WHITE PAPER

How Fusion® F07 Outperforms Typical Fluoroelastomers in Semiconductor Applications without the Cost Premium of Perfluoroelastomers

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Introduction

The quest for higher performance has steadily increased the complexity of semiconductor manufacturing. Corrosive, exotic, and highly reactive gases combined with new metallization chemistries have increasingly challenged subfab vacuum and abatement systems, requiring more advanced seals to help ensure uptime. Greene Tweed's Fusion® F07 was developed to address these key challenges for subfab sealing materials.

Fusion® F07 is an enhanced Fluoroelastomer sealing material designed to deliver high performance at a lower cost of operation than existing premium sealing technologies. Its ability to withstand excursion temperatures up to 220°C (428°F), continuous service temperature of 180°C (256°F), and a broad range of harsh chemicals while reducing cost of operation compared with premium sealing materials makes F07 ideal for sealing in subfab applications. In this white paper, we focus on specific sealing elements that are frequently replaced in subfab equipment and the cost and performance benefits of F07 for these applications.

Subfab Sealing Applications

Today, manufacturing processes require the utilization of more exotic gases at higher temperatures. The combination of new gases and higher temperatures has driven the development of new subfab sealing solutions that can perform reliably under these harsh conditions.

The subfab is critical to maintaining the operational effectiveness of the cleanroom environment above it. As wafers undergo a variety of processes including etch and deposition, effluent gases like flammables, oxidizers, and corrosives are shuttled through exhaust lines into the subfab for safe disposal.

Gases flowing into the subfab condense within system exhaust lines, causing particle deposition which can lead to premature equipment failure. To keep gas molecules moving, thermal management systems are utilized to increase temperatures within the exhaust lines. The use of these higher temperatures heightens the need for more robust seals in pumps, abatement units, and valves.

Seal material selection considerations include temperature and chemical resistance to highly reactive gases and radical species. Selecting or installing the wrong material into a subfab application could compromise the integrity of the seal and possibly lead to safety hazards and other unplanned maintenance events that impact production in the cleanroom above.

Elastomer Seals

Within the subfab, elastomers are often chosen as the seal material because they are flexible, durable, easy to install, and conform well against many different surfaces. An elastomer or rubber is a polymer chain with viscoelasticity, meaning that it can be stretched and retracted. Elastomers make excellent sealing materials due to their self-energizing property which provides a sealing force response when compressed.

Elastomers are often molded into shapes such as O-rings or gaskets. Compared to other sealing solutions such as metal or plastic, elastomeric seals are more effective in mitigating leakage because they are generally more forgiving and conform well to most surfaces and thereby establish a tighter, more reliable seal.

Choosing the optimal elastomer material depends largely on the application requirements. As high-performance materials, Fluoroelastomers (FKMs) and Perfluoroelastomer (FFKMs) are often chosen for semiconductor applications requiring a high degree of temperature resistance, chemical compatibility, or both. FKMs have excellent compression set resistance, are resistant to a broad range of chemicals, and can operate in temperatures up to 220°C (428°F). FFKMs are resistant to nearly all chemicals, including plasma, and can operate in temperatures up to 323°C (614°F).

The Importance of Plasma Resistance

The increasing aggressiveness of conditions in the fab process chambers and reactors has effectively limited the reliability of general purpose FKMs in the subfab environment. Semiconductor manufacturing processes produce plasma gas, which is extremely damaging to most conventional seals. Even FKM polymers, which are known for their broad chemical resistance against many aggressive chemicals such as acids and solvents, are attacked by plasma.

When traditional FKMs are attacked by plasma, they will break down, crack, or fail prematurely, particularly in remote plasma NF3 conditions (Refer to Fig. 1 where the Fusion® 742 - a type 1 FKM compound - samples were destroyed in remote plasma). The higher the level of plasma exposure, the more quickly seals fail. Historically, subfab processes had very minor exposure to plasma and traditional FKM seals were acceptable. But as fabrication processes use more aggressive forms of plasma and higher temperatures, traditional FKMs are breaking down.

