCL) and the solid surface taken inside of liquid is called as contact angle (CA) or Young’s angle, \( \theta_Y \).

\[ \theta_Y = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}} \quad \text{------- 1.1} \]

where \( \gamma_{LV} \) is surface tension of liquid with respect to air, \( \gamma_{SV} \) is surface tension of dry solid and \( \gamma_{SL} \) is surface tension of solid with respect to liquid.

**Figure 1.1:** A sessile drop placed on a solid surface. The three forces depicted by arrows constrain the droplet to an equilibrium shape of spherical cap.

This equilibrium state of the droplet is usually defined by Young’s equation for contact angle \( \theta_Y \) as:\(^13\)

\[ \cos \theta_Y = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}} \]

1.2.2 Contact angle hysteresis

It is observed that there exists a wide range of practically stable and apparent liquid contact angles on many flat surfaces. However, in practice, this CA for a pair of solid-liquid contact is not uniquely defined. When the volume of drop is increased, the motion of TCL does not follow simultaneously due to local pinning force resulting
in an increase in apparent contact angle on the same surface. The apparent contact angle eventually reaches to some maximum value referred to as advancing contact angle $\theta_a$ before the movement of TCL. If the drop volume is further increased, the contact line advances to a new position. Similarly, when the drop volume is reduced, TCL does not move immediately but retract after the apparent contact angle reaches to minimal value termed as receding contact angle $\theta_r$. Further reduction in volume of drop causes the contact line to recede. The difference between advancing and receding contact angles $\Delta \theta = \theta_a - \theta_r$, is termed as contact angle hysteresis (CAH).

This hysteresis can be the result of different effects. Firstly, it can be the effect of chemical heterogeneity of surface. As a result, the contact angle will vary throughout the surface. Secondly, the contact angle hysteresis is dependent on surface roughness. The surface roughness is not uniform all over the surface that leads to different contact angles.

The classic experiments by Johnson and Dettre\textsuperscript{16} on CA of water drop on wax surfaces show that the surface roughness has a considerable influence on both contact angle itself and CAH (figure 1.2).

![Figure 1.2: Water contact angle on wax surfaces as a function of surface roughness.\textsuperscript{16}](image)

In the regime of low surface roughness, advancing angle ($\theta_a$) increases with surface roughness, whereas receding angle ($\theta_r$) decreases. Therefore, CAH increases
in the first regime. Beyond a certain value of roughness, both the angles increase sharply. At the same time, the CAH drops to a lower value.

1.2.3 Electrowetting Theory

In modern EW setup an insulator is used on conducting surface to avoid a direct contact of liquid with electrode. The dielectric material is chosen so as to get large Young’s angle with minimum CAH. A conducting liquid drop is dispensed on the surface and the voltage is applied between conducting electrode and liquid droplet. Both AC as well as DC voltages can be used. We present energy minimization approach to derive EW equation. The electric energy from battery is utilized for charging liquid-solid interface. Thus charge density $\sigma_L$ at liquid-solid interface induces image charge density $\sigma_M$ on the planar bottom electrode as shown in figure 1.3. This is a thermodynamics system that includes droplet, dielectric layer, metal electrode, and voltage source (battery). Throughout the derivation, we assume that the system is in equilibrium at constant voltage $U$ and at constant temperature $T$.

![Figure 1.3: A conducting droplet sitting on dielectric surface. The battery performs work in setting charge density at liquid-solid interface and countercharge density at the bottom conducting electrode.](image)

