Surface Potential Decay and DC Conductivity of TiO_2-based Polyimide Nanocomposite Films

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***Abstract*—Polymer nanocomposites have attracted wide interest as a method of enhancing polymer properties and extending their applications. Surface potential decay has been used widely as a tool to monitor charge transport and trapping characteristics of insulating materials. Polyimide (PI) as an engineering material has been paid more attention due to high thermal and chemical stability, good mechanical property and excellent insulating property in a wide range of temperature. There has been a lot of work over last few years on optical, thermal and mechanical properties of polyimide nanocomposites. However, little attention has been given to the effect of nano-fillers on charge transport and trapping in polyimide nanocomposites. In the present paper, pure, 1%, 3%, 5% and 7% polyimide nanocomposites was examined by using surface potential decay in conjunction with dc conductivity measurement and both experiments showed that 3% is the optimal value for electrical insulation.**

I. Introduction

Surface potential decay has been widely used to exam dielectrics properties. Since the cross-over phenomenon was observed in 1967 [1], many researchers attempted to understand the physics behind it. It has been found that bipolar charge injection is the main mechanism for the decay of corona charged sample [2]. As nano dielectrics is getting more and more popular and a wide range of the quantity of nano-fillers in dielectrics were used. Previous research [3] shows that adding 5% nano TiO_2 particles into polyimide (PI) gives the best insulation property from 5%, 10%, 15% and pure PI. In this paper, lower amount of TiO_2-based polyimide nanocomposite material will be carried on study by using both surface potential decay and dc conductivity measurement to find out the optimized value for electrical insulation.

II. Experimental Details

In this paper, Polyimide/TiO_2 (PI/TiO_2) nanocomposite films containing surface modified nano-TiO_2 particles by employing silane coupling agent were prepared using in-situ dispersion polymerization process with 70 μm thickness was used. Due to the surface potential decay is affected by initial charging voltage, initial charging time, temperature and humidity, the surface potential decay experiments were done in a controlled environment where temperature and relative humidity were kept at 23^{o}C and 20%, respectively. A schematic diagram of the experiment set up is shown in figure 1. As the potential was measured by a static monitor, the size of the sample was kept as a square with 55 mm bounder. The DC conductivity was measured for 1 hour charging current under 30^{o}C with varies range of voltage.

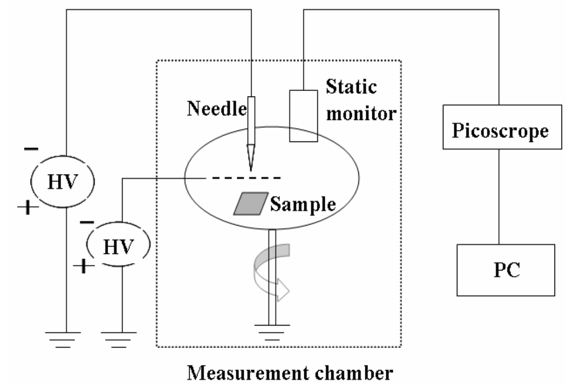

Figure 1. Surface potential decay measurement set up

III. Results and Discussion

A. Surface Potential Decay

As PI is a good insulator, no significant surface potential decay can be observed from the low field test (-2 kV grid potential). Figure 2 gives the results for all the samples on -8 kV grid potential with 3 min charging. From the results, it can be seen that the nanocomposite materials have a higher initial voltage compared with pure PI. It is very clear that for those nano dielectrics, 3% has the best insulation property, 1% is slightly better than 5%, 7% is the worst. The pure PI is difficult to compare with others because of significant difference in the initial surface potential. It is possible that breakdown strength for pure PI is much higher (about 210 MV/m) than the nano dielectrics (180 MV/m for 5%) [4] for a very short charging period (few minutes) less charges are injected into the pure PI and results in a lower initial potential.

