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The Effect of Doping on Metal-Induced Lateral Crystallization Rate

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The effect of dopants on the behavior of metal-induced lateral crystallization (MILC) growth was studied in this work. Two types of dopants (B_2H_6 and PH_3) were doped over 50Å Nickel films deposited on amorphous silicon. It was found that the MILC growth rate of The MILC growth rate of B_2H_6- and PH_3doped amorphous silicon (a-Si) thin film by ion mass doping (IMD) is slower than that of intrinsic a-Si. The decrease of growth rate was caused by the bonding of Si-P and the break down of the dangling bond between silicon and hydrogen during bonded ion mass doping. In addition, a phenomenon of growth stoppage at the boundary of the a-Si and ion mass doped range was observed. The rate of MILC growth decreased as dopant density increased.

Keywords: MILC, doping, dopant, IMD, ion mass doping

1. INTRODUCTION

Due to the escalating use of mobile instruments, display devices are in increasingly high demand. The global call for dynamic random access memory (DRAM) and liquid crystal displays (LCDs) in particular has pushed development of those products to the forefront of the high-tech industry.

Current LCDs require a process of pixel switching, which is presently achieved with amorphous silicon (a-Si) thin film transistors and a drive Integrated Circuit (IC). In fact, the determining quality factor for an LCD is the switching speed of the thin film transistor it employs. Intensive investigation is underway in support of the competition to set the latest trend in high-definition and high-speed mobile devices, including through the determination of the appropriate number of electrons for poly-crystalline silicon thin film transistors. In addition to this research, the next generation technology is monitoring the commercial use of organic light emitting diode (OLED) displays, and due to this high interest, the use of poly-crystalline thin film transistors will only become a more vital necessity.

There are two different approaches to the manufacturing of poly-crystalline silicon thin-film transistors: Solid Phase Crystallization (SPC),[1] and Excimer Laser Annealing (ELA).

The poor element properties and high-temperature annealing requirement of SPC are drawbacks to this method. On the other hand, ELA shows excellent electric properties, but problems like suspect uniformity and high cost make the technique difficult to deploy commercially.

Among various crystallization methods, the recently discovered Metal-Induced Lateral Crystallization (MILC) technique has proven to be more successful than all other methods in terms of lowering the silicon thin film crystallization temperature. Annealing after deposit metal like Pd and Ni on the a-Si, Catalytic phase transformation is possible when crystallizing under a low-temperature of 500°C, unlike in the process of metal-induced crystallization, metal contamination rarely occurs, good quality poly-crystalline silicon is available and highly efficient poly-Si TFT can also be produced.[1, 2]

Fabricating an actual device by means of MILC must be done over the doping area. According to previous experiments, it is known that the MILC temperature changes depending on the type of dopant, but the causes of the specific changes in speed and phase are not exactly known. To investigate the causes of these changes in speed and phase, boron and phosphorus are doped using ion mass doping (IMD) in this experiment, yielding several observed changes in the MILC rate. Also, in order to observe and measure more changes in the rate of MILC, a two-minute interval doping pattern was performed on a fixed shape.

2. EXPERIMENTATION

On top of Corning 1737 glass, SiO_2 of 3000Å was chemical vapor deposited with SiH_4 by the PECVD method, and a-Si of 500Å was chemical deposited with Si_2H_6 as depositing source using the LPCVD method.

Various forms of a-Si patterns were dry etched using

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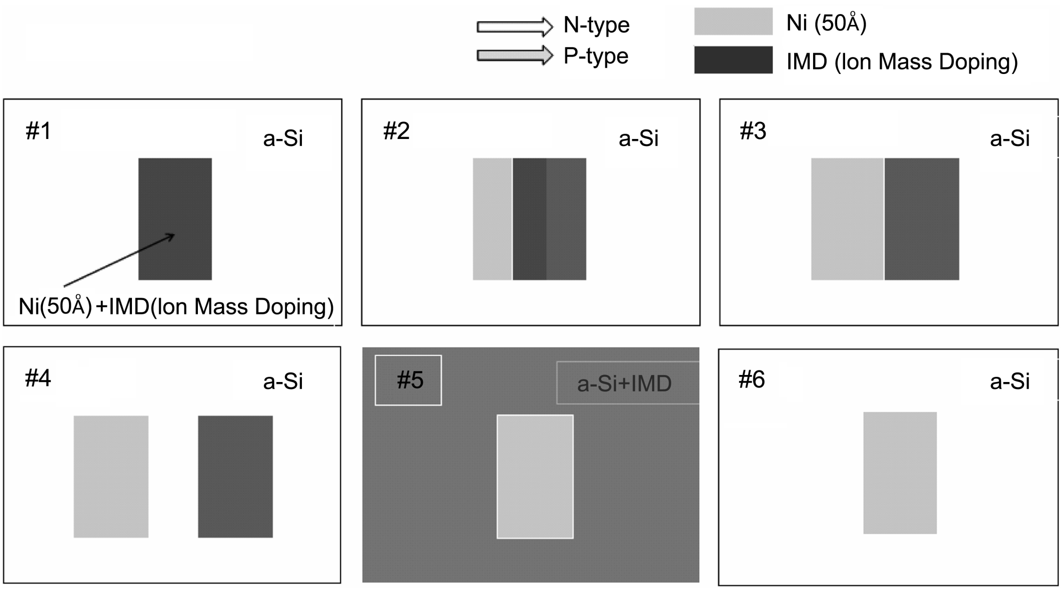