An infinitesimal increase of the base area $dA$ results in contributing to the free energy from surface energies and also contribution to the additional charge density $d\sigma_L$ in liquid and its image charge density $d\sigma_M$ on metal electrode. The voltage source performs the work $dW_B$. The change in the free energy ($F$) of the system can be given as:

$$dF = \gamma_{SL} dA - \gamma_{SV} dA + \gamma_{LV} dA \cos \theta + dU' - dW_B \quad \text{-------- 1.2}$$
Where $dU'$ is the energy stored in electric field between liquid and counter electrode. $\gamma_{SL}$, $\gamma_{SV}$ and $\gamma_{LV}$ are free energies of solid/liquid, solid/vapor, and liquid/vapor interface respectively. In the absence of applied voltage:

$$dU' = dW_B = 0$$

For minimum free energy we have $\frac{dF}{dA} = 0$. By using this condition the equation 1.2 gives Young’s equation 1.1. For nonzero potential it is needed to include the energy of charge distribution. The electrostatic energy per unit area below liquid is given by

$$\frac{U'}{A} = \frac{1}{2} \int_0^d \vec{E} \cdot \vec{D} \, dz$$

where $z$ is the coordinate perpendicular to the surface, $d$ is dielectric thickness, $\vec{E}$ is electric field and $\vec{D} = \varepsilon_0 \varepsilon \vec{E}$ where $\varepsilon_0 \varepsilon$ being dielectric permittivity of medium. The increase in energy due to infinitesimal increase in droplet base area can given as

$$\frac{dU'}{dA} = \frac{1}{2} dED = \frac{1}{2} U \sigma_L \quad - - - (1.3)$$

The work done by the voltage source in redistribution of charges is given by

$$\frac{dW_B}{dA} = U \sigma_L \quad - - - (1.4)$$

Using equations 1.3 and 1.4 and for minimum free energy $(\frac{dF}{dA} = 0)$, equation 1.2 becomes

$$\cos \theta(U) = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}} + \frac{1}{2} \frac{U \sigma_L}{\gamma_{LV}} \quad - - - - - - - - - (1.5)$$

The charge density can be written as $\sigma_L = \varepsilon_0 \varepsilon E = \frac{\varepsilon_0 \varepsilon}{d} U$. Using this value and equation 1.1 the above equation 1.5 becomes

$$\cos \theta(U) = \cos \theta_Y + \frac{1}{2} \varepsilon_0 \varepsilon \frac{U^2}{d \gamma_{LV}} = \cos \theta_Y + \eta \quad - - - (1.6)$$

Equation 1.6 is Young-Lippmann equation. The last term in this equation is called as electrowetting number ($\eta$). In most of EW experiments oil medium is used as ambient that provides a lubricating layer to reduce CAH and also it arrests the evaporation of liquid droplet.
1.3 Progress of electrowetting on dielectric

Bruno Berge was first to initiate the recent developments by introducing a thin insulating layer that separates liquid and actuation electrode to avoid electrolysis.\textsuperscript{9,19} This concept is known EWOD or EW. Even though a higher voltage is needed, the arrangement is preferred because of two advantages. Firstly, the insulator separates liquid from electrode thereby allowing much higher field before dielectric breakdown and secondly the insulator provides a smooth surface with less CAH so that the liquid can easily move over the surface.\textsuperscript{10} B. Janocha et al.\textsuperscript{20} carried out EW using a large variety of polymeric dielectrics. The polymers include paraffin, polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), perfluoroalkoxy (PFA) etc. PVDF and PET did not give good EW response. Emilie Seyrat et al.\textsuperscript{21} used amorphous fluoropolymers as insulators for EW. They achieved reversible EW by virtue of hydrophobicity of fluoropolymers using lower values of applied voltages. Jiwoo Hong et al.\textsuperscript{22} succeeded in detaching droplets in immiscible fluids from a solid substrate with the help of electrowetting. Wei Dai et al.\textsuperscript{23} presented a model for EW on rough surfaces. Dale L. Herbertson et al.\textsuperscript{24} carried out EW on superhydrophobic patterned surface of SU-8. Jason Heikenfeld et al.\textsuperscript{25} carried out EW in air and oil ambient on superhydrophobic and patterned surfaces. Jiang-Tao Feng et al.\textsuperscript{26} performed EW on a lotus leaf. EW has been utilized to control the transition from Cassie to Wenzel state on superhydrophobic surfaces.\textsuperscript{27-29} J. Y. Chen et al.\textsuperscript{30} accomplished EW in carbon nanotubes for filling mercury in single walled carbon nanotubes. Because of the presence of mercury the conductance in both metallic and semiconducting nanotube probes was increased by decreasing contact resistance. Ying Wang et al.\textsuperscript{31} achieved EW on curved surfaces. They used energy minimization method to extend EW equation on curved surfaces. The electrofreezing of water droplets was achieved utilizing EW phenomenon.\textsuperscript{32} Steve Arscott\textsuperscript{33} used semiconductor dielectric for EW and succeeded in changing wetting properties with light. The phenomenon was termed as photoelectrowetting-on-semiconductors.

