Automotive Grade Silicon Capacitors for 'Under the Hood' Applications

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Abstract
This paper covers technological results achieved with silicon capacitors in low power automotive applications (smart sensors) including stability and reliability data at high temperatures. Size constraints of the capacitors for 'under the hood' applications will also be addressed.

Keywords
Automotive grade capacitor, automotive sensor, smart sensor, high reliability capacitor, high temperature capacitor, 'under the hood' application.

Introduction

The need for more and more electronics in the automotive field has led the manufacturers to reconsider the car design with more concern for space savings. A solution has been found by placing some of the electronics under the hood, avoiding the use of cumbersome harnesses. However, this has led to another constraint: produce long life components with performance preserved when exposed to harsh conditions. The most challenging parameters to be considered by 'under the hood' sensor manufacturers are reliability, operating temperature range and size. Most of capacitors used in these sensors assure a stable and reliable function up to 150°C. For current and future requirements, this is not sufficient. Sensors used in ignition, oil pressure, ADS, motor management, etc. need better electronics integration and compliancy with operating temperatures from -55 °C to +200 °C.

IPDiA silicon capacitors, already used extensively for many years in miniaturized equipment, show stability and reliability coupled with a low profile. IPDiA R&D center has developed a new range of silicon capacitors called ATSC dedicated to 'under the hood' applications that provide a reliable and stable solution up to 200 °C. ATS capacitors have been qualified according to the Automotive Electronics Council's AEC-Q100 requirements. Within the AEC-Q100, five different Part Operating Temperature Grades have been defined. The most stringent is Grade 0 with an operating temperature range from -40 °C to +150 °C. It must be pointed out that ATS capacitors have been subjected to tests from -55 °C to 200 °C which exceed the Grade 0 requirements of the AEC-Q100.

The manufacture of IPDiA passive components is based on the PICS technology (Passive Integration Connecting Substrate). The benefits of this integrated passive silicon technology have already been demonstrated in terms of low leakage current, high stability, low aging and compliancy with operating high temperature. Due to their close integration to active components and innovative assembly technology, passive devices "on silicon die" offer significant improvements for signal integrity and space savings compared with the commonly used SMD components.

This paper reports on IPDiA high-density silicon automotive grade capacitors for 'under the hood' applications. It presents some results on capacitance stability, voltage derating, leakage current, lifetime and electromagnetic compatibility.

Miniaturization of sensors implies availability of miniaturized capacitors

The race to more and more miniaturization is the daily concern of electronic designers and this is especially true for automotive applications where increasingly compact sensors are required in order to minimize their volume and weight in the final system. First step into miniaturization and integration, high-density silicon capacitors are a solution to reduce the dimensions of the sensors. 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 resistors, accurate planar MIM capacitors and trench MOS capacitors for numerous applications, such as switched capacitor voltage multiplier or buck converter, decoupling and filtering. This process provides a fully CMOS-compatible solution for 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 a single product [1].

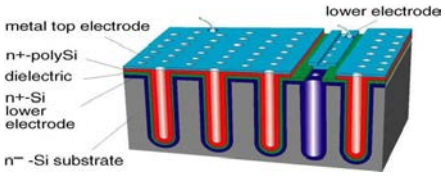


Figure 1: Schematic of a PICS capacitor

The capacitors are manufactured in etched arrays of macropores by reactive ion etching with high aspect ratios of up to 60 with a typical width of 1 µm [2]. A range of silicon capacitors using this technology has thus been specifically developed to meet 'under the hood' requirements with the following capacitance values and sizes:

Capacitance	Case size	Thickness
1 nF	0202	250 µm
47 nF	0505	250 µm
100 nF	0605	250 µm

These capacitors – so called ATSC - with Oxide/Nitride/Oxide dielectric stacks and polysilicon top electrodes yield a capacitance density of 100 nF/mm², an electrical breakdown voltage of 30 V and very low leakage current (< 0.5 nA at the working voltage and room temperature). They also show low loss factors (equivalent series resistance ESR < 100 mΩ and equivalent series inductance ESL < 250 pH). The ATS capacitors have been developed with a rated voltage of 16 V, in order to meet the automotive voltage ratings requirements that have been specified at a minimum value of 14 V [3].

