Silicon Capacitors with extremely high stability and reliability ideal for high temperature applications

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Abstract

With the wide range of existing capacitors , the end user's requirements are roughly met but most of the capacitors see their performances largely impacted when they are submitted to high temperature .In this paper we present the Silicon Capacitors highly recommended for applications in the geothermal , oil well logging , automotive and military .They can operate in a wide operating temperature range and they withstand temperature up to 250°C, with extremely high insulation resistance and very good stability . These capacitors , already extensively used for years in miniaturized equipment and computers ,feature high miniaturization with a large capacitance to volume ratio , thanks to the IPDiA 3D Silicon technology , extremely stable and reliable even at 100µm thickness . Available in hundreds or thousands of nanofarads , in various sizes and custom configurations ,these capacitors are usable at low frequencies but they are also appropriate for RF applications .The recent progress in the 3D Silicon Capacitor IPDIA technology , which moves the world wide record from 250nF/mm² up to 550nF/mm² , will give even more room to higher integration. This is an ultra key driver to growth for High reliability applications.

Keywords: High-density Silicon capacitors, decoupling capacitors, passive integration, high reliability, high stability, PICS.

1. Introduction

The capacitors are existing in different forms. The type of dielectric (paper, plastic, glass, mica, ceramic, and oxide), the structure of the plates and the packaging all strongly affect the characteristics of the capacitor, and its applications. While very low values (picofarad range) are easily designed , performances of the high value capacitances (µF range) are limited by many factors .Above approximately 1 microfarad electrolytic capacitors are usually used because of their small size and low cost compared with other technologies but life and polarized nature make them unsuitable. Electrolytic capacitors use an aluminum or tantalum plate with an oxide dielectric layer, they are used to store small and larger amounts of energy and they offer very high capacitance but suffer from poor tolerances, high instability, gradual loss of capacitance especially when subjected to heat, and high leakage current. The second electrode is a liquid electrolyte and poor quality capacitors may leak electrolyte, which is harmful to printed circuit boards. Tantalum capacitors offer better frequency and temperature characteristics than aluminum, but higher dielectric absorption and leakage. Plastics capacitors often used in timer circuits, offer good stability and aging performance but they are limited to low operating temperatures and frequencies. Ceramic type 2 or type 3 capacitors are generally small, cheap and useful for high frequency applications, although their capacitance varies strongly with voltage and they age poorly. Glass and mica capacitors are extremely reliable, stable and tolerant to high temperatures and voltages, but are too expensive for most applications.

This paper reports on the high-density 3D Silicon capacitors commercially available at IPDiA , highly stable and reliable at high temperature (up to 250°C) [1]

2. High-density 3D Silicon Capacitors

The capacitors are fabricated in reactive ion etching etched arrays of macropores with high aspect ratios up to 60 with a typical width of 1 µm.

Capacitors with Oxide/Nitride /Oxide dielectric stacks and polysilicon top electrodes yield a capacitance density of 250nF/mm² ,an electrical breakdown voltage of 11V and very low leakage current (<1nA at the working voltage).These capacitors also show low loss factors (equivalent series resistance ESR < 150mohms and equivalent series inductance ESL < 250pH). Last year , IPDiA released this process for mass production , launched derivative options with higher breakdown voltage (figure1) and demonstrated the feasibility to reach 550nF/mm² at 11 volts breakdown .Obviously this huge capacitance density increase is achievable thanks to higher k-dielectric layers and to the ALD (atomic layer deposition) enabling excellent step coverage of the deposited layer [2].

Fig.1: Process nodes available at IPDiA

C nF/mm²	Vbd (V)
250	11
100	30
80	17
25	28
20	50
6	150

These capacitors in ultra deep trenches have been developed and implemented in a process called PICS (Passive Integration Connective Substrate) in order to integrate passive components such as high-Q inductors , resistors , accurate planar MIM capacitors and trench MOS capacitors for many applications like for example switched capacitor voltage multiplier or buck converter , decoupling and filtering .This process is providing a fully CMOS compatible solution for the integration on chip or multiple chip module .Its potential for miniaturization means smaller component size , reduced manufacturing costs per product ,low power consumption and integration of more basic functions into one product.

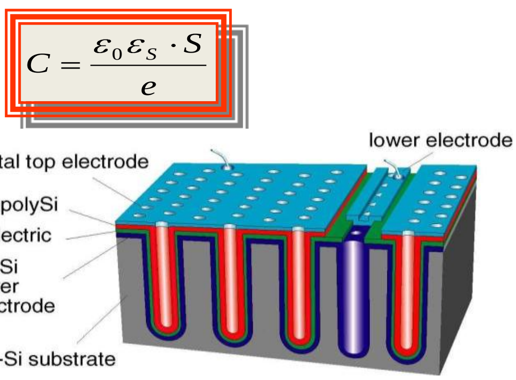

Fig.2: Capacitor scheme.