Balaji Raj et al.\textsuperscript{34} performed EW using liquids containing various ions. They found that dielectric breakdown in EW is dependent on ionic size. Manjeet Dhindsa et al.\textsuperscript{35} carried out EW without electrolysis on parylene-C deposited on aluminum electrode. They found that after breakdown the system shows self-healing property
within a time span of 100 ms. Thibault Roques-Carmes et al. used surfactants for EW and observed a significant decrease in applied electric field to modify contact angle. The reduced voltage was enough to induce contact angle change because the surface tension of liquid with respect to the environment is considerably reduced. F. Li et al. showed that CAH is considerably reduced using AC voltages in comparison with DC voltages. AC EW depends on the applied frequency and conductivity of the liquid. At high frequencies the liquid does not behave as a conductor. F. J. Hong et al. studied frequency dependent resonance and asymmetric droplet oscillations under AC EW. For the oscillations above resonance frequency but below critical frequency (in low frequency regime) the large amplitude oscillation of the contact line deforms it from a circular shape to have lobes and the number of lobes increases with the frequency. Sung Hee Ko et al. studied hydrodynamic flows generated inside a droplet in AC electrowetting. The fast flow was observed in the low-frequency range of about 10 Hz to 15 kHz. However a different type of flow was observed in the high-frequency range of about 35 to 256 kHz. Figure 1.4 shows hydrodynamic flows for low and high frequencies. The figure depicts that the flow directions are different for the two cases. Similar study was carried out by Horim Lee et al.

![Figure 1.4: Frequency dependent internal flow pattern.](image)

When a drop of colloidal solution on solid surface is allowed to evaporate, coffee ring effect is observed. H. B. Eral et al. found that EW can be used to suppress coffee ring effect of colloidal particles and DNA solutions using AC frequencies ranging from a few Hz to a few tens of kHz. According to them, two factors are responsible for suppression of the effect. AC electrostatic force prevents pinning of three phase contact line. Also internal flows generated by AC EW prevent the accumulation of solutes along the contact line.

The researchers have used inorganic materials along with the top coating of fluoropolymers to increase the dielectric constant so as to reduce the applied voltage.
The oxide insulators like Bismuth Zinc Niobate (BZN), Ta$_2$O$_5$, Al$_2$O$_3$, and BaTiO$_3$ nano-particle dispersion were employed for reliable and reversible electrowetting in low voltage regime.

1.4 Key issues in EW

In spite of recent development in EW and related applications, there are certain issues in EW that are not yet resolved. There are different views and no common consensus has been reached up till now regarding contact angle saturation and asymmetry in EW response. They are briefly discussed in following sections.

1.4.1 Contact angle saturation

Young-Lippmann equation predicts that the CA decreases with voltage without any limit. But practically it is observed that beyond certain voltage value the contact angle does not decrease as per the equation but saturates. Different mechanisms have been proposed to explain contact angle saturation in EW.

