Sensitiveness of Porous Silicon-Based Nano-Energetic Films

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Abstract: Nanoporous silicon (pSi) films on a silicon wafer were loaded with sodium perchlorate and perfluoropolyether (PFPE) oxidizing agents. Sensitiveness to impact, friction and electrostatic discharge (ESD) of the resulting energetic thin films were investigated. It was observed that pSi loaded with perchlorate was sensitive at the lowest limit of detection for the available equipment (<4.9 J impact energy, <5 N friction force, and <45 mJ ESD spark energy). When loaded with PFPE the material was very sensitive to impact (<4.9 J), moderately sensitive to ESD (between 45 and 100 mJ) and insensitive to friction (>360 N). pSi loaded with either perchlorate or PFPE displayed behavior during sensitiveness testing similar to other primary explosive materials.

Keywords: Porous silicon · Sensitiveness · Nano-energetic films

1 Introduction

Porous silicon (pSi) is a well characterized material prepared by the electrochemical etching of silicon wafers using various hydrofluoric acid (HF) based etching solutions, resulting in nano- to micrometer sized cavities in the surface whilst leaving the bulk dimensions of the wafer unchanged [1]. Manipulation of the etching conditions allows precise control over the resulting porous layer, including the size of the pores, the shape (from highly ordered channels to highly disordered sponge-like structures), depth and overall porosity [1].

The explosive behavior of pSi films, impregnated by an oxidizing agent, has been recognized and steadily investigated since 1992 [2]. The behavior originates from the very high internal surface area of pSi (in the order of 800 m² per gram) which permits a very intimate mixture between the oxidizing agent and the fuel (silicon), leading to materials that are stable at room temperature and are able to react explosively upon application of an energy stimulus. Indeed, pSi energetic materials prepared in this way are sensitive to a wide variety of stimuli. Methods of initiation that have been reported include heating using for example a hot-plate [3] or a hot bridge-wire [4,5], mechanical stimulus (such as scratching the surface or light friction) [6], or by an electrical spark [6]. Additionally, laser ignition of pSi energetic materials has been reported using a variety of wavelengths and laser fluences [6–9]. It has also been observed in several reports that pSi energetic materials are highly sensitive to initiation by weak mechanical stimuli such as scratching or mechanical fracture [2].

Cautionary notes are present in much of the work reported on pSi, which recognize the hazards posed by these materials and serve as a reminder to readers to handle the materials carefully. In order to fully realize the potential for these materials to be adopted into widespread use, the sensitiveness to initiation by various stimuli must be quantified. Standard tests are available to measure the sensitiveness to impact, friction and electrostatic discharge (ESD) enabling pSi energetic materials to be compared to more conventional alternatives [10]. Mason [11] reported that sili-
con nanoparticles (<100 nm particle diameter) loaded with sodium perchlorate (SP) would not initiate if struck by a drop-weight (unspecified mass) from a height of 0.38 m but would initiate if the weight was dropped from a height of 2.20 m. Churaman et al. [12] found that pSi films loaded with SP would not initiate when subjected to sudden acceleration forces at up to 5131 g. Mason [11] further reported that mixtures of silicon nanoparticles and SP would initiate if subjected to electric sparks having energies of less than 1 mJ.

Terry et al. [13] reported that similar mixtures of SP and silicon nanoparticles had ESD initiation thresholds of between 16 and 25 mJ. Similarly, Subramanian [14] reported that pSi powders would initiate with ESD spark energies of 25 mJ. A variety of oxidizing agents (typically nitrate or perchlorate salts) have been shown to react energetically with pSi, however SP has emerged as the oxidizer of choice since it delivers the most powerful and consistent energetic reaction [2]. Conveniently, controlling the material properties of the pSi substrate (by tuning the etching conditions) permits control over the stoichiometry of the system by limiting the volume of the pores available to be filled. The burning rate of pSi energetic films has been reported from as high as ≈3600 m s⁻¹ [15] to less than 1 m s⁻¹ [16]. The choice of oxidizing agent, porosity, pore depth, and pore diameter are all interdependent factors, which govern the burning rate of the system under investigation.

