Improved Electrical Characteristics and Reliability of MILC Poly-Si TFTs Using Fluorine-Ion Implantation

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***Abstract*—In this letter, fluorine-ion (F^+) implantation was employed to improve the electrical performance of metal-induced lateral-crystallization (MILC) polycrystalline-silicon thin-film transistors (poly-Si TFTs). It was found that fluorine ions minimize effectively the trap-state density, leading to superior electrical characteristics such as high field-effect mobility, low threshold voltage, low subthreshold slope, and high ON/OFF-current ratio. F^+-implanted MILC TFTs also possess high immunity against the hot-carrier stress and, thereby, exhibit better reliability than that of typical MILC TFTs. Moreover, the manufacturing processes are simple (without any additional thermal-annealing step), and compatible with typical MILC poly-Si TFT fabrication processes.**

***Index Terms*—Fluorine-ion implantation, metal-induced lateral crystallization (MILC), polycrystalline-silicon thin-film transistors (poly-Si TFTs).**

I. INTRODUCTION

LOW-TEMPERATURE polycrystalline-silicon thin-film transistors (poly-Si TFTs) have attracted considerable interest for their use in active-matrix liquid-crystal displays because they exhibit good electrical properties and can be integrated in peripheral circuits on inexpensive glass substrates [1]. As poly-Si TFTs require glass substrates, intensive studies have thus been carried out, reducing the crystallization temperature of amorphous silicon (α-Si) films. Ni-metal-induced lateral crystallization (MILC) is one of these efforts. In MILC, Ni islands are selectively deposited on top of α-Si films and allowed to crystallize at a temperature below 600 °C [2], [3].

Unfortunately, the poly-Si grain boundaries trap Ni and $NiSi_2$ precipitates, thus increasing leakage current and shifting the threshold voltage [4]–[8]. A hydrogen plasma-treatment process has been utilized to reduce the trap states of poly-Si film to improve the device performance [9]. However, not only was it difficult to control hydrogen concentration in the poly-Si film but the formed Si–H bonds were also not strong enough to avoid the hot-carrier generation. Fluorine (F)-ion incorporation has been applied in the manufacturing of many electronic devices [10], [11]. On poly-Si TFTs implanted with fluorine, the Si–F bonds can eliminate the trap-state density, thus enhancing the performance of n-channel TFTs.

In this letter, a new manufacturing method for MILC poly-Si TFTs using fluorine-ion implantation was proposed. This uncomplicated and effective method involves implanting fluorine atoms into poly-Si films, which produces MILC poly-Si TFTs of high performance and high reliability.

II. EXPERIMENT

A 100-nm-thick undoped (α-Si) layer was deposited onto a 500-nm-thick oxide-coated silicon wafer by low-pressure chemical-vapor-deposition (LPCVD) system. The photoresist was patterned to form desired Ni lines, and a 20-Å-thick Ni film was deposited on the α-Si, subsequently annealed at 540 °C for 18 h to form the MILC poly-Si film. To reduce Ni contamination, the unreacted Ni metal was removed by chemical etching. The islands of poly-Si regions on the wafers were defined by reactive-ion etching; fluorine ions were then implanted into the MILC film. The projection range of fluorine ions was set at the middle of MILC layer. The dosage of fluorine ions and ion-accelerating energy was 2×10^{13} cm^{-2} and 30 KeV, respectively. Next, a 100-nm-thick gate insulator was deposited by plasma-enhanced CVD. Then a 200-nm-thick poly-Si film was deposited for gate electrodes by LPCVD. After defining the gate, self-aligned 40 KeV P ions were implanted at a dose of 5×10^{15} cm^{-2} to form the source/drain and gate. The F^+-implanted MILC film and the P-implanted source/drain/gate were then annealed/activated at 600 °C for 24 h. Moreover, the manufacturing processes without any additional thermal annealing step and compatible with typical MILC poly-Si TFT fabrication processes.

III. RESULTS AND DISCUSSIONS

Fig. 1 shows the I_D–V_G transfer characteristics for the MILC poly-Si TFTs, with and without F^+ implantation. The measured and extracted key device parameters are summarized in Table I. The performance of F^+-implanted TFTs was far superior to that of MILC TFTs. This indicates the trap-state density (N_t) was effectively terminated using F^+ implantation. The trap-state density was extracted using Levinson's and Proano's method, which can estimate the N_t from the slope of the linear segment of $\ln[I_{DS}/(V_{GS}–V_{FB})]$ versus $1/(V_{GS}–V_{FB})^2$ at low V_{DS} and high V_{GS}, where V_{FB} is defined as the gate voltage that yields the minimum drain–current at $V_{DS} = 0.1$ [12], [13]. The trap density of F^+-implanted MILC TFTs is 4.24×10^{12} cm^{-2}, which is less than that of MILC TFTs (6.29×10^{12} cm^{-2}). The reduction in N_t values implies that those defects have been terminated using F^+ implantation. As a result, the carrier mobility increases. The minimum OFF-current of the F^+-implanted device, however, did not