I. Dielectric charging

H. J. J. Verheijen et al. showed that after some threshold value of applied voltage the induced charges at solid-liquid interface are trapped in or on the dielectric. This trapped charge in the dielectric does not contribute to electrowetting effect and reduces available electromechanical force by screening the electric field. This leads to contact angle saturation. The electric field diverges near contact line. The electric field locally becomes so strong that it exceeds the dielectric breakdown strength of insulating layer. Consequently the dielectric layer breaks down locally. The transferred charges to the dielectric layer screen the electric field and lead to contact angle saturation.

II. Gas ionization and insulating fluid charging

Vallet et al. reported that when applied voltage is larger than the saturation voltage, ionization of air medium around the contact line takes place. This could lead to contact angle saturation. This argument is equally applicable for oil ambient medium.

III. Contact line instability and micro-droplet ejection

In AC electrowetting study, Vallet et al. showed instability of contact line close to the critical voltage for water. They observed spontaneous ejection of
micro drops from the contact line when applied voltage was increased beyond a critical value. Similar results were obtained by Mugele et al. and they attributed it to the divergence of charge density around the contact line. When applied voltage was larger than the critical value, emission of (charged) satellite droplets were observed. This instability at the contact line could be a possible cause for contact angle saturation.

IV. Zero interfacial tension

The change of EW contact angle is entirely attributed to reduction in the liquid-solid interfacial tension ($\gamma_{SL}$). V. Peykov et al. suggested that the $\gamma_{SL}$ should not be less than zero so as to keep thermodynamic stability. The model predicts that contact angle saturation occurs when the effective solid–liquid interfacial energy vanishes at a certain critical voltage. The results from the model are in reasonable agreement with the experimental data. Thus, the thermodynamic limit with $\gamma_{SL} = 0$ leads to contact angle saturation. Berry et al. confirmed this model by low voltage electrowetting.

1.4.2 Asymmetry in EW response

H. J. J. Verheijen et al. observed that when applied voltage is increased beyond a threshold value the charges from liquid are trapped in or on the dielectric. Similar study carried out on polymeric dielectrics revealed that the trapped charges were related to the applied field intensity and the breakdown strength of the dielectric shown by Shaun Berry et al. This introduces asymmetry in EW response which could lead to irreversibility of CA variation. M. K. Kilaru et al. used nanocomposite dielectrics from BaTiO$_3$ nanopowder dispersed in a fluoropolymer/fluorosolvent solution. They observed bistable EW. The strong charge trapping was confirmed by studying charge-voltage hysteresis. D. Y. Kim et al. studied the effect of charge trapping induced by plasma treatment on EW.

1.5 Applications of EW

Due to the variety of properties possessed by EW it has diversified applications. Some of the applications highlighting the importance of EW are discussed here.
I. Liquid lenses

At equilibrium the droplet on a dielectric surface acquires spherical shape that can act as a liquid lens. The focal length can be tuned by changing curvature of the drop by using applied electric field. B. Berge et al.\textsuperscript{18} used EW for liquid lens application. S. Kuiper et al.\textsuperscript{60} used two immiscible liquids to form EW based lens. They studied various properties of the liquid lens. Figure 1.5 depicts the schematic cross section of a liquid-based variable lens in the cylindrical glass housing.

![Schematic cross section of a liquid-based variable lens.](image)

**Figure 1.5:** Schematic cross section of a liquid-based variable lens.\textsuperscript{60}

Kartikeya Mishra et al.\textsuperscript{61} prepared adaptive micro-lenses design. The liquid micro-lens has a superior imaging performance that allows for simultaneous and independent tuning of both focal length and asphericity. This was achieved by varying hydrostatic pressure and electric field to control the shape of refracting interface between an electrically conductive lens liquid and a non-conductive ambient fluid. Other researchers also prepared liquid lenses using EW.\textsuperscript{62,63}