An interesting alternative to perchlorate oxidizing agents is perfluoropolyether (PFPE). Fluorinated polymers are well recognized as powerful oxidizing agents for metallic fuels [17]. Mason et al. [16] found that PFPE produced an effective energetic reaction in pSi but the system demonstrated very low burning rates of 0.014 m s⁻¹. Furthermore, it was observed that their formulation was very insensitive and required application of a flame for 10–20 s to ignite the sample.

It is the aim of this work to determine the sensitiveness of SP and PFPE loaded pSi energetic materials to impact, friction, and ESD. A secondary aim of this work is to determine the viability of PFPE as an alternative oxidizing agent, comparing it to the more commonly used SP.

2 Experimental Section

2.1 Porous Silicon Preparation

Porous silicon was prepared from p-type boron doped wafers, 3–6 Ω cm resistivity, <100> orientation, supplied by Virginia Semiconductors. Hydrofluoric acid (48% aqueous solution, Merck Chemicals) was diluted with acetonitrile to a final volumetric concentration of 20%. Electrochemical etching was conducted using standard techniques [1, 3], in a Teflon etching cell incorporating a platinum cathode and stainless steel anode [18]. The etching cells used in these experiments produced an etched area 45 mm long by 8 mm wide (etch area of 3.79 cm²), or a circular etched area 15 mm in diameter (area of 1.76 cm²).

Electrochemical etching was performed by a TTI PLH-250 power supply, operated under conditions of constant current controlled by a purpose-built LabVIEW interface on a Windows PC. The applied current was pulsed with a 66% duty cycle (10 seconds on, 5 seconds off), for a desired number of cycles, at current densities of either 22.5 or 45 mA cm⁻². Previous work has determined that these etching conditions produce pSi surfaces with pore sizes of 3.6 ± 1.4 nm and a porosity of 64.7 ± 0.5% [18]. Wafers were washed with ethanol and acetone prior to and after etching, and dried in a stream of nitrogen gas. All samples were stored in a desiccator when not being handled. For all investigations reported herein the pSi layer remains attached to the supporting Si wafer. In this configuration, only the pSi forms the reactive material and the supporting wafer takes no part in the reaction [19].

2.2 Surface Characterization

The depth of the porous layer was measured on a FEI Phenom scanning electron microscope (SEM), with samples cleaved and mounted as a cross-section of the etched wafer.

2.3 Loading of Oxidant into pSi

A stock solution of sodium perchlorate monohydrate (Ajax Chemicals) was prepared at a concentration of 400 g L⁻¹ in methanol. Secondly, a stock solution of PFPE (Fomblin Y HVAC 25/9) was prepared at a concentration of 200 g L⁻¹ in the fluorinated solvent perfluoro(butyltetrahydrofuran) (available as Fluorinert FC-75). The solution of the selected oxidizing agent was micropipetted onto the wafer and impregnated into the pores as the solvent evaporated. The solvent was evaporated in a stream of nitrogen gas, leaving the oxidizing agent deposited into the pores. The volume of solution used was adjusted for each sample to fill the pore volume completely with the selected oxidizing agent.

The degree of volumetric loading of the oxidizing agent into the pores was determined gravimetrically. The distribution of the oxidizing agent deposited into the pores was investigated by two separate methods. The inorganic oxidizing agent was investigated using a FEI Inspect F50 SEM coupled with EDAX energy dispersive X-ray analysis (EDX). It was reasonably anticipated that samples of live energetic material would initiate if exposed to the electron beam within the SEM. Therefore, in order to simulate the behavior of SP being deposited into the pores, calcium chloride (CaCl₂) was chosen as a non-energetic simulant due to its high solubility in methanol (prepared at 246 g L⁻¹) and the ease with which Ca and Si signals can be resolved by EDX.

Similarly, it was reasonably anticipated that the PFPE would also initiate within the SEM. No suitable non-energetic simulant was available having similar properties to the pSi substrate (by tuning the etching conditions) permitted control over the stoichiometry of the system by limiting the volume of the pores available to be filled. The burning rate of pSi energetic films has been reported from as high as ≈3600 m s⁻¹ [15] to less than 1 m s⁻¹ [16]. The choice of oxidizing agent, porosity, pore depth, and pore diameter are all interdependent factors, which govern the burning rate of the system under investigation.