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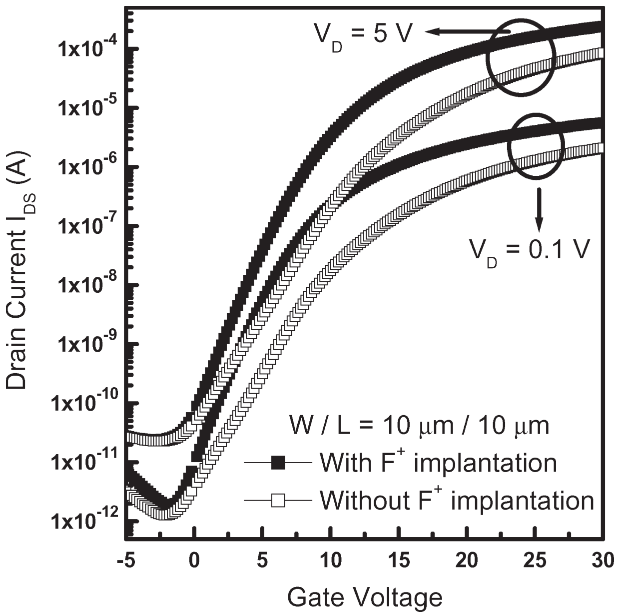

Fig. 1. Typical I_{DS}–V_{GS} transfer characteristics of the MILC poly-Si TFTs, with and without F^{+} implantation.

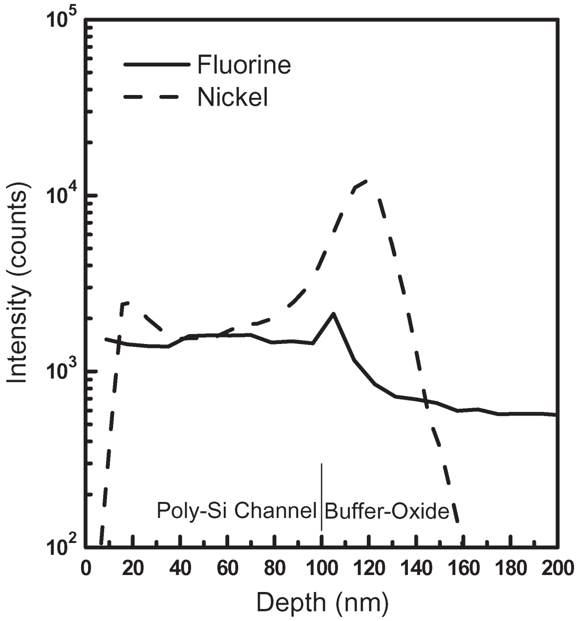

Fig. 2. SIMS depth profile of nickel and fluorine in the structure of MILC poly-Si channel/buffer-oxide.

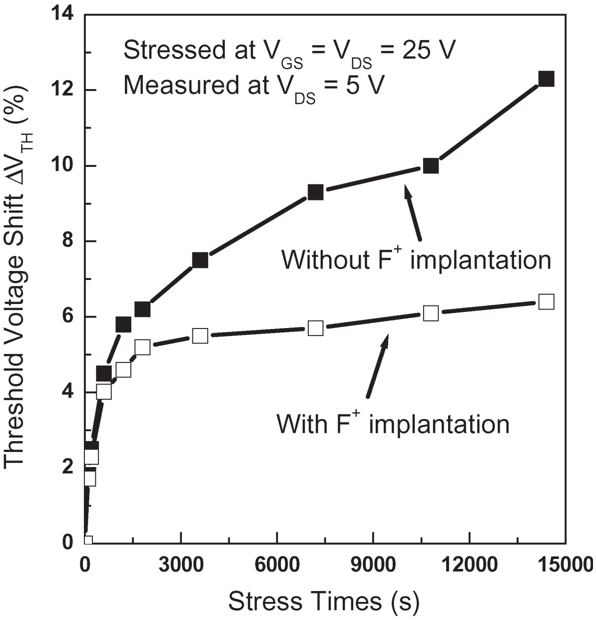

Fig. 3. Threshold-voltage variation versus stress time for the MILC poly-Si TFTs, with and without F^{+} implantation.

TABLE I
DEVICE CHARACTERISTICS OF THE MILC POLY-Si TFTs, WITH AND WITHOUT F^{+} IMPLANTATION

Device Parameters	Unit	Without F^{+} implantation	With F^{+} implantation
Field-effect mobility	$(\mathrm{cm}^2/\mathrm{V}\text{-}\mathrm{s})$	50	94.5
Subthreshold slope S.S	(V / dec)	1.9	1.09
Threshold voltage V_{TH}	(V)	9.1	5.9
ON/OFF current ratio I_{ON}/I_{OFF}		3.72×10^6	9.91×10^6
Trap-state density N_T	$(10^{12}\mathrm{cm}^2)$	6.29	4.24

change much. Similar performances and defects have been previously reported in other poly-Si TFTs that were passivated by the F^{+} implantation [14]–[16].

