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FABRICATION AND CHARACTERIZATION OF HIGH TEMPERATURE FILM CAPACITORS (PREPRINT)

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14. ABSTRACT
Capacitors that perform well at temperature exceeding 150 °C and have energy densities in excess of 1 J/cc are an enabling technology for many applications in automotive, geophysical exploration, aerospace, and the military. To address this need Nanohmics has produced temperature-stable film capacitors using amorphous silicon dioxide as the dielectric material. The capacitors are fabricated by depositing submicron films of silicon dioxide on both sides of a thin metalized poylimide substrate to form dielectric-coated electrodes. Next, two coated electrodes are wound together into a cylindrical shape to produce the capacitor core. Electrical contact is then made to the ends of the cores and electrical wires are attached to the contacts. Measurements indicate that capacitors with amorphous silicon dioxide dielectric have fairly stable capacitance, dissipation factor, and breakdown threshold over a wide temperature range. In this paper Nanohmics presents test results that show1-2μm film capacitors fabricated using SiO_2 dielectric have stable properties over a wide temperature range and a lifetime in excess of 1,000 hours at temperature of 200 °C under applied voltages from 50 to 75 VDC.

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Fabrication and Characterization of High Temperature Film Capacitors

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Abstract

Capacitors that perform well at temperatures exceeding 150˚C and have energy densities in excess of 1 J/cm^3 are an enabling technology for many applications in automotive, geophysical exploration, aerospace, and the military. To address this need Nanohmics has produced temperature-stable film capacitors using amorphous silicon dioxide as the dielectric material. The capacitors are fabricated by depositing submicron films of silicon dioxide on both sides of a thin metalized poylimide substrate to form dielectric-coated electrodes. Next, two coated electrodes are wound together into a cylindrical shape to produce the capacitor core. Electrical contact is then made to the ends of the cores and electrical wires are attached to the contacts. Measurements indicate that capacitors with amorphous silicon dioxide dielectric have fairly stable capacitance, dissipation factor, and breakdown threshold over a wide temperature range. In this paper Nanohmics presents test results that show 1-2 μF film capacitors fabricated using SiO_2 dielectric have stable properties over a wide temperature range and a lifetime in excess of 1,000 hours at temperatures of 200˚C under applied voltages from 50 to 75 VDC.

Introduction

In order to produce electronic systems that operate reliably at elevated temperatures all components including integrated circuits, transistors and capacitors must function efficiently in this environment. Even though a capacitor is generally thought of as an inexpensive passive component, its ubiquity in electrical energy storage, filtering, and power conversion, and its tendency to fail catastrophically, emphasize the need for more stable and reliable capacitors for harsh environments. The key to producing highly reliable and temperature stable capacitors is through improvements in the capacitor dielectric.

Previous studies have been made on diamond like carbon [1] and oxynitrides [2] to identify alternative dielectrics for fabrication of film capacitors. In this paper we present test results from capacitors fabricated using flexible amorphous silicon dioxide as an alternative dielectric to polymer films in the fabrication of non-polar, film capacitors. Amorphous silicon dioxide has a higher dielectric constant, improved breakdown strength, and is more temperature stable than its polymer counterparts. This allows capacitors fabricated using silicon dioxide as the dielectric to achieve high energy densities with consistent operational properties over a large temperature range. This improves capacitor performance and lifetime in harsh environments. By increasing the breakdown strength and dielectric constant compared to traditional polymer dielectrics, film capacitors can be made smaller, thereby reducing the weight and size of many electrical systems. In addition, the temperature stability of the amorphous silicon dioxide dielectrics will make these capacitors compatible with the next generation of high temperature / high power electronic devices made using SOI, GaN and SiC.

Experimental

Preliminary studies of the silicon dioxide dielectric based film capacitor performance have been discussed elsewhere. [3,4] To fabricate the film capacitors, a thin polyimide web with a metal coating on both sides is used as the starting electrode. Next, a submicron layer of SiO_2 is deposited on both sides of the electrode using a custom built web coater. The thin, metal coated polyimide film serves as a flexible electrode that maintains the clearing properties of traditional film capacitors. To fabricate the capacitor, two such coated electrodes are placed together, slightly offset, and wound into a cylinder. A metal end spray is used to make electrical contact to the ends of the film.

Using the above fabrication method the capacitance of the device is determined by the thickness and dielectric constant of the deposited SiO_2. The metalized polyimide web serves as a support structure for the electrodes and should be as thin as possible to maximize energy density. Figure 1 shows the web coating system used to produce the SiO_2 coated electrodes and Figure 2 shows capacitors wound from SiO_2 coated polyimide film after end spray.