II. Display technology

Robert A. Hayes et al.\textsuperscript{64} showed that electrowetting can also be used to form the basis of a reflective display that is significantly faster than electrophoretic displays, so that video content can be displayed. It is based on the voltage-controlled movement of a coloured oil film adjacent to a white substrate. The reflectivity and contrast is similar to that of paper. Additionally, they have demonstrated a colour concept, which is intrinsically four times brighter than reflective liquid-crystal displays. Patricia T. C. Lee et al.\textsuperscript{65} fabricated pigment particle-based electrowetting display (EWD) by using the requisite poly(isobutylene)-imide (PIB-imide) for effectively dispersing insoluble colourant in decane/water system. It was demonstrated that the pigment-based EWD had a
maximum viewable area ratio of 80% at a driving voltage of 20 V. Figure 1.6 shows schematic of the operation.

![Schematic of EWD pixels](image)

**Figure 1.6:** (a) Schematic illustration of a cross section of OFF and ON EWD pixels with reservoirs (b) Top view of pixel operation.\(^{65}\)

The work on EW based display is continuously going on by increasing viewable area ratio and reflectivity.\(^{66-69}\)

### III. Microfluidics

M. G. Pollack et al.\(^ {70}\) used EW for microfluidic applications. The droplet transport was rapid and efficient with average velocities exceeding 10 cm s\(^{-1}\). The small droplet was transported over 1000 times their length per second. The formation, mixing, and splitting of microdroplets were also demonstrated using same microactuator structures. Figure 1.7 shows the schematic of the set-up. EW was also utilized for microfluidics on a single planar surface (open microfluidics).\(^ {71,72}\) Michael G. Pollack et al.\(^ {73}\) used EW in closed microfluidics. An architecture combining both closed and open systems on a chip would facilitate many of the chemical and biological processes now envisioned for the laboratory on a chip. Wang et al.\(^ {74}\) tried to predict the required wetting conditions for a droplet to cross the open/closed boundary using a model. They have also performed experiments to confirm the predictions.
Raphael Renaudot et al.\textsuperscript{75} presented a programmable and reconfigurable microfluidic chip by controlling the temperature of the chip. EW was also utilized for paper-based digital microfluidics\textsuperscript{76} and for digital microfluidics powered by finger actuation.\textsuperscript{77}

EW based microfluidics has also been employed for biological applications. A. Rival et al.\textsuperscript{78} incorporated EW based microfluidic device for single cell analysis. They fabricated an automated system that is capable of isolation of a single cell followed by mRNA purification and gene expression analysis. Hsien-Hua Shen et al.\textsuperscript{79} also exploited EW assisted microfluidic systems for biomedical applications.

**IV. Energy harvesting**

Tom Krupenkin et al.\textsuperscript{80} used a new approach of reverse EW for high-power energy harvesting. They have converted mechanical energy into electrical energy using reverse EW. The droplet and the electrode are connected to the external electrical circuit that provides a constant bias voltage between the droplet and the electrode as shown in figure 1.8 (d). The external mechanical actuations, like out-of-plane vibration, in-plane shear, and in-channel droplet motion as shown in figure 1.8 (a) to (c), are used to reduce the contact of the liquid with the dielectric coated electrode. Consequently the charge at liquid-solid interface is reduced. The excessive electrical charge then flows back through the electrical circuit that can be used to power the external load. It can produce high power densities, up to $10^3 \text{ W m}^{-2}$.
Figure 1.8: Schematics of three major droplet actuation mechanisms (a) vibration (b) shear and (c) pressure. (d) Schematics of reverse-electrowetting-based energy generation process in a microchannel geometry.

V. Other applications
Banpurkar et al.\textsuperscript{81} performed EW contact angle measurements to determine the interfacial tension between aqueous drops laden with various inorganic and organic solutes and various ambient oils. They used Young-Lippmann equation to calculate interfacial tension. Figure 1.9 shows the key results of their measurements.