In MILC poly-Si, there are two kinds of defects related to trap-state density: 1) Ni-related defects and 2) grain-boundary defects. Most of Ni-related defects were located at poly-Si/buffer-oxide interface and grain boundaries, which trap Ni and NiSi_2 precipitates [4]–[8]. Ni-related defects would degrade electric performance because the trap states introduced dangling and strain bonds. Secondary-ion mass spectroscopy (SIMS) was used to study the distribution of Ni and F. Fig. 2 shows the depth profile of the F^{+}-implanted MILC poly-Si/buffer-oxide structure after thermal annealing at 600 °C for 24 h. High-Ni and high-F contents are both present at the MILC poly-Si/buffer-oxide interface. This observation suggested that F ions have diffused to the interface/boundaries to terminate Ni-related trap states and lead to improve electrical characteristics.

On the other hand, the trap states in the grain boundaries will also increase the leakage current. Use of F atoms to fluorinate poly-Si films can improve performance and reliability of poly-Si TFTs [16]. This is because F atoms can terminate dangling bonds and replace weak bonds in the grain boundaries and SiO_2/poly-Si interface and, thus, reduce the trap states in the poly-Si channel. As a result, the carrier mobility increases due to the decrease in the boundary scattering by passivation-of-boundaries defects. However, the minimum OFF-currents were nearly unchanged [14]–[16].

The other important issue of poly-Si TFTs is their reliability, which was examined under hot-carrier stress. As shown in Figs. 3 and 4, the threshold voltage and the ON-current of TFTs were degraded, because dangling bonds are created due to the trapping of electrons at weak Si–Si and Si–H bonds [17], [18]. Compared with those of typical MILC TFTs, the threshold voltage and ON-current degradations of F^{+}-implanted

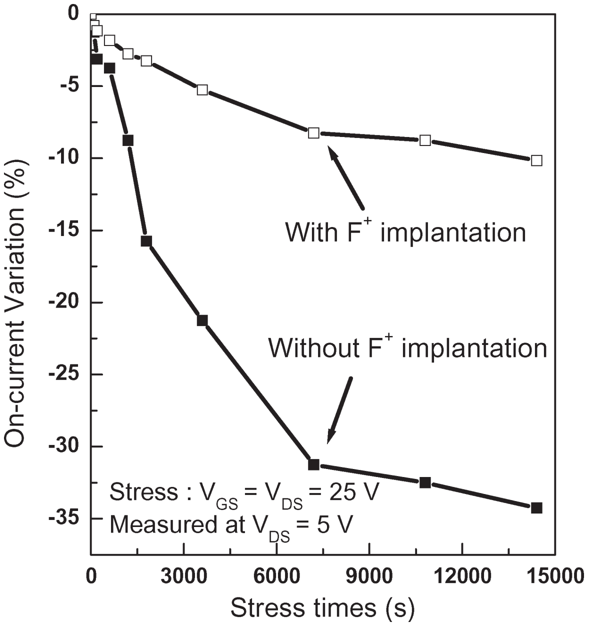

Fig. 4. ON-current degradation versus stress time for the MILC poly-Si TFTs, with and without F^+ implantation.

MILC TFTs are greatly improved by the implantation process. F^+-implanted MILC TFTs also possess high immunity against the hot-carrier stress and, thereby, exhibit lower $\Delta V_{\rm TH}$ and $\Delta I_{\rm ON}/I_{\rm ON}$ than that of typical MILC TFTs. In other words, weaker Si–H and Si–Si bonds were replaced by stronger Si–F bonds, which could not be broken under hot-carrier stress, thus leading to improved electrical reliability.

Electrical properties of the F^+-implanted MILC TFTs with heavy implantation dosages (2×10^{14} and 2×10^{15} $\rm cm^{-2}$) were also studied in this letter. It is found that the electrical characteristics of MILC TFT are degraded as the implantation dosage increases. When the dosage reached 2×10^{15} $\rm cm^{-2}$, the device performance was very poor. This is because, when the implantation dosages are higher than Si solid solubility, the trap-state density and fluorine clusters increased with the dosage [19].

IV. CONCLUSION

An investigation of the effects of F^+-implantation process on the electrical characteristics and reliability of MILC poly-Si TFTs has led to the development of a simple effective process for improving the TFT electrical properties. Results show that, compared with typical MILC TFTs, F^+-implanted TFTs exhibit higher field-effect mobility, superior subthreshold slope, lower threshold voltage, higher ON/OFF-current ratio, and lower trap-state density (N_t). It was also found that F^+-implantation process can greatly alleviate the threshold voltage and the ON-current degradations under hot-carrier stress. F^+-implanted MILC TFTs possess high immunity against the hot-carrier stress and, thereby, exhibit lower $\Delta V_{\rm TH}$ and $\Delta I_{\rm ON}/I_{\rm ON}$ than that of typical MILC TFTs. This is because the weaker Si–H and Si–Si bonds were replaced by stronger Si–F bonds, which could not be broken under hot-carrier stress, thus leading to improved electrical reliability.

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