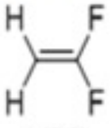
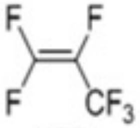
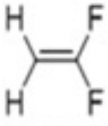
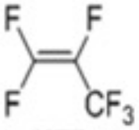
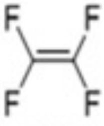
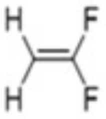
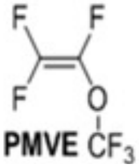
What is Fusion® F07?

Greene Tweed's high-performance Fusion® F07 is a robust, plasma-resistant FKM material that was designed by industry leading material scientists specifically withstand the increasingly aggressive conditions in semiconductor subfab processes. Fusion® F07 contains higher amounts of fluorine than general purpose FKM materials, contributing to its exceptional chemical resistance to plasma.

The objective in developing Fusion® F07 was to improve the performance that can be achieved with an FKM while avoiding the cost premium associated with using an FFKM. This was accomplished by optimizing three specific building blocks in Fusion® F07 that enhance the performance and suitability of its use in semiconductor subfab applications.

The first building block is the type of polymer used in Fusion® F07. It is a Type 2 high fluorine terpolymer (FKM Types 1-3 are shown in table below - ref ASTM D1418), where the high percent fluorine in the polymer provides improved chemical resistance over standard FKMs.

Table 1: Type of FKM as per ASTM D1418

ASTM D1418	Composition	Description	Nominal % Fluorine in Polymer	Typical Low Temp. Flexibility (TR10, °C)
Type 1	 VDF  HFP	Dipolymer of hexafluoropropylene and vinylidene fluoride.	66	-17
Type 2	 VDF  HFP  TFE	Terpolymer of vinylidene fluoride, hexafluoropropylene, and tetrafluoroethylene.	68 to 70	-6 to -13
Type 3	 VDF  PMVE	Terpolymer of vinylidene fluoride, a fluorinated vinyl ether and tetrafluoroethylene.	64 to 67	-30 to -24

The second building block for Fusion® F07 is the cure system. The two most widely used cure systems for FKM elastomers are the bisphenol cure system and the peroxide cure system. While bisphenol provides a faster cure, it typically requires the addition of 3 parts per hundred rubber (PHR) of magnesium oxide and 6 parts (PHR) of calcium hydroxide. These high levels of metals are of concern in any applications within close proximity to semiconductor chambers. Fusion® F07 uses the peroxide cure system where high metal additives are not required, resulting in a lower metal content in the final cured FKM material.

The third important building block of Fusion® F07 is the selection of the filler. The high fluorine organic polymeric filler used in Fusion® F07 was selected because of its low metals content, high fluorine content, and ability to add this specific filler in higher concentrations than other similar fillers without stiffening or hardening of the end product.

The color of Fusion® F07 is dark gray (Fig. 1) and can be readily distinguished from typical carbon black filled FKM, such as Greene Tweed's Fusion® 742, for this type of application. This compound does not require cleanroom processing and can be mixed and processed in larger production equipment, another factor in providing lower cost of ownership for our subfab customers.

The result is a higher total fluorine content FKM compound with broad chemical resistance and good plasma resistance offering excellent performance at a more advantageous price than FFKM materials.

Fusion® F07 – Application & Use Within the Subfab

Seals in semiconductor subfab equipment are exposed to harsh conditions that often exceed the capabilities of a typical FKM fluoropolymer seal. Historically, the next level of performance above an FKM material has been FFKM materials, which can run several orders of magnitude higher in cost compared with FKMs.

Fusion® F07 is an ideal material for subfab applications, where resistance to continuous high temperatures (180°C continually for up to 6 months) and chemical resistance to common Etch and CVD (oxygen or fluorine-based) gases may be advantageous, but where environments are less harsh than fabrication (Fab) applications. Fusion® F07 delivers a lower-cost material compared to FFKMs for Subfab applications while providing increased temperature and chemical performance compared to a typical FKM material.