Figure 1.9: Variation of $\Delta \cos \theta$ versus $U^2/\gamma_{wo}$ for several systems with interfacial tensions between 5 and 38 mJ m$^{-2}$.\textsuperscript{81}
The inset graph shows deviation because of variation in the surface tension values. Upon scaling by surface tension all the curves overlap on each other. The surface tension values measured with this technique are in close agreement with the macroscopic tensiometry. The measurements were carried on nanoliter volume of the liquid. Seungyul Choi et al.\textsuperscript{82} also used planar EW geometry for the estimation of surface tension. Banpurkar et al.\textsuperscript{83} used electrowetting (EW) as a tool to assess the elastic properties of aqueous jellifying materials placed on a hydrophobic substrate. For that aqueous solutions of gelatin (2-10 wt %) was used in ambient oil for various temperatures (8-40 °C).

J. Heikenfeld et al.\textsuperscript{84} utilized EW for high-transmission electrowetting light valves. The switching speed depends on cell size, typically for 1 and 3 mm\textsuperscript{2} cells, it was observed to be 10–100 ms. C. U. Murade et al.\textsuperscript{85} demonstrated an electrowetting based optical switch with tunable aperture. By applying the electric field a non-transparent oil film can be replaced locally by a transparent water drop creating an aperture through which light can pass. Its diameter can be tuned between 0.2 and 1.2 mm. The ON and OFF response time of the switch was of the order of 2 and 120 ms respectively. Kwang-Seok Yun et al.\textsuperscript{86} demonstrated surface-tension driven micropump based on EW. The micropump consists of a microchannel filled with electrolyte where the mercury drop is inserted. The movement of the mercury pushes or drags the electrolyte, resulting in the deflection of a membrane. The actual liquid pumping was carried out up to 70 µl min\textsuperscript{-1} with a driving voltage of 2.3 V.

\textbf{1.6 Motivation for present study}

The electric as well as wetting properties of the dielectric are very crucial for durable EW response. In the present study mainly polystyrene (PS), Poly(vinylidene fluoride-\textit{co}-hexafluoropropylene) (PVDF-HFP), and Teflon AF dielectric are used for electrowetting experimentation. The motivation of the work is as follows.

1. Almost all the hydrophobic polymers including high performance fluoropolymer like Teflon AF (DuPont, USA) and Cytop (Asahi Glass, Japan) has negative zeta potential at neutral pH showing affinity to ‘negative’ surface charge. The electrical double layer is generated at polymer-water interface that could affect charge
neutrality on the polymer surface. The consequences of water contact electrification of Teflon AF using DC voltage EW is investigated in detail.

2. Polystyrene (PS) is another polymer extensively used for biological and microfluidic applications. Yet it has not been explored as a dielectric in the EW applications. We explore the possibility of its use as a dielectric for EW process using aqueous droplet. EW increases wetting of water generating microscopic water-ion contacts to the polymer surface. This favors the creation of electric-double layer at polymer-water interface. The associated electric field is in the range of $10^7$ V m$^{-1}$. The consequence of this field on EW response is examined in detail.

3. Dielectric breakdown puts limitations in EW based applications. The systematic study of dielectric breakdown is carried out on Teflon AF and PS for aqueous solution containing electrolytes, surfactants etc.

4. The enhanced electrowetting response is always needed to get large CA tuning range. But it requires high dielectric constant materials. PVDF-HFP is a ferroelectric polymer with dielectric constant of $\varepsilon \sim 10$. But previous reports say that CA recovery on this fluoropolymer is very poor. To make use of this polymer that would give CA recovery, we applied a thin layer of Teflon AF and EW was studied on this bilayer sample in detail.

5. The EW response can be affected by various parameters such as liquid conductivity, surface tension, etc. Effect of liquid conductivity on DC voltage EW is not much studied. As mentioned before EW can be used in handling various aqueous solutions containing nano-particles, electrolytes etc. The detailed study is carried out to handle such a high conducting liquid with DC voltage EW using generic planar and interdigitated electrode geometry.
References