Fig. 1. Samples are classified by doping area after Ni film deposited and, #6 sample is non-doped to use reference.

50sccm and 5sccm each of SF_6 and O_2 gas. Sputtering was done for Ni at a thickness of 50Å, and in order to deposit metal vapor only in the desired areas, the lift-off method was applied. Also, B_2H_6 15sccm, PH_3 8sccm was applied for the doping at a two-minute intervals using the ion mass doping method and, in order to observe the rate of crystallization of the doping areas, ion mass doping was continued for about ten minutes.

Annealing was done at a temperature of 550°C in a vacuum furnace four times at two-hour time intervals. With the degree of vacuum below 1×10^{-6} Torr, the growth phase was observed under an optical microscope.

3. EXPERIMENTAL RESULTS AND ANALYSIS

In order to investigate the rate of MILC related the doped areas, six samples were prepared as shown in Fig. 1, and the ion mass doping conditions of each sample are presented in Table 1. All samples shown in Fig. 1 have a common ion mass doping installation where dopant was implanted.

In this investigate, RF electric power of 150W, and the Inductively Coupled Plasma (ICP) structure was supplied by fixed plasma and DC acceleration voltages of 16 kV of n-type, and of 11 kV of p-type. The hydrogen-diluted source gasses 5%PH_3 and 3%B_2H_6, as well as highly purified H_2, were used.

The photolithography method was used to form patterns, using Ni, on the front surface of the vapor-deposited a-Si thin film sample, and the lift-off method from photo-resist was used later on. In order to limit the areas being doped, a mask was used during the process of the nickel-pattern formation.

In sample #1, in order to form the nickel pattern on the top surface of the a-Si sample, dopants were doped only on this area, and a crystallization speed growth of 10 μm/h was observed on both the p-type and n-type regions.

Table 1. Ion Mass Doping conditions: N-type is doped phosphorus and, P-type is doped boron by IMD

	N-type	P-type
Accelerating Voltage	11 kV	16 kV
RF Power	150 W	
Working Pressure	3 mTorr	
Doping Time	10 min	
Source Gas	PH_3 8sccm	B_2H_6 15sccm
Sheet resistance	200 Ω/□	180 Ω/□

A Ni vapor deposition was produced equally on both samples #2 and #1, where the dopant shifted 50 μm to the right where ion mass doping took effect. As a result, the crystallization rate for p-type was 5 μm/h, and the crystallization rate for n-type was 4 μm/h. When these two samples are compared with a non-doped sample like #6, as doping is proceeding on sample #1's nickel dopant, we can observe that the rate at which MILC takes place decreases 30%.

When sample #6 is compared to sample #2, the rate of MILC on the doping areas on a-Si is also decreased by 60%. This result is evidenced in sample #3 where the p-type MILC rate was 7.5 μm/h, and the n-type rate was 4.5 μm/h. Even though the rate of MILC proved to be the same on samples #4 and #6, sample #4 not having dopant doped in the silicon areas, it can be observed that past the doped areas, in both a rate of n-type is 4.5 μm/h and p-type is 6 μm/h was shown. It can be also observed that samples #5 and #3 yield similar