As mentioned previously, electronic components in cars need to withstand extremely harsh conditions throughout their lifecycle. The following paragraphs will show the results obtained with IPDiA silicon capacitors in terms of capacitance stability, voltage derating behavior, leakage current, reliability and transient pulses. Some of these results are extracted from 'Silicon Capacitors with extremely high stability and reliability ideal for high temperature applications' [2].

Capacitance stability over temperature

The 3D Silicon Capacitors developed by IPDiA for harsh automotive environment are compatible with operating temperatures up to 200 °C. They offer very stable performance compared with typical MLCC components. At temperatures 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 derating their rated voltages. For example, X7R dielectrics with good reliability can be used at 150 °C after 50 % voltage derating. The C0G capacitors have the advantages of high capacitance stability over temperature and voltage, no aging of capacitance, but despite the progress in the technology, the capacitance density is limited.

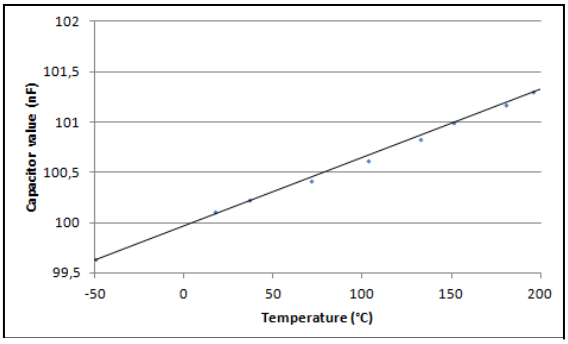
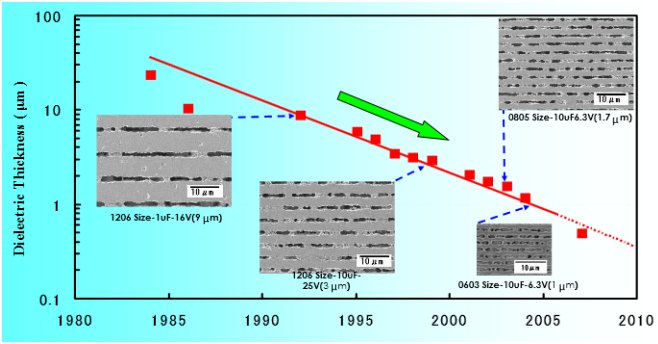


Figure 2: Capacitance dependence on temperature for an ATS capacitor, 0605 100 nF

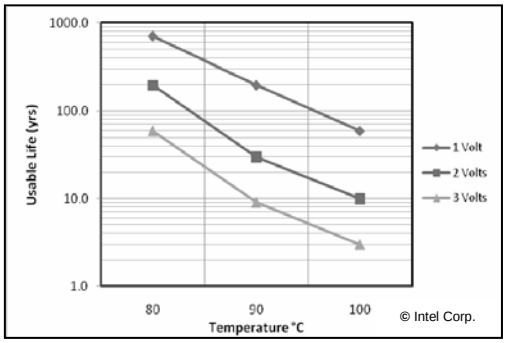
The temperature dependence of capacitance is expressed in parts per million (ppm) per °C. A linear function is obtained even at extreme temperatures (see Figure 2). The temperature coefficient is positive and equal to + 62 ppm per °C. The capacitance variation of a 0605 100nF capacitor is around 1 % from room temperature to 200 °C whereas the MLCC industry shows more than 50 % variation.

Voltage derating concern

Market Trend for the MLCC manufacturers and for customer applications is mainly driven by miniaturization. In order to reach a given capacitance and voltage in a smaller case, MLCC manufacturers developed thinner electrodes and thinner dielectrics (see graph below).



To date, failure due to dielectric wear has not been a concern for the MLCCs. Over the last decade, however, as the capacitance per volume has increased, the long term reliability has been significantly impacted (such as shown in graph below).