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the PFPE. Therefore, the distribution of the PFPE was investigated directly using a Horiba Xplora Raman microscope (785 nm illuminating laser, 90 s spectra collection time), operated at 1% of maximum laser intensity to reduce the possibility of initiation.

2.4 Burning Rate

The burning rates of the samples were measured across a distance of 20 mm using a 5-point fiber optic array [18]. This system recorded the time, at which the flame front arrived at each equally spaced fiber optic probe, enabling the velocity of the flame front to be easily calculated. Samples were ignited using a custom-built high voltage spark generator (100 ± 2 mJ per spark at approximately 10 kV). The mounting block used to align the fiber optic probes permitted the samples to be initiated in either an unconfined manner, or clamped and confined between two stainless steel blocks.

2.5 Sensitiveness Testing

Samples were initially screened for sensitiveness using simple uninstrumented laboratory tests as a means to subjectively assess the potential sensitiveness of the sample. Impact sensitiveness was evaluated by striking a sample with a steel hammer against a stainless steel backing plate, observing any visual or auditory evidence of a reaction, whereas friction sensitiveness was evaluated by scratching the surface with a stainless steel spatula.

Following the simple indicative tests, quantitative measurements were performed using standard lab-based instrumentation. Impact sensitiveness was measured with a Rotter Impact apparatus (5 kg drop weight) [20] and was conducted by successively lowering the height from which the weight was dropped, until the point at which ignition was not observed. Subsequently, the drop height was raised or lowered up to 50 times to determine the threshold impact energy. The minimum height from which the weight could be dropped was 10 cm. Friction sensitiveness was measured on a Julius Peters BAM Friction apparatus [20], increasing or decreasing the applied weight until six successive samples failed to ignite at the selected test level. ESD sensitiveness was measured on a custom-built high-voltage discharge instrument with pre-determined spark energy levels of 0.045, 0.45 and 4.5 J, again seeking the level of energy at which 6 successive samples would fail to ignite. For these three tests, evidence of an ignition at any particular test level was determined either directly (by actually observing an ignition event), or indirectly by observing the state of the material after the test (unreacted pSi has a dark purple/black glassy appearance, whereas reacted material has a dull powdery brown appearance).

2.6 Safety Precautions

As indicated earlier, pSi energetic materials are known to be very sensitive to initiation. Throughout this work, additional precautions beyond standard laboratory safety protocols were applied. Portable conductive mats and wrist straps provided a means to minimize the risk of initiation through a static discharge event. Laboratory clothing consisted of natural cotton lab coats and cut resistant protective gloves. Standard safety glasses were worn. Initiation events were conducted with a safety shield in place to prevent injury if fragments of material were projected. Hearing protection was required, and samples were temporarily stored and transported between laboratory areas in conductive sample containers packaged into a secondary containment vessel. Further administrative controls included reducing the net explosive quantity (NEQ) of prepared samples to an experimentally necessary minimum.

Supporting information (see footnote on the first page of this article): detailed Raman spectra of the pSi/PFPE system generated during the investigation of the pore loading profile.

3 Results and Discussion

3.1 Pore Loading

It has been previously observed that the loading of SP (as a solution in methanol) into a pSi layer is problematic [15, 16]. A common problem is that as the methanol evaporates and the solution becomes saturated, the SP will tend to nucleate on the exterior face of the pSi and then quickly form crystals outside of the pores instead of seeping into the pores as intended, requiring the sample to be washed and re-loaded. Careful evaporation using a stream of nitrogen can assist in preventing this, but even with very careful preparation small crystals may still form on the surface of the wafer, creating uncertainty regarding the exact distribution of the oxidizing agent.

