技 術 紹 介

“Epitaxsil ™” 次世代 CMOS デバイス向け シリコンエピタキシャルプリカーサーの開発

EpitaxSil ™ : A New Silicon Epitaxial Precursor for Next-Generation CMOS Devices

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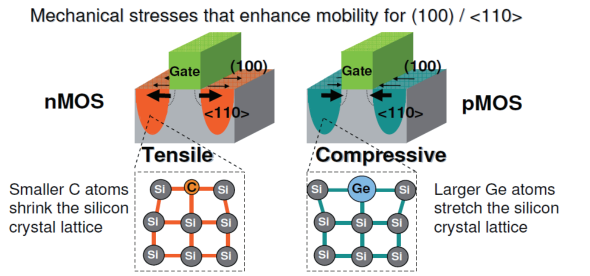
1. Introduction

To stay on track with Moore's Law, a cost-effective method is required to improve transistor performance on advanced logic devices in high volume manufacturing. A major challenge is that complementary metal oxide semiconductor (CMOS) performance is limited by carrier mobility and this must be increased for the 22 nm node and beyond.

As shown in Figure 1, existing p-channel solutions use compressively strained SiGe source drain structures that contain 30% metastable Ge. However, higher Ge levels (50% or more) are required to enhance electron mobility for advanced nodes. Similarly, current n-channel solutions, use source drain structures that incorporate 1.5% substitutional carbon in the Si film to generate tensile strain, but this needs to be increased to 2 to 3% substitutional carbon.



Node	90 nm	65 nm	45 nm	32 nm	22 nm
Ge Content	20%	25%	30%	35%	40% to 50%
C Content			Stress memorization*	Stress memorization*	>1.8% (~2.4% max)
SiGe Dep. Temp. Si:C Dep. Temp.	700-650℃	650-600℃	600-550℃	550-500℃	? 500℃ ? 550℃

Stress memorization techniques use silicon nitride stress caps to produce small amounts of tensile stress

Fig. 1 Stressor effects of C and Ge in nMOS and pMOS and required incorporation levels and processing temperatures with node.

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Growing strained silicon films is very challenging because dopant solubility limits occur at the higher deposition temperatures. Lower process temperatures are therefore necessary to successfully incorporate high levels of C and Ge in Si films. However, as the deposition temperature is decreased to 500°C and below, it becomes increasingly difficult to meet throughput requirements with conventional silicon precursor technology [1, 2].

Further, since the incorporation of impurities in the stained Si films also increases as the process temperature decreases, the purity requirements of the silicon precursor used becomes increasingly important, especially with regard to oxygenated species such as moisture [1].

To meet the requirements for strained silicon at advanced nodes, Matheson Tri-Gas Inc.(MATHESON) has developed EpitaxSil ™ , a new silicon chemical vapor deposition (CVD) precursor that addresses the low temperature processing and throughput requirements for high volume manufacturing. In this report, we discuss important aspects of this product, including its synthesis, purification, analysis and performance for low temperature silicon epitaxial process development. Features and benefits of this novel product are also presented.

2. EpitaxSil ™ Overview

EpitaxSil ™ is a novel low vapor pressure higher order silane with the molecular formula Si_nH_{2n+2} (n>3). This molecule has been specifically selected based on its decomposition chemistry during CVD, so that high growth rates can be obtained at deposition temperatures of 500°C or below.

Figure 2 shows the growth rates obtained with EpitaxSil ™ versus other precursors used in existing best known methods. At temperatures of 600°C and above it is equivalent to conventional precursors. However, as the deposition temperature decreases to 500°C, the growth rate using EpitaxSil ™ is significantly higher and therefore manufacturing throughput can be maximized.

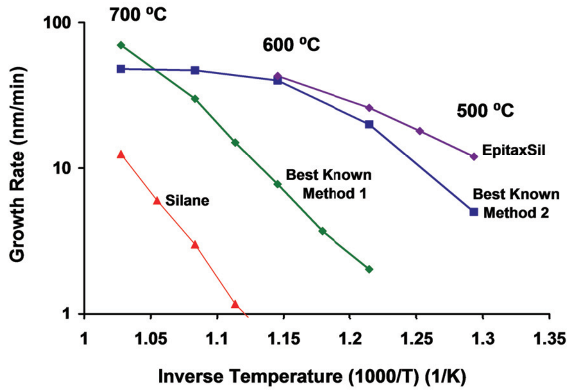

Figure 2. Graph showing growth rate at various deposition temperatures for conventional silicon precursors versus EpitaxSil ™ .

MATHESON has developed a dedicated and cost effective synthetic route and process for the production of EpitaxSil ™ . Although the synthesis method is proprietary and cannot be discussed here, the process allows for easy scale up to meet cost requirements of high volume wafer manufacturing.