3. Stability to high temperature

These 3D Silicon Capacitors, available in a full range of sizes are compatible with operating temperatures of 150, 200, and 250°C. The high temperature capacitors are popular for many applications that require stable performance in harsh environment applications like down-hole oil exploration and logging, jet aircraft engine controls, automotive, avionics or military applications .IPDiA high temperature capacitors offer very stable performance when compared to typical MLCC components. At temperature above 150°C, the X7R and X8R capacitors suffer from severe reduction in capacitance and degradation of reliability performance, especially under DC bias conditions. One approach to use these capacitors at temperatures above their design limit is by de-rating their rated voltages. For example, X7R dielectrics with good reliability can be used at 150°C after 50% voltage de-rating. The C0G capacitors have the advantages of high stability of capacitance over temperature and voltage, no aging of capacitance, but despite the progress in the technology, the capacitance density is limited.

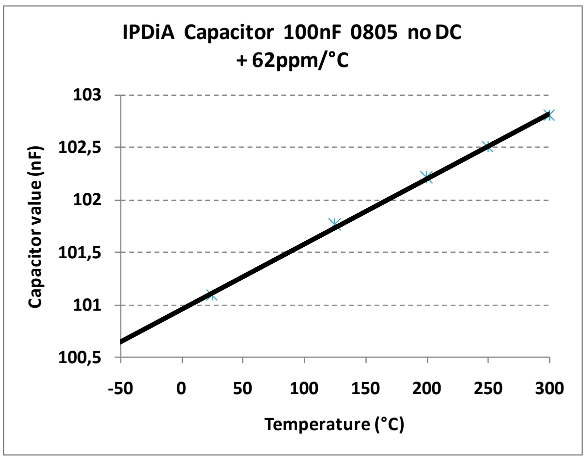

Fig.3: Capacitance dependence on temperature.

The temperature dependence of capacitance is expressed in parts per million (ppm) per °C. A linear function is obtained even at the temperature extremes (see figure 3). The temperature coefficient is positive equal to + 62ppm per °C. The capacitance variation of a 0805 100nF capacitor is 1.8% from room temperature to 300°C whereas the MLCC industry shows more than 60 % variation. The IPDiA 3D Silicon capacitor also exhibits highly stable capacitance as a function of temperature and voltage (see results on fig4 plotted at 3 temperatures -55°C , 125°C and 200°C) while still maintaining good reliability (fig 7).

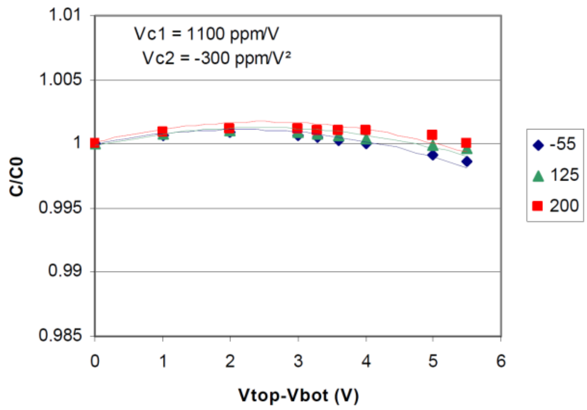

Fig.4: Capacitance dependence on DC bias and temperature

4. Leakage current at high temperature

Leakage is currently one of the main factors limiting performance at high temperature. Increased leakage is a common failure mode resulting from non-catastrophic overstress of a dielectric [3]. A single valued leakage current is of no value for analysis
The leakage current must be measured under a range of conditions of time, voltage, and temperature. The leakage current of a IPDiA 0805 100nF capacitor was measured after 120s stabilization at 3V. The leakage as a function of temperature is shown in Figure 5. Even at 300°C , the leakage current doesn't exceed 2nA .This is very impressive compared to the other High Temperature capacitors available on the market which demonstrate , when there are still functional ,a leakage current 1000 times higher .

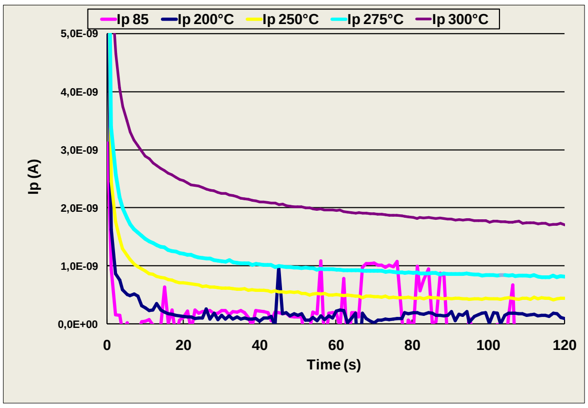

Fig.5: Variation of leakage current over the temperature range of 25C to 300C.