A sample of pSi was etched (45 mA cm⁻², 2700 seconds @ 66% duty cycle, 40 μm etch depth) and loaded with 120 μl of CaCl₂ solution (as a non-energetic material to simulate the behavior of SP). After evaporation in a stream of nitrogen and conditioning for 20 min in a vacuum desiccator, the samples were cleaved and a cross-section mounted for imaging and EDX analysis. The added quantity of CaCl₂ was calculated to be approximately 41% of the maximum loading of the available pore volume – this was deliberately chosen to be a sub-optimal loading level to assist visualization of the CaCl₂ distribution within the pores. Figure 1 displays a cross section of the resulting sample, with EDX spectra collected at defined intervals across the depth of the pSi layer.

The CaCl₂ was found to be distributed toward the base of the pores, visualized as a distinct contrast band starting at a depth of approximately 20 μm. This is supported by
the atomic concentrations presented in Figure 1b which show that the CaCl$_2$ increased in concentration through the depth of the sample, reaching a maximum at the base of the pSi layer (41.0 μm). The final sample point (at a depth of 44.6 μm from the surface) is in the unetched wafer (region iii). Small crystals of CaCl$_2$ are clearly visible across the surface of the cross-section of pSi, while the presence of large crystals of CaCl$_2$ (indicated by the marker arrow in Figure 1a) layer are believed to be caused by migration and evaporation of aqueous species at the freshly cleaved surface under the high vacuum of the SEM chamber. It is clear that, at least for the CaCl$_2$ simulant, the crystalline material deposited into pSi as a solution in methanol is preferentially loaded towards the base of the pores. One possible explanation for this phenomenon is that contraction of the solvent deeper into the pores, caused by a combination of capillary forces and reducing liquid volume through evaporation, carries the solute to the base of the porous layer until it reaches saturation and subsequently precipitates. It is reasonable to infer from this that the SP would behave in a similar manner, and that the biased loading effects would be minimized by loading the pores to their maximum volumetric capacity. These results support very similar observations by Piekiel et al. [21].

Whilst SP is a crystalline solid after the solvent has evaporated, PFPE is a high viscosity liquid polymer at room temperature (viscosity 285 cSt, MW ≈ 3800 g mol$^{-1}$, density 1.9 g cm$^{-3}$). A single loading application of the PFPE solution only partially seeped into the pores, and once the solvent has evaporated an oily film of PFPE was left on the exterior surface of the pores. Loading was improved by successive loading steps, which included evaporating the solvent under vacuum in a desiccator and then returning the desiccator to atmospheric pressure (backfilling the desiccator with N$_2$) to help drive the PFPE deeper into the pores—it was observed that after three successive load-vacuum-backfill cycles no further loading of the pores was achieved (as determined gravimetrically for each successive cycle). A sample of pSi was etched (45 mA cm$^{-2}$, 1350 seconds, 12 μm etch depth) and loaded with PFPE in this manner, and a cross-section of this sample was investigated using Raman microscopy, collecting spectra at 0.5 μm steps across the layer. By comparison to separate reference samples of pSi and PFPE, a broad spectral band at centered at 625 cm$^{-1}$ was found to be unique to pSi (due to a combination of various phonon modes in pSi [22]), whilst smaller bands centered at 744 and 810 cm$^{-1}$ were unique to the PFPE possibly due to multiple C=O and C–F vibrations [23]. The intensity of the pSi and PFPE bands as a function of the depth are presented in Figure 2, along with the relative ratio of these two bands. Detailed spectra are presented in the Supporting Information. The overall signal intensity of those bands increased towards the top of the porous layer, but the ratio of the PFPE:pSi bands was higher at the base of the porous layer than the top. This indicates that the PFPE was being preferentially deposited towards the top of the porous layer, and whilst the concentration of PFPE decreased at the base of the porous layer, the oxidizing agent was still present throughout the pSi layer.

![Figure 1](image.png)

**Figure 1.** (a) Cross-section SEM image of pSi (regions i and ii) loaded with CaCl$_2$ (region ii) supported by the unetched Si wafer (region iii), and (b) atomic concentrations of Si and Ca through the depth of the sample into the unetched wafer (the depth reference of 0 μm is the top of the pSi layer).