Fusion® F07 Compared with Two Other FKM Based Compounds:

Fusion® F07 is a dark gray colored peroxide-cured 81 duro shore A compound using a high fluorine Type 2 FKM with a high fluorine filler processed in higher volume standard equipment.

Fusion® F10 is a tan colored peroxide cured 78 duro shore A compound using a high fluorine Type 2 FKM with a high fluorine organic filler. The same performance enhancements that can be found in Fusion® F07 can also be found in Fusion® F10, however F10 is tan in color and is mixed and processed in smaller cleanroom equipment. Fusion® F10 was developed for applications where low particulation is critical, while Fusion® F07 was specifically developed for subfab applications where particulates are not as critical. Critical locations are defined as sealing locations that will impact yield if the sealing solution sheds particles (contaminants) while in operation.

Fusion® 742 is a carbon black filled black 75 duro shore A compound using a standard Type 1 FKM and a bisphenol cure system that includes calcium and magnesium salts as part of the cure and is processed in higher volume standard non-cleanroom equipment.

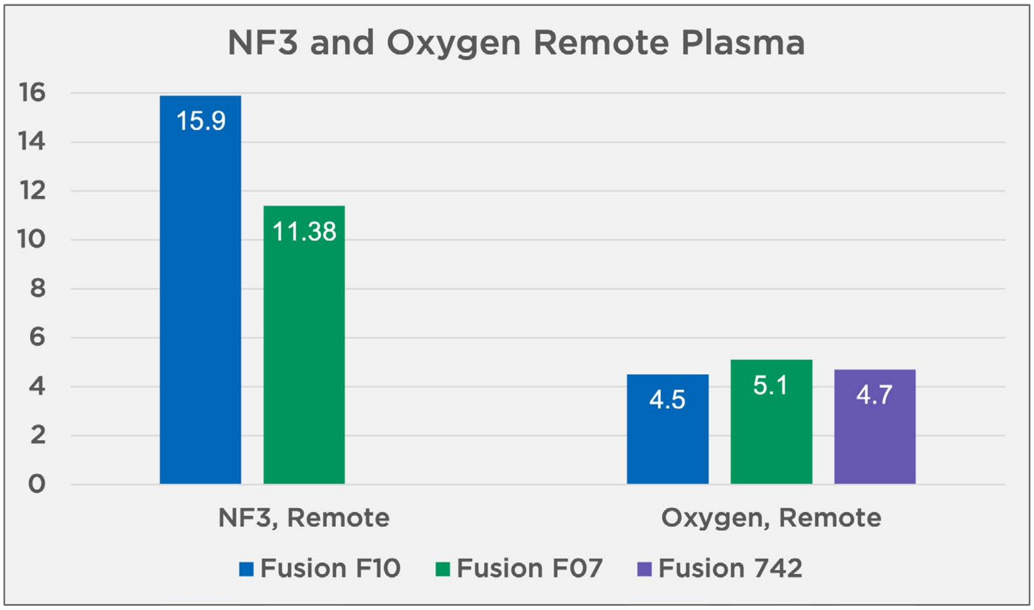
Table 2: Properties of Fusion® Materials			
Description	**Typical Properties**		
	Fusion® F07	**Fusion® F10**	**Fusion® 742**
Color	Dark Gray	Tan	Black
Hardness, Shore A (ASTM D2240)	81	78	75
Tensile Strength @ Break, psi (MPa), (ASTM D1414)	2047 (14.11)	1450 (10.00)	2050 (14.14)
Elongation, %, (ASTM D1414)	284	240	182
Tensile Modulus @ 100 % Elongation, psi (MPa), (ASTM D1414)	604 (4.16)	550 (3.79)	1026 (7.08)
Compression Set @ 25 % Deflection, 70 Hours @ 392°F (200°C), %, (ASTM D395)	29	23	20

Figure 1: Color Identifications of Various Fusions Compounds

Figures 2 and 3 compare the plasma resistance between Fusion® F07 and the other FKM compounds.