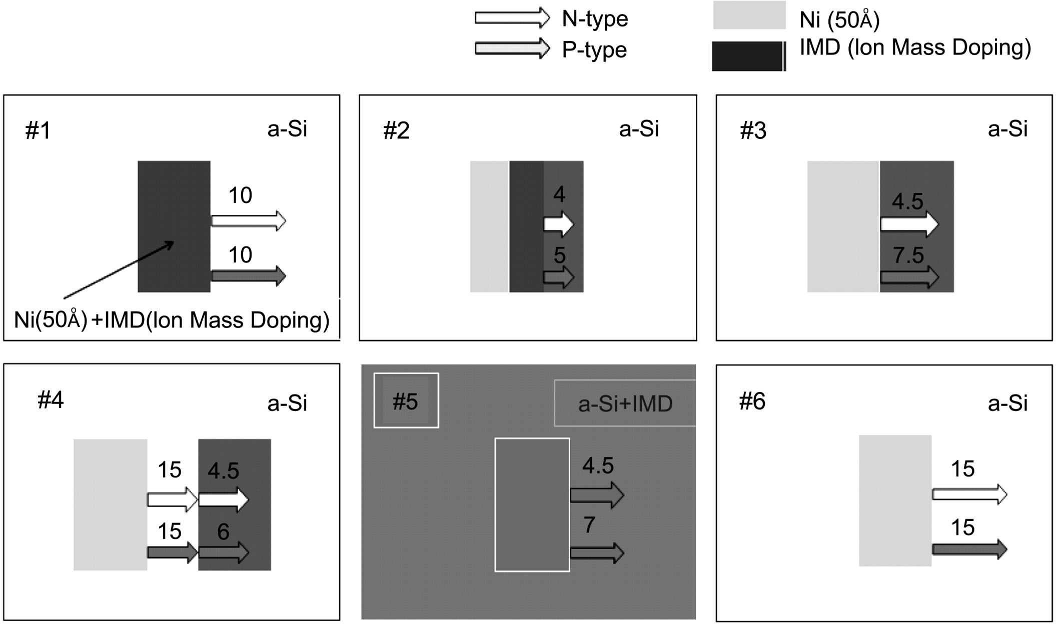

Fig. 2. The rate of MILC annealed at 550°C 2 hour after ion mass doping.

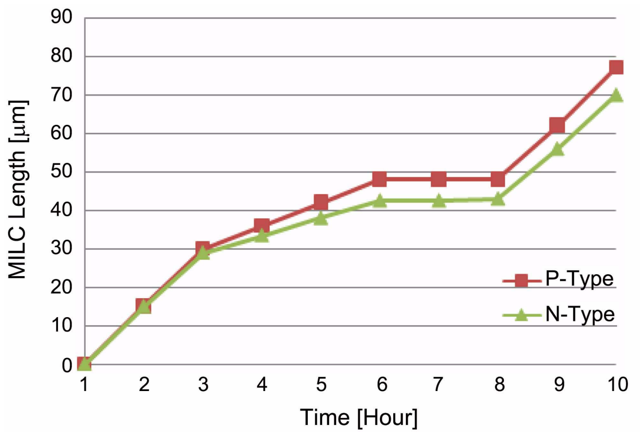

Fig. 3. MILC dependency on doped area. B2H6, PH3 was doped after the deposition of Ni films and it was annealed at 550°C 4 times.

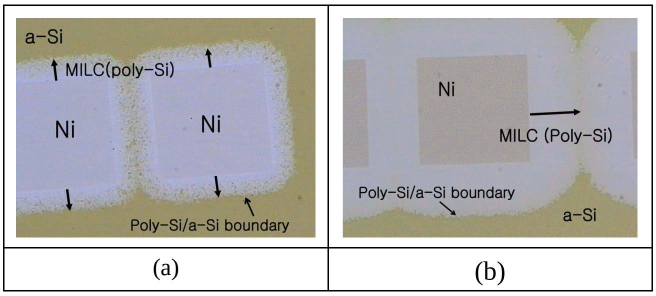

Fig. 4. Optical microscope images of crystallized silicon in case of (a) doped a-Si (b) undoped a-Si.

results, and that despite doping with either PH_3 or B_2H_6, the rate of MILC is certain to decrease.

Nevertheless, we found that sample #4 merited our attention in this experiment. It was observed that the MILC process began in the Ni vapor deposition area, passing the Si and doped Si area, where MILC was seen to be taking effect in the Si area again. The crystallization phase of this sample is shown in the graph below Fig. 3.

The length of MILC continued to grow in Sample #4's silicon area, but as soon as it reached the end stages of the doped areas, no growth of MILC could be observed. In order to investigate the aspect of MILC growth, an additional annealing process was done for one time. The result of this process showed us that crystallization took place up to the boundary between the doped silicon areas and undoped silicon areas. This aspect of crystallization on doped areas can be explained by comparing the MILC on the doped areas in sample #4, and the MILC on the un-doped areas in sample #6. See Fig. 4.

It can be observed from Fig. 4, which shows the poly-Si/a-Si boundary on both undoped and doped areas, that the crystallization took effect more evenly and uniformly on undoped silicon areas than on the doped Si areas. Looking at the MILC results from sample #4, passing the undoped silicon area, MILC does not start to take effect until it reaches the doped silicon area. As shown in Fig. 4 (a), in the MILC area, crystallization did not take place and we can observe that the a-Si formed sparsely on the sample. However, after having annealed the sample for two additional hours and after crystallization had taken place, MILC began taking effect immediately upon entering the undoped silicon areas, passing the end stages in the doped silicon area.