![Figure 2](image.png)

**Figure 2.** Penetration of PFPE into pSi layer. Signal intensity corresponds to the pSi band at 597–693 cm$^{-1}$ and the PFPE band at 792–817 cm$^{-1}$ (the depth reference of 0 μm is the top of the pSi layer).
3.2 Burning Rate

Elongated samples of pSi were prepared by etching at 22.5 mA cm\(^{-2}\) for 2700 seconds, resulting in pSi layers of 26.2 ± 0.2 µm depth. These were loaded with PFPE as described before and initiated either without confinement, or confined by being clamped between two stainless steel blocks) [18]. The burning rate was measured to be 0.24 ± 0.01 m s\(^{-1}\) and 0.23 ± 0.01 m s\(^{-1}\) for unconfined and confined samples, respectively. Previous work with the same experimental conditions found that the burning rate of pSi loaded with SP was 88 ± 11 m s\(^{-1}\) (unconfined) and 276 ± 70 m s\(^{-1}\) (confined) [18]. The velocity of pSi loaded with PFPE is clearly much lower than when loaded with SP. However, it is somewhat higher than the 0.014 m s\(^{-1}\) reported by Mason [11]. In that work, only very small samples of pSi loaded with PFPE (3 × 5 mm\(^2\)) were ignited, and the pSi had a significantly higher porosity (80 to 90 %) compared to the 66 % porosity of our material. It is well known that for perchlorate-based systems, the structure of the pSi substrate has a significant influence on the burning rate [18, 21] and there is every expectation that similar influences would be observed for fluorocarbon-loaded pSi.

Mason further observed that the samples loaded with PFPE failed to ignite using a nichrome hot-wire, or from the heat liberated from a nanothermite formulation, but would ignite upon application of a naked flame for 10 to 20 s. Here, ignition was not attempted using such heat sources, and it was found that samples ignited promptly with a high voltage electric spark. It is known that one path in the reaction between a fluorocarbon and a metallic fuel commences by rupturing of the perfluoropolymer molecule to liberate a variety of highly reactive radicals [17, 24], with the molecules pyrolyzing at greater than 290 °C [25]. So, while PFPE has a high viscosity and low vapor pressure at room temperature, application of a point-heat source may not cause sufficiently fast temperature rise to initiate the reaction if the PFPE is being driven away from the heating point (due to the combined effects of reduced viscosity and increased vapor pressure at elevated temperatures), thereby reducing the oxidizing agent concentration in the immediate vicinity of the heat source. However, the prompt ignition of the sample upon application of the high voltage spark suggests that the sample is either being heated very rapidly (faster than the PFPE can diffuse away from the point heat source), or, alternatively that the PFPE molecule is being ionized directly by the spark [17].

3.3 Sensitivity

Samples of pSi were etched (45 mA cm\(^{-2}\), 2700 seconds) and loaded with either SP or PFPE, and were subjected to uninstrumented screening tests. All samples (both SP and PFPE) initiated promptly when subjected to a 100 mJ electric spark during burning rate experiments. Samples loaded with SP also initiated promptly when subjected to a very weak strike with a hammer, or if the surface was scratched by a stainless steel spatula, reinforcing the earlier observations that these materials are extremely sensitive. Moreover, any process which exposed a fresh face in the pSi surface (such as snapping a sample in half) would cause initiation in almost every instance if the sample was loaded with SP.

However, samples of pSi, which were loaded with PFPE did not initiate when struck with a hand-held hammer, nor if scratched with a spatula. The strength of the hammer strike was sufficient to crush the wafer and cause a slight dent in the stainless steel backing plate, while the amount of force applied with the spatula to assess friction was sufficient to fracture the pSi surface. Fragments of these samples were then subjected to electric spark initiation and verified that the samples remained energetic even after these treatments.

A second series of samples were prepared and subjected to the instrumented friction, impact and ESD tests, with the results presented in Table 1. In these tests, the sizes of the etched samples were greater than the space available within the respective instruments. The etched wafers were fractured into smaller sections (≈6 × 6 mm\(^2\)) prior to being loaded in the normal manner, and only one section of wafer was tested at any one time (i.e. multiple small sections were not combined to re-form the original sample mass). Whilst this is a slight deviation from the normal form of the material, it was felt that having only a single cut wafer sample would be representative of the behavior of the material in its un-sectioned form. The NEQ for each sample for any of these tests was in the order of 1–2 mg supported on the non-reactive Si wafer.