Figure 2:

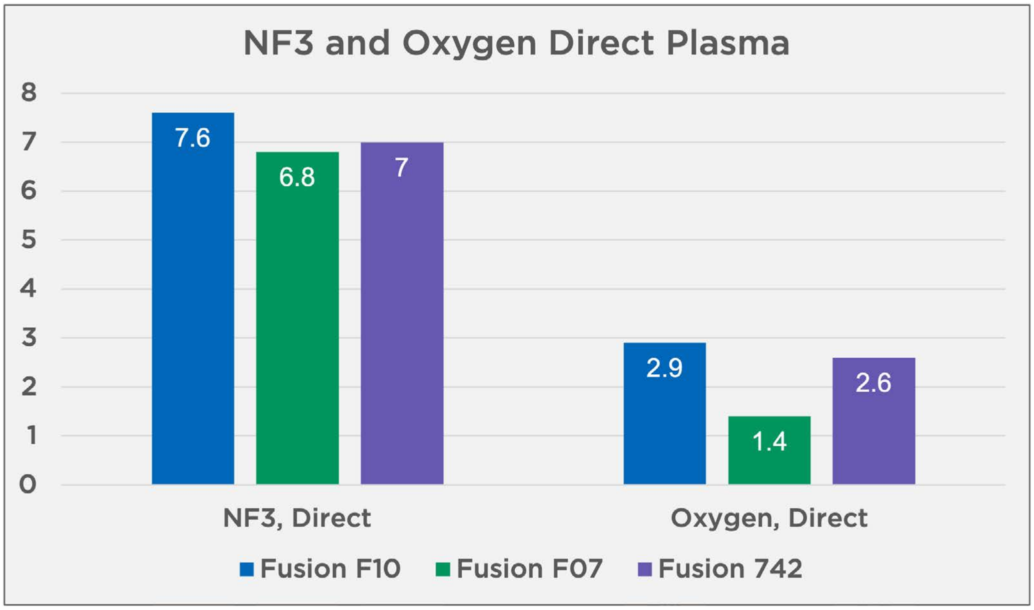
Effect of NF3 and Oxygen Remote Plasma on Three Different Fusion Materials at 200°C



**Fusion 742 sample destroyed when exposed to remote NF3*

Figure 3:

Effect of NF3 and Oxygen Direct Plasma on Three Different Fusion Materials, 90 Minutes Exposure



Determination of Excursion and Continuous Service temperature of Fusion® F07:

Excursion and continuous service temperature of Fusion® F07 were determined by using a long-term compression set testing method.

Compression set measurement was performed based on ASTM D395 (Method B) on AS568A-214 o-ring samples at 25% deflection. Figure 4 shows a plot of the compression set results for Fusion® F07 at 175°C, 200°C and 225°C at multiple time-points from 70 to 1000 hours. Each data point represents a median of three compression set determinations.

The time to reach 80% compression set at each of the three temperatures was then calculated and a separate plot based on this result was generated (see Fig. 5).

A log linear regression model was used to determine the best-fit line, after which the temperature at which 80% compression will be reached after 168 hours, 1000 hours, and 4368 hours (6 months) can be calculated. Table 3 summarizes the upper use temperature results of Fusion® F07.