In order to investigate the extent of the effect that the dop-

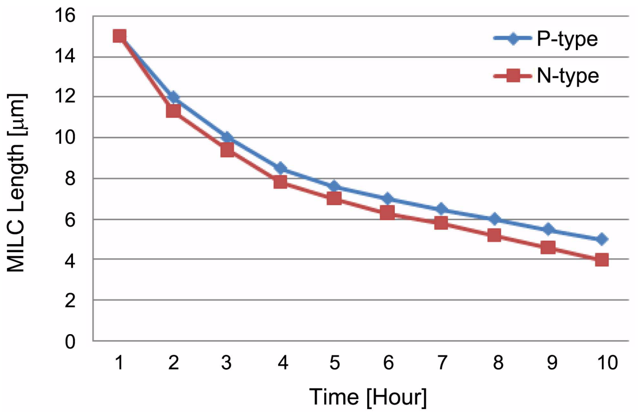

Fig. 5. MILC dependency on doping time.: B2H6, PH3 was doped two minute times interval after the deposition of Ni films.

ing time had on the rate of MILC, a sample shaped similarly to sample #5 was made, and even though they each had the same doping time, the new sample displayed a change in MILC length. See Fig. 5.

After experimenting with the effect that doping time had on the rate of MILC, it was found as expected that the MILC rate of the n-type was slower than that of the p-type.

In 2002, Tianfu Ma *et al*.[5] reached a conclusion regarding the effect that dopants have on MILC, stating that when a non-crystalline silicon of 1000Å and boron at a high dose of 3 $\times 10^{15}/Cm^2$ is injected at 550°C, the growth rate will double at that temperature. According to the same study, when a large amount of boron is used as a dopant, the formation temperature of $NiSi_2$ starts to decrease and the boron atoms of $NiSi_2$ are capable of lowering the energy formation. However, if we follow what is said in that investigation, a high degree of boron doping can cause a decrease in the rate of MILC growth. Also, the MILC mechanism through nickel silicide allows Si atoms of a-Si to easily situate themselves in the Si crystalline lattice. Keeping this in mind, it can be assumed that because of the additional annealing process of the nickel silicide, the formation temperature may have been affected and it is believed that the rate of growth should be followed by the,annealing time which should probably be the same.

However, it can be concluded that instead of the actual annealing period and growth rate being intrinsic, it probably depends on a larger condition, and having said that, an inference can perhaps be made that the mechanism might not be as dominant as it is perceived to be. It was found through this experiment that the rate of MILC will show a decrease when using boron or an undoped phosphorus, even when compared to the rate of MILC of undoped a-Si, and the drop in MILC rate can be particularly observed upon the doping of phosphorus.

The decrease in the rate of MILC results from disturbance of dopant migration through segregation and the NiSilayer of dopant.

Particularly, the rate of MILC was reduced due to the strong bonding between Ni and phosphorous. it is reported that rate of MILC increased by 40% when doped with boron,[11] but in our experiment, the rate of MILC decreased when doped with two dopants because the ion mass doping diluting source gas in Hare contain 3% B_2H_6 and 5% PHç is different from ion implantation in separation of source gas by mass. This phenomenon was reported that the rate of crystallization decreased through research of SPE (solid phase epitaxy).[7, 8]

Generally Hinside the a-Si have similar types of combinations like Si-Hand Si-H. It is reported that both the combination of Si-H_2 around 400°C and Si-H around 550~600°C breaks down, hence Hescapes from the thin film.[9, 10] This combination of Si atom and H_2 atoms bonding is thought a primary factor that the rate of MILC growth decrease. Nevertheless, Si atoms in a-Si grow through the $NiSi_2$ boundary, this combination breaks down, and that during this process, Si atoms cannot be supplied enough to fill the vacant spaces.

4. SUMMARY

This experiment was carried out to investigate the behaviors of MILC growth and the effect dopants have on those behaviors. Our experiment yielded the following results.

First of all, when we deposit Ni 50Å on a-Si and use the same patterning, the decrease in MILC of the ion mass doped a-Si region is higher than that in the MILC of the undoped amorphous region. Also, in the case of doped amorphous Si, the decrease in the rate of MILC is more than 60% compared to the MILC rate of undoped a-Si. This phenomenon explains that the combination of Si atoms and H_2 atoms breaks down, and that during this process, Si atoms cannot be supplied enough to fill the vacant spaces.

Secondly, the MILC rate varies by dopant type. In the case of phosphorous dopant, the MILC rate slows down more than when the dopant is boron. This occurs due to the disintegration of the Si and phosphorus atom combination.

The last result that we found was that the behavior of MILC depends upon the region being doped. When the process of MILC is done to the area of doped a-Si, MILC stops as soon as it reaches the boundary between the doped area and the amorphous area. This is due to the fact that the boundary shows characteristics of MILC in the doped area. This phenomenon explains how non-uniform boundaries become completely crystallized.

These results suggest that annealing time is critical in producing a device, but further investigation of the mechanisms of MILC will be necessary.

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