Since epitaxy requires an anatomically clean surface without the presence of SiO or SiO_2 bonds, not only the tool but also the purity of the precursor is very important. Oxygenated impurities such as water must be minimized to prevent the formation of SiO_2 via the reversible reaction below.

$$2H_2O + Si \rightleftarrows SiO_2 + 2H_2$$

Figure 3 shows the Si surface at different temperatures versus partial pressure of water. As can be seen, for every 100°C decrease in temperature, the critical partial pressure requirement for water vapor becomes orders of magnitude more stringent. Therefore it is important that CVD conditions are optimized in the process chamber to minimize the partial pressure of water as much as possible. MATHESON controls process purity by using the EPISURE and PICO-TRAP gas purification systems to remove oxygen containing species from all dopant

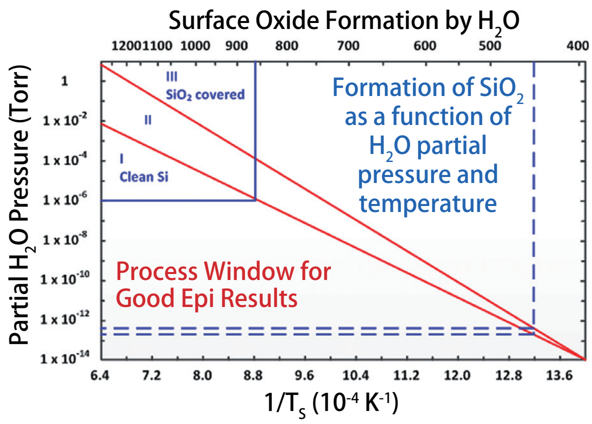

Fig. 3. Formation of SiO_2 as a function of H_2O partial pressure and temperature, reconstructed from Racanelli et al. [3].

and etch gases. In addition, it is also important that the silicon precursor is purified to prevent oxygen incorporation.

EpitaxSil ™ is purified via a number of methods such as distillation and adsorption to greater than 99.99%. During purification, oxygenated species such as water vapor (moisture) and disiloxane are removed to below 1 ppm. The levels of these species are confirmed in the final product using moisture analysis and gas chromatography-mass spectrometry (GC/MS) methods that were specifically developed for the application. Figure 4 shows the removal of moisture from the EpitaxSil ™ precursor during a purification process. This is a time plot of the moisture impurity concentration as argon bubbled EpitaxSil ™ precursor is flowed sequentially via an adsorption-based purifier and then via the purifier by-pass line. In this case, the moisture concentration in the neat (100%)

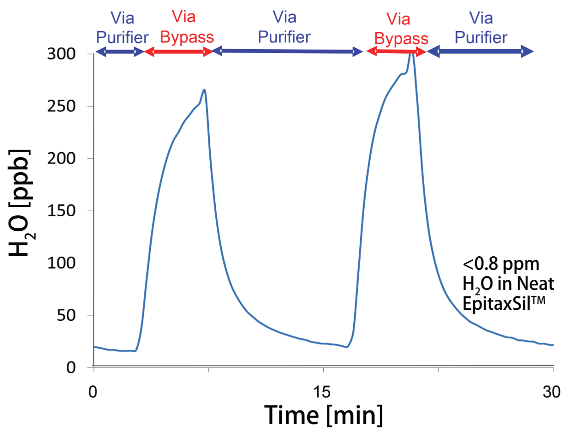

Fig. 4. Time plot showing moisture in argon bubbled EpitaxSil ™ as the stream is switched sequentially between purifier and a purifier bypass line.

purified precursor was back-calculated using the moisture measurements made from the diluted/Ar bubbled precursor and determined to be <800 ppb. Levels of oxygen in wafers processed with EpitaxSil ™ have also been measured by secondary ion mass spectrometry (SIMS) and meet purity requirements ($<1x10^{18}$ atoms/cm^3).

3. Features and Benefits

Low temperature silicon-based epitaxial growth is a key requirement for source/drain formation in CMOS devices at the 22 nm node and beyond. EpitaxSil ™ is a new silicon precursor that offers significant advantages over other silicon precursors for strained Si technology. EpitaxSil ™ enables growth of strained Si films at temperatures greater than 450°C with high carbon (>3%) and germanium (>50%) levels without sacrificing manufacturing throughput. This unique molecule is purified to greater than 99.99% to ensure removal of detrimental oxygenated species and is packaged in an aluminum vessel for stability and purity. Since this molecule is delivered to the process in the vapor phase using a carrier gas such as hydrogen, custom analytical technology is employed to confirm that moisture and disiloxane levels are at sub-ppm levels in the vapor phase. This is an important requirement to minimize oxygen incorporation in the films during CVD processes.

For further information on EpitaxSil ™ please contact Robin Gardiner, MATHESON at the following telephone number: +1-804-2480145

References

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