These developments therefore led to lower reliability, which is a major problem for the automotive market. In this market, in order to avoid reliability issues when using MLCC, it is common to use a voltage derating factor of at least 3. This means that very high rated voltage capacitors (i.e. 50 V or 100 V) must be designed for a typical operating voltage of 16 V. Voltage derating improves MLCC reliability, but generates a significant overspecified voltage, hence bigger case size and therefore poor miniaturization. IPDiA technology can solve this miniaturization issue. Derating is no longer even required, in fact, as the ATSC range is specified to operate at 200 °C continuously, under 16 V for 18 000 hours (see paragraph on capacitor lifetime below). A 1 nF in a 0202 package, or a 100 nF in a 0605 package, can therefore be offered with the characteristics of an ultra stable capacitance value over temperature, voltage & lifetime (0.01 % capacitance drift per 1000 hours).

Leakage current concern at high temperature

Leakage is currently one of the main factors limiting performance at high temperature. The leakage current must be measured under a range of time, voltage, and temperature conditions. The leakage current of an IPDiA 0505 47 nF capacitor was measured after 120 s stabilization at 16 V. The results at 25 °C and 200 °C are given in table 1. Even at 200 °C, the leakage current does not exceed 28 nA. As a comparison, other high temperature capacitors available on the market demonstrate, when there are still functional, a leakage current 100 times higher.

Capacitance	Case size	Leakage current (nA) @ 25 °C	Leakage current (nA) @ 200 °C
47 nF	0505	0.430	28

Table 1: Leakage current at room temperature and at 200 °C

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 with NPO/COG dielectrics and the result is shown in Figure 3. The 2 orders of magnitude observed between the 2 types of capacitor are primarily due to the type of dielectric used. The thickness of the dielectric and the magnitude of the charge 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 a malfunction or undesirable results. Prime examples of this type of application are those involving DC and low AC frequencies in most blocking, coupling, and timing circuits.

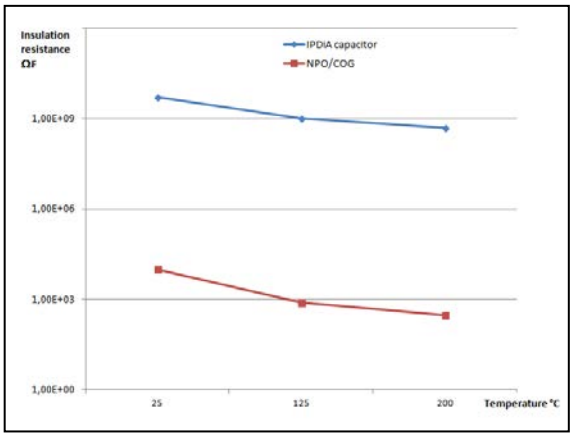


Figure 3: Typical insulation resistance (ΩF) over the temperature range of 25 °C to 200 °C

Reliability results throughout capacitor lifetime

In order to confirm the compatibility of the ATSC series with the automotive applications, reliability data have been obtained by testing the lifetime of a 100 nF 0605 capacitor at elevated voltage. The Time-Dependent Dielectric Breakdown (TDDB) measurements are used to model the intrinsic behavior of the capacitor dielectric under elevated temperature and strong electric field. The acceleration factors for temperature and electric field are used to extrapolate the capacitor lifetime under typical operating conditions. The results are shown on Figure 4.

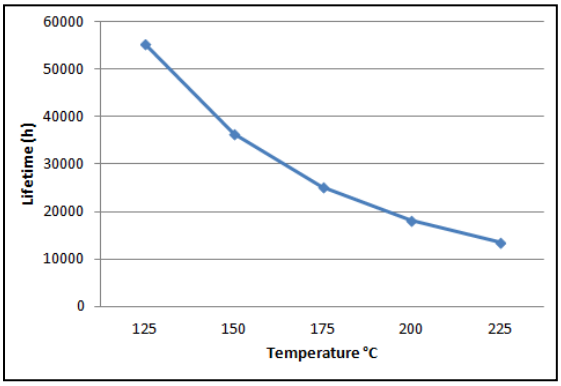


Figure 4: Lifetime evolution over temperature

This graph shows some important figures. The lifetime of an ATSC 100 nF 0605 exceeds 25 000 hours at 175 °C and 18 000 hours at 200 °C. As a comparison, X8R capacitors show a useful life of 10 000 hours at 125 °C at the rated voltage.