Figure 4:

Plot of Raw Data from Compression Set Testing on Fusion® F07 at Three Temperatures

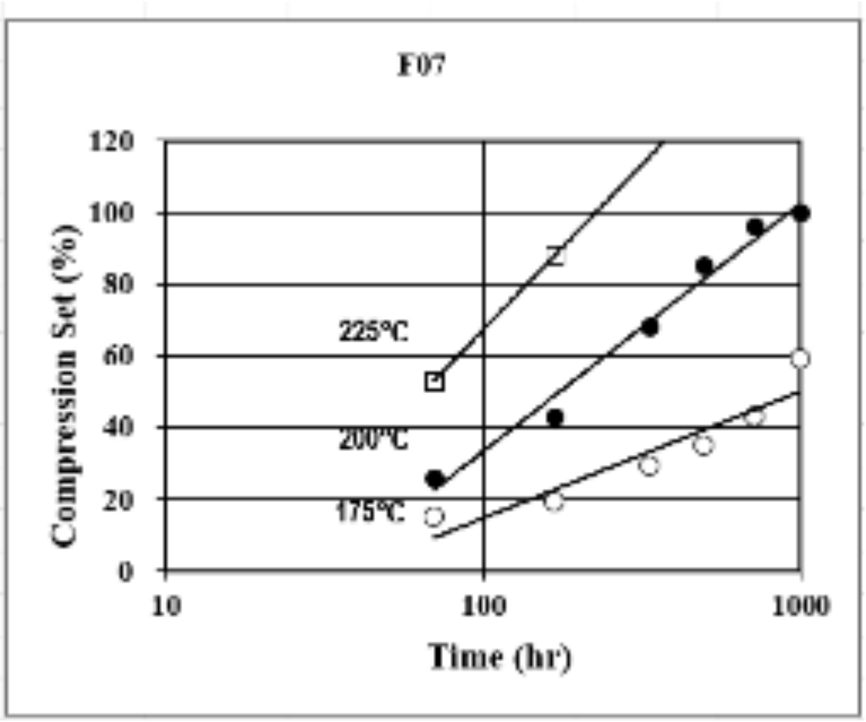


Figure 5:

Plot of Temperature vs Time to Reach 80% Compression Set for Fusion® F07

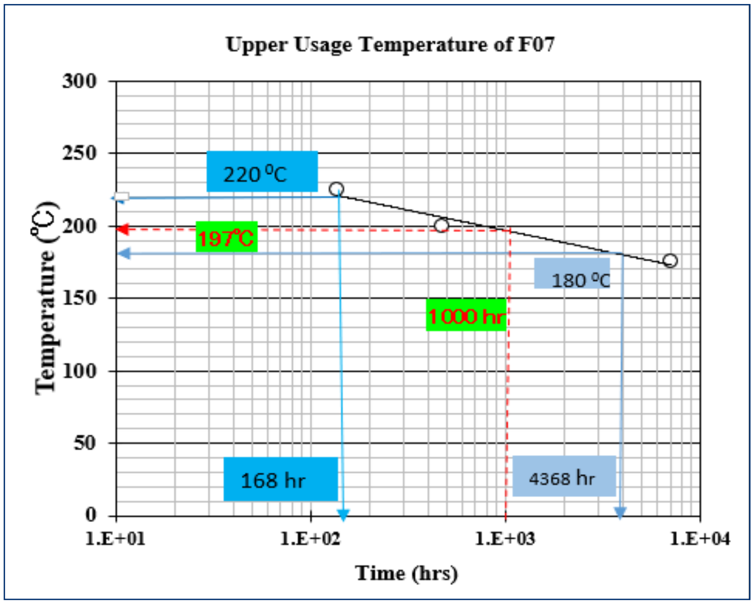


Table 3: Upper Usage Temperature at different set hours with 80% compression set (+/- 5°C)			
Compound	**Temp, °C at 168 hours**	**Temp, °C at 1000 hours**	**Temp, °C at 4368 hours**
Fusion® F07	220	197	180

Summary

Fusion® F07 is a new peroxide cured FKM compound made from a high fluorine Type 2 FKM with a high level of high fluorine organic filler that gives better chemical and plasma resistance than standard FKMs. Fusion® F07 is mixed and processed in higher volume equipment, unlike Fusion® F10 and FFKM materials. Fusion® F07 is designed for subfab applications that require sealing materials with effective chemical, heat, and plasma resistance while offering a lower cost of operation than premium FFKM materials.

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