B. DC Conductivity

The dc conductivity test was done in an oven, with a 20 mm diameter gold electrodes on both sides. The testing temperature was fixed at 30^{o}C to avoid the influence of small temperature fluctuation in the room on measured current. Figure 3 shows the conduction current for all the samples under 6.5 kV for a period of 1 hour. It can be clearly seen that the results show very good agreement with the surface potential decay results. The pure PI sample can be also examined and it represents that its insulation property is only better than 7% in this case.

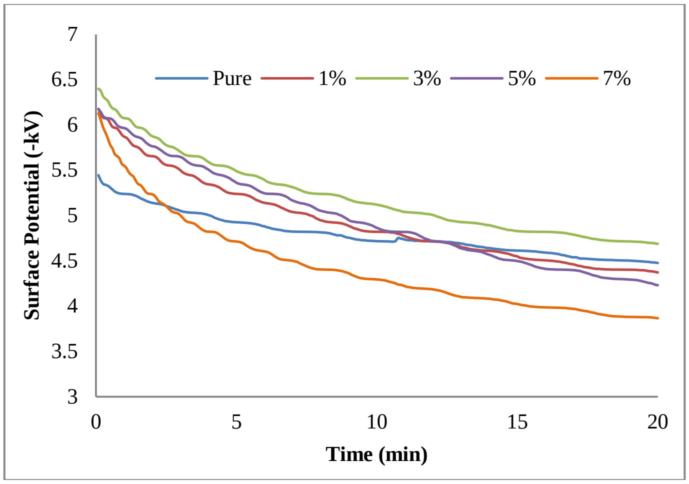

Figure 2. Surface potential decay at -8 kV grid potential with 3 min charging

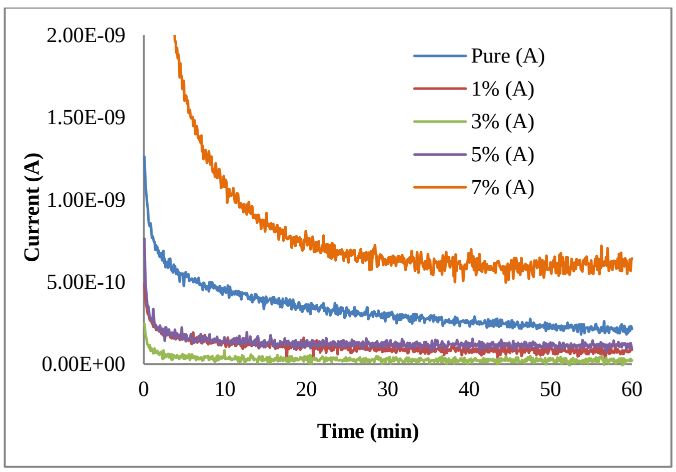

Figure 3. Currents at 6.5 kV for 1 hour

C. Discussion

From the results above, it can be concluded that adding nano particles into dielectrics can improve its electrical properties. However, different amount of nano-fillers will give different results. As 1% and 3% samples reduce the conductivity to the lowest point, it can be known that a small amount of nano-fillers is separated inside the dielectric with a certain wide distance, which can be known as 'extra traps' for the dielectric, and therefore improve the insulation property. However, if more nano particles adding into the dielectrics, for example, 5% sample has a better insulation property than the pure PI, but its conductivity is higher than 1% and 3% samples. This is because that some of the nano-fillers are too closed to each other, and each nano particle has an interaction zone around it [5], which results some overlap of interaction zones. For 7% sample or higher amount nano dielectrics in Reference [3], the probability of interaction zones overlap is getting higher and higher, and therefore, the nano particles may alien together, which helps the charges moving across the dielectric.

IV. Conclusion

In conclusion, it can be said that surface potential decay measurement can be used to compare unknown nano dielectrics properties. The dc conductivity test verifies the surface potential decay result, and also proves that the main mechanism for charge decay is charge injection. The advantage for surface potential decay measurement is that it takes less time to examine one sample; also it can test a bigger sample than the dc conductivity measurement. However, the testing environment has to be carefully controlled and if the initial potential had a big difference, then the comparison cannot be made.

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