Figure 1. Picture of the custom built web coating system used to deposit the dielectric on the metalized film.

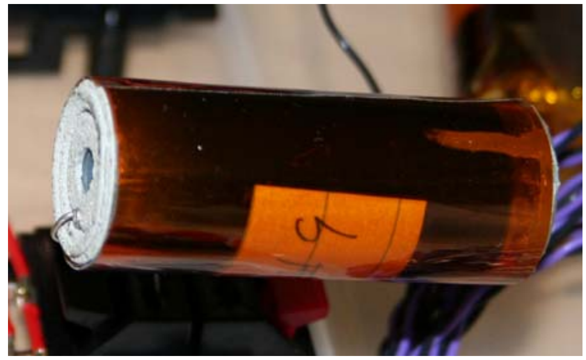

Figure 2. Picture of pre-packaged capacitor cores after winding the SiO_2 coated metalized polyimide electrodes into a cylindrical shape and end spray.

Capacitor Testing and Discussion

Initial test capacitors were made using ~0.35μm of SiO_2 sputter deposited on each side of a 13 micron thick metalized polyimide film. Two of these films were then placed on top of each other and wound ~30 times around a ½" mandrel using a hand winder to produce ~1,5 μF film capacitors. We initially used a ½" diameter mandrel to wind the film but tests indicate that we can wind films on mandrels as small as 1/8".in diameter Future work will focus on smaller diameter capacitors.

Initially the capacitors were tested at room temperature for stability and leakage under a 50 VDC bias. No change in either capacitance (~1.5 μF) or dissipation factor (<1%) was noted during the 800 hour test and leakage remained well under 1 microampere. Next two capacitors were selected and tested to breakdown. One of the capacitors remained at room temperature for the breakdown test and one capacitor was heated 150˚C then tested to breakdown. Both capacitors failed between 130 VDC and 150 VDC.

For the first long term test of temperature stability, three of the capacitors were heated to 150˚C and the capacitance and leakage was measured over a 1000 hour time period under a continuous 50 VDC bias. Results for these capacitors are shown in Figure 3. The capacitance remained fairly stable over the 1000 hour time period and the leakage dropped for all of the capacitors.

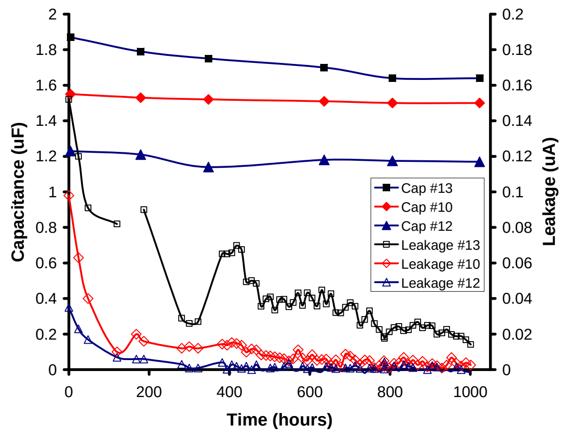

Figure 3. Capacitance and leakage current of three test capacitors as function of time at 150C under a 50 VDC bias

Next the capacitors were heated to 200˚C for 380 hours again under a continuous voltage bias of 50 VDC. The capacitance and dissipation factor (df) at 1000 Hz as a function of temperature is shown in Figure 4 for the combined set of experiments. During the 1000 hr life test at 150˚C and the 380 hour life test at 200˚C the capacitance drops slightly. Upon cooling the capacitance returned to near what it was when the heating experiment started although the df remained at the higher value. We believe the increasing df over time is due to oxidization of the end contact at high temperatures. Work is underway to minimize this effect.

The capacitance of the three capacitors what were tested did not change the same relative percentage as a function of temperature with capacitor #13 changing the most.

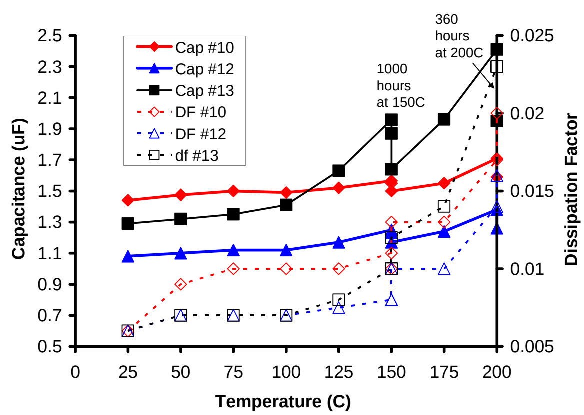

Figure 4. Capacitance and dissipation factor as a function of temperature under 50 VDC bias.