This "leakage current" through the dielectric is usually converted to the expression "insulation resistance" by using Ohm's law. The Insulation Resistance (ΩF) of the IPDiA 3D Silicon capacitors is compared to NPO/COG dielectrics and the result is shown in Figure 6.

The 2 orders of magnitude observed between the 2 types of capacitors are primarily due to the type of dielectric used. The thickness of the dielectric and the magnitude of the charging voltage have a comparatively minor effect on the leakage current.
The effect of the insulation resistance value is quite critical in circuitry where leakage of current through the capacitor can cause malfunction or undesirable results to occur. Prime examples of this type of application are those involving DC and low AC frequencies in most blocking, coupling, and timing circuits.

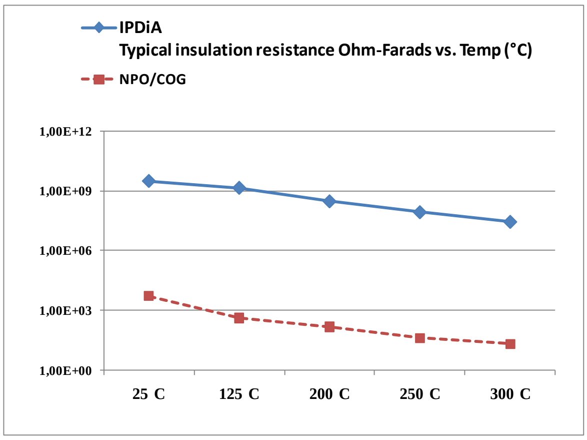

Fig.6: Typical insulation resistance (ΩF) over the temperature range of 25C to 300C.

5. Failure Rate

The capacitors are essential passive components in electronic and they constitute 30% of the passive components world market .Their main fault is their relatively high rate of failure compared to the other components.
Information on component failure rates provides the manufacturer with a basis for reliability forecasts and allows him to estimate future service requirements. The failure rate depends on the failure criteria, the load and the operating time. The dimension of the failure rate is the reciprocal of time and the unit used is 10^{-9} / h = 1 FIT (failure in time).
IPDiA has done extensive reliability testing and has compiled the FIT's data which is very impressive (figure 7).This result is compared to the High Temperature X8R.The gap between the robustness of the 2 Types of capacitors visible at room temperature is increasing in favor of IPDiA as a function of temperature .

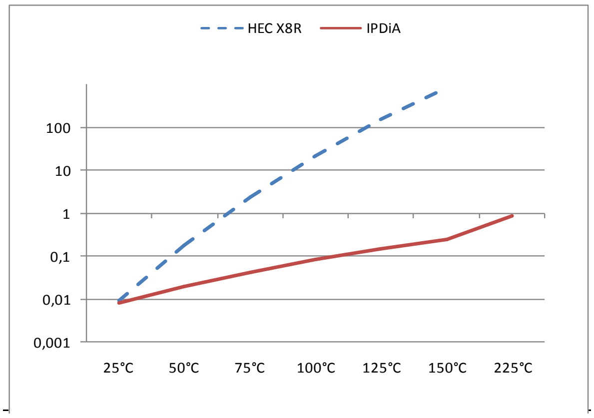

Fig.7: FIT rates calculated at 60% confidence level

6. Applications.

These capacitors are commercially available in different sizes from 1005 to 2016 with conventional terminations, low profile (die thickness of 100µm, 250µm and 400µm) [4]. They can be stacked (see figure 8) and as mentioned in chapter 2 , these capacitors can be customized , embedded as capacitor arrays with R, L components in a single integrated passive die[5] . The stability to high temperature makes them usable for harsh environment applications.

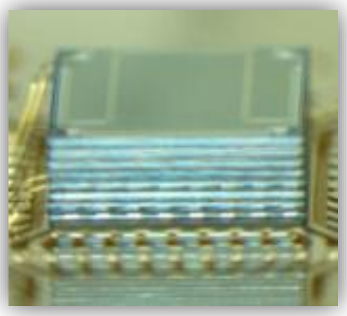

Fig.8: a 33µF Capacitor in a package size of 4.8mm*4.4mm*2 mm

7. Conclusion

The electrical properties of the IPDiA 3D Silicon capacitors over the entire temperature range of 25°C to 300°C were presented in this paper.
The capacitance dependence on DC bias and temperature exhibits nearly flat response and the reliability is maintained at a very high level with 1 FIT at 225°C (more than 10^5 lower than the competition).
The leakage current is very low and the insulation resistance is 1000 higher than with the more stable capacitors available in the market.
IPDiA's technology offers a very high capacitance density, typically 250nF/mm² in production, enabling large capacitor values in small spaces.
The 550nF/mm² which should be commercially in the coming years will bring drastic miniaturization and derivative process options for high breakdown voltage.

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