Table 1. Initiation sensitivities of pSi loaded with SP or PFPE.

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>pSi/SP</th>
<th>pSi/PFPE</th>
<th>Lead azide</th>
<th>Nitroglycerine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact</td>
<td>&lt; 4.9 J</td>
<td>&lt; 4.9 J</td>
<td>2.5–6.5 J(^{\text{a}})</td>
<td>0.2 J(^{\text{a}})</td>
</tr>
<tr>
<td>Friction</td>
<td>&lt; 5 N</td>
<td>&gt; 360 N</td>
<td>0.1–1.0 N(^{\text{a}})</td>
<td>&gt; 353 N(^{\text{a}})</td>
</tr>
<tr>
<td>ESD</td>
<td>&lt; 0.045 J</td>
<td>&gt; 0.045 J, &lt; 0.45 J, 0.05–0.06 J(^{\text{a}})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{\text{a}}\) Ref. [26]. \(^{\text{b}}\) Ref. [27].
faces would escape without being heated. This extra heating of the sample due to adiabatic compression of the trapped air volume during the drop-weight test may explain the difference in the observed results between these two tests.

The nature of the samples under investigation required a slight deviation from the standard form of the BAM Friction test. Specifically, the energetic material (pSi loaded with oxidizing agent) was rubbed between the ceramic pistil of the apparatus and the supporting Si wafer instead of a ceramic base plate as required by the test. When loaded with SP, samples were found to initiate at the lowest limit of detection. The fact that the SP loaded material initiated at the lowest limit of detection gives confidence that the result accurately represents the sensitive nature of this energetic material in spite of the slight deviation from the standard BAM test. However, when loaded with PFPE no sample initiated even at the greatest applied force – at this level (360 N) the supporting Si wafer was pulverized when the energetic material was rubbed between the two ceramic surfaces of the apparatus.

Again as expected, samples of pSi loaded with SP initiated at the lowest limit of detection for ESD sensitiveness. Loaded with PFPE, samples would not initiate at 0.045 J, but initiated reliably at 0.45 J. However, it is also noted that samples of pSi loaded with PFPE would initiate reliably with a spark energy of 0.1 J during the reaction velocity testing described earlier. The true threshold level for pSi/PFPE is therefore between 0.045 and 0.1 J spark energy.

The impact, friction, and ESD sensitivities of pSi-based energetic materials are analogous to other sensitive energetic materials. For example, the behavior of pSi loaded with SP is very similar to lead azide for all three modes of initiation investigated herein [26]. However, pSi loaded with PFPE can exhibit high sensitiveness to impact under certain conditions but displays low sensitiveness to friction, and only moderate ESD sensitiveness. Whilst this might seem incongruous, sensitiveness to one mode of initiation is not a predictor to sensitiveness by another mode – nitroglycerine is an example of an energetic material which displays high impact but low friction sensitiveness [26].

4 Conclusion

Porous silicon-based energetic materials were studied to determine their sensitiveness to common modes of initiation. When loaded with SP, the energetic material was found to be sensitive to impact, friction, and ESD at the lowest limit of detection for the available apparatus. PFPE was found to be slightly less sensitive to ESD than SP, and insensitive to friction. However, it was determined to be very sensitive to impact using the Rotter Impact Apparatus. This was in contrast to the observation that pSi/PFPE energetic material did not initiate when struck sharply with a steel hammer, reinforcing the difficulty of applying standard high-explosive sensitiveness tests to this novel material. Nevertheless, it was concluded from these results that pSi-based energetic materials should be regarded as having the sensitiveness of primary explosives, and afforded all appropriate care with which those types of energetic materials are handled. Finally, while pSi loaded with PFPE has a lower burning rate compared to pSi/SP systems, PFPE may be a viable alternative to SP as an oxidizing agent for certain applications of pSi energetic material systems. An example of this could be initiation systems subject to high levels of vibration (and therefore friction within the pore matrix) but which are otherwise protected from impact or ESD.

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References

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