To further investigate the temperature dependence of the capacitors and to obtain more lifetime data, five capacitors were heated to 200˚C. (the original three capacitors that had been previously tested to 200˚C and two new capacitors that had never been heated). These capacitors were compared to small "dot" capacitors that were fabricated by placing a small (3mm diameter) dot on a SiO_2 coated metalized polyimide film. The results are shown in Figure 5. The three capacitors that have already been heated to 200˚C show a smaller change in capacitance as a function of temperature, the two "new" capacitors show a slightly larger change and the dot capacitor does not change capacitance significantly when heated. We believe that the change in capacitance shown in these capacitors is due to thermal movement of the electrodes during the initial heating and not a fundamental property of the dielectric. Work is underway to minimize this effect. Regardless the capacitance remains fairly constant as a function of temperature between room temperature and 200˚C.

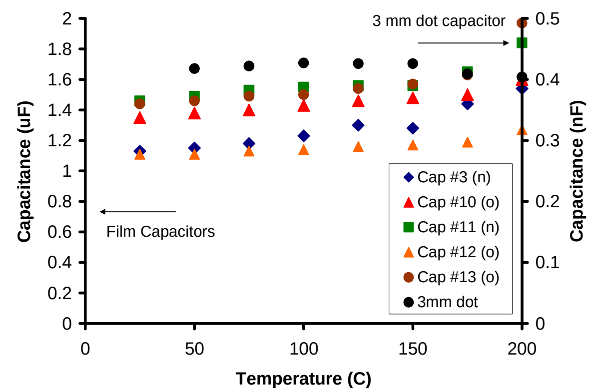

Figure 5. Plot of capacitance as a function of temperature for five SiO_2 dielectric film capacitors and one dot capacitor. (n) signifies that this is the first time the capacitor has been heated (o) signifies that the capacitor has been previously heated to 200^{o}C.

Figures 6 and 7 show life test of five capacitors at 200˚C under a 75 VDC continuous bias. Figure 6 shows the three capacitors that were previously tested at 150˚C and 200˚C and Figure 7 shows the two new capacitor that were heated to 200˚C. The dissipation factor of all the capacitors at 200˚C ranged between 0.008 and .025. There is noticeably more leakage in two of the capacitors that had been at elevated temperatures for a longer period of time. The others operated well with leakages well below a microampere at 200˚C.

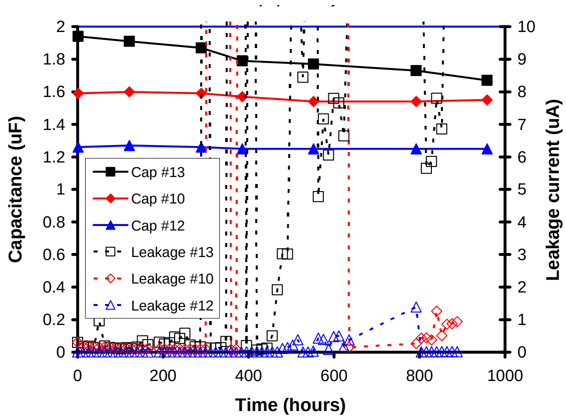

Figure 6. Capacitance and leakage current of three capacitors at 200˚C as a function of time under 75 VDC bias. These capacitors had been previously life tested at 150˚C and 200˚C.

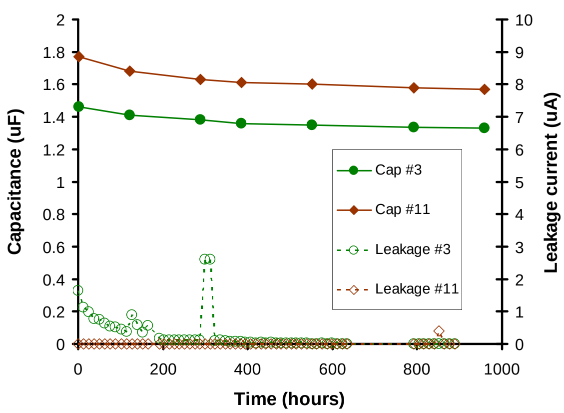

Figure 7. . Capacitance and leakage current of three capacitors at 200˚C as a function of time under 75 VDC bias

Conclusions

Silicon dioxide shows promise as a dielectric material for fabrication of temperature stable film capacitors necessary for systems operating at temperatures >150˚C. Testing to date has been limited due to lack of significant quantities of test capacitors. We are in the process of scaling our fabrication process to faster deposition speeds to produce more capacitors. This will allow us to obtain more statistically significant test data and begin sampling these capacitors to potential customers.

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