Chapter 7

Conclusions and Scope for Further Work

7.1. Conclusions:

In this thesis, the energy harvesting capabilities of PVDF hybrids were explored. The energy harvesting provides awareness for low self-powered electronic devices. Energy harvesting not only reduces the cost of batteries by powering the wireless systems but also eliminates the time required to replace the batteries and install them in a complex wired system especially in medical implants and safety monitoring devices. It is environment-friendly as it eliminates the use of batteries, limit the disposal of batteries, and utilize waste mechanical energy. Energy harvesting uses energy from available resources such as heat, light, and vibrations, etc., and converts them into a useable form, often in electrical energy. Mechanical energy harvesting uses a variety of mechanical energy such as vibrations, fluid flow, air movements, walking, and inner body motions such as heart and chest movements and converts them into electrical energy to power various implants including pacemakers. Different types of materials are used for energy harvesting, here we have used the polymer as it has advantages like light-weight, flexibility, bio-compatibility and scalability.

Here, Poly(vinylidene fluoride) is used for energy harvesting and mechanical stretching, filler reinforcement is used to induce piezoelectricity in the PVDF. The organically modified nanoclay is able to induce piezoelectric β-phase and further stretching enhances its piezoelectric phase. The bio-wastes like eggshell membrane, orange peel, and pomegranate peel also used to induce the piezoelectric phase in PVDF. The structural and morphological changes after have been discussed. The major findings of the thesis are explained below chapter wise:

In **chapter 3** the nanohybrid of P(VDF-HFP) is prepared with nanoclay, the structural changes show that there is induction of piezoelectric β-phase on the addition of nanoclay. To further enhance the piezo-phase these films are stretched, which shows the significant increment in the piezoelectric phase from 18 to 75% in nanohybrid. The piezoelectric coefficient after poling of the stretched sample has been found to be 12 pC/N. The unimorphs are prepared, which is able to produce ~3.8 V voltage.

In **chapter 4** the mechanically processed PVDF is used for energy harvesting. The PVDF film samples were stretched with temperature to enhance the piezoelectric phase. The structural and morphological changes over stretching have been discussed and the piezoelectric phase found to be 75 %. The piezoelectric coefficient measured was 30 pC/N. The samples were further poled to enhance their performance as energy harvesting material. The devices were prepared for energy harvesting, which on finger tapping gives maximum open circuit voltage of 23 V and power density of 55 $\mu W/cm^2$.

In **chapter 5** the nanohybrid of PVDF and nanoclay has prepared, which induces the piezoelectric phase in PVDF. The structural changes show there are both β and γ-phase nucleation in the presence of nanoclay. Further, the samples were stretched and structural and morphological changes show the maximum 80 % piezoelectric phase after stretching. The mapping of piezodomains was done using piezo force microscopy. The prepared device shows maximum open circuit voltage of 30 V and power density of 60 $\mu W/cm^2$.

In **chapter 6** the hybrids of PVDF with Eggshell membrane, Orange peel, and Pomegranate peel is prepared. The eggshell membrane alone is not able to induce piezoelectricity in PVDF so we add both nanoclay and ESM, which induces ~82 % piezoelectric phase due to synergism. The device prepared shows open circuit voltage of 56 V and power of 55 $\mu W/cm^2$. The orange peel alone is able to induce ~70 % piezoelectric phase in PVDF and the device produces 90 V and 135 $\mu W/cm^2$. The pomegranate peel also induces the piezoelectric phase and produces 65 V and 84 μW/cm^2 power on finger tapping. It is important that this performance of the devices are without any mechanical stretching or electric poling. The devices are able to produce voltage on different kinds of stress and can be used in practical applications like capacitor charging and LEDs lightening, as shown.

7.2. Scope for Further work:

The present work reported the synthesis, characterization, and performance of PVDF hybrids for energy harvesting. The effect of different fillers on the induction of the piezoelectric phase has been discussed. Some practical applications of the devices are also shown. However, there is scope for further studies, some of these are given below:

- Exploring other two dimensional materials and bio-wastes for hybrid preparation.
- A better and efficient energy storage circuit.
- Develop a method to enhance the output of the hybrid, which can be used to replace the conventional sources.
- Draw some new fabrication techniques for the device, which can be used in real life.