Reliability results through transient pulses

Electronic systems must operate without interfering with each other and without reacting to external interference signals. However, transient phenomena occur involving very short duration events of high amplitude which can disrupt or destroy electronic circuits and components in an electronic device. Reliability of automotive electronic equipment also depends on its capability to cope with these transient events and has to be tested via transient testing. To check the performance of its silicon capacitors, IPDiA R&D has tested them according to the

ElectroMagnetic Compatibility (EMC) specifications for road vehicles written by the Society of Automotive Engineers (SAE) and the International Organization of Standardization (ISO). For instance, failure analysis of damaged electronic systems revealed that transistors directly connected to the DC supply lines were completely destroyed by high energy pulses, so-called 'Load Dump' [4]. The results for the load dump pulse testing (suppressed pulse, also known as Pulse 5b) are given below for a 12 V system.

The test specification details the values of the test voltage (Ua), peak voltage (Us), internal resistor (Ri), pulse duration (td) and rise time (tr).

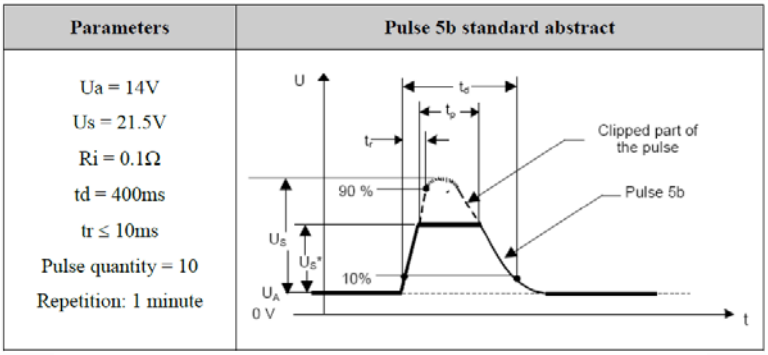


Figure 5: Suppressed Pulse 5b wave shape and parameters

Pulse 5b testing for a 12 V system of ISO 7637-2 standard has been applied on 1 nF, 47 nF and 100 nF ATS Capacitors. The devices all withstand pulse 5b testing of ISO 7637-2 standard. As part of the EMC Directive, tests on the transient characteristics for pulse 2a, 3a, 3b have also been conducted, leading to the conclusion that the ATSC series meet the requirements of these standards.

Conclusion

IPDiA has developed a range of silicon capacitors for 'under the hood' applications that is perfectly adapted to the automotive market segment expectations in terms of long-term stability and long-term reliability from -55 °C up to 200 °C. IPDiA technology provides higher capacitance values in smaller case sizes which are difficult to achieve with conventional ceramic capacitors. Furthermore, the ATSC series from IPDiA complies with the EMC specifications for road vehicles. The table below summarizes the electrical performance of the IPDiA 100nF ATS capacitor.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
C	Capacitance value		-	100	-	nF
ΔC_P	Capacitance tolerance		-15	-	+15(*)	%
T_{OP}	Operating temperature		-55	20	200	°C
ΔC_T	Capacitance temperature variation	-55 °C to 200 °C	-1	-	+1	%
RV_{DC}	Rated voltage		-	16		V_{DC}
ΔC_{RVDC}	Capacitance voltage variation	From 0 V to R V_{DC}	-	-	0.1	$\%/V_{DC}$
IR	Insulation resistor @16 V, 200 °C		-	1	-	GΩ
ESR	Parasitic series resistance		-	100	-	mΩ
Q	Quality factor	@ 1 kHz	-	1500	-	
ESL	Parasitic series inductance		-	250	-	pH

(*) Other capacitance tolerances available on request.

The results are in accordance with the Absolute Maximum Rating System (IEC 60134).

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[1] G. Raimbault, 'Architecture of industrial sensors – interest of silicon passive networks'
[2] C. Bunel, L. Lengignon 'Silicon Capacitors with extremely high stability and reliability ideal for high temperature applications'
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