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Multiple-Pulse Laser Thermal Annealing for the Formation of Co-Silicided Junction

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Abstract—Formation of Co-silicide contact layers on narrow silicon regions using multiple-pulse excimer laser annealing is demonstrated. Excellent performance of junction leakage behavior can be attained on narrow-width n^+/p and p^+/n junction as compared with standard rapid thermal annealed samples. Liquid-phase epitaxial Co-silicide regrowth has been found to occur and create a smooth and abrupt silicide/Si interface with high junction integrity using multiple-pulse laser annealing. Heat confinement created by the shallow trench isolation surrounding the narrow-width n^+/p and p^+/n junctions has minimized rapid quenching that might result in an amorphous structure. This has facilitated the crystallization of Co-silicide with multiple-pulse laser annealing.

Index Terms—Contact, pulsed laser annealing, silicide.

I. INTRODUCTION

PULSED laser annealing has been used in growing thin silicide films [1], [2]. In comparison with furnace and rapid thermal annealing (RTA), it offers several advantages such as confinement of the heat within localized areas, metastable phase formation, contamination reduction, etc. Pulsed laser annealing has shown advantageous on postimplantation junction activation [3] and in reducing gate depletion [4]. We have recently reported the formation of Co-silicide using Co/Ti bilayer with single-pulse laser of high fluence at 0.6 J/cm^2 [5]. In this letter, we demonstrate the feasibility of multiple-pulse low-fluence laser thermal annealing (LTA) for the formation of silicided junctions with improved interface roughness and excellent junction performance.

II. EXPERIMENTAL

The substrate materials used in this study are p-type Si(100) wafers. Isolated narrow-width n^+/p and p^+/n Si active lines of

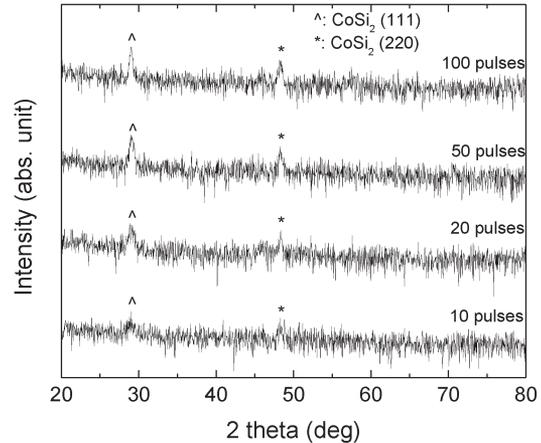


Fig. 1. XRD spectra of a 13-nm Co/Si system after multiple-pulse laser annealing at 0.3 J/cm^2 .

$0.5 \mu\text{m}$, configured in perimeter-intensive leakage structures of $100\,000 \mu\text{m}$ in total length, were used for the electrical characterization. The junctions were formed using the spike annealing at $1080 \text{ }^\circ\text{C}$ of As-doped (10^{15} cm^{-2} at 45 keV) or B-doped (10^{13} cm^{-2} at 3.5 keV) Si. The patterned wafers were cleaned using dilute HF prior to the deposition of a layer of 8–13 nm Co using dc magnetron sputtering. The control samples were subjected to a two-step rapid thermal processing of $450 \text{ }^\circ\text{C}$ followed by $800 \text{ }^\circ\text{C}$ for Co-silicide formation. Other samples were subjected to LTA using a KrF_2 excimer laser of 248 nm in a class 100 cleanroom. Multiple-pulse LTA was performed at room temperature with a repetition rate of 1 Hz of low laser fluence of $0.2\text{--}0.3 \text{ J/cm}^2$. The formations of silicides were characterized using X-ray diffraction (XRD), Auger electron spectroscopy (AES), transmission electron microscopy (TEM), and microdiffraction analysis.

III. RESULTS AND DISCUSSION

Fig. 1 shows the XRD spectra of a 13-nm Co on Si(100) after LTA between 10 and 100 pulses at 0.3 J/cm^2 . The CoSi_2 peak intensity is higher for the 100-pulse LTA sample, signifying that enhanced silicidation was attained as compared with the 10-, 20-, and 50-pulse samples. Auger analysis (not shown) indicates that the film is about 60 nm thick and with good CoSi_2 stoichiometry being established after the 100-pulse laser annealing at 0.3 J/cm^2 . Although single-pulse LTA at 0.3 J/cm^2 has shown nonmelt phenomenon [6] [verified using simulation of laser interactions with materials (SLIM)], this letter demonstrates that using multiple-pulse LTA at 0.3 J/cm^2

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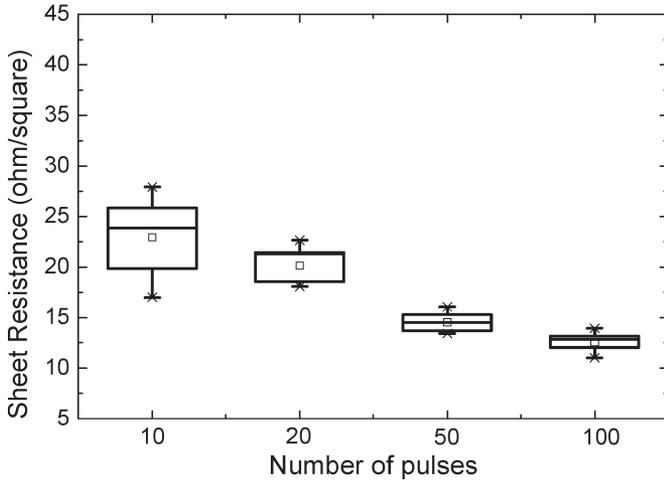


Fig. 2. Sheet resistance for multiple-pulse laser annealing of samples at 0.3 J/cm^2 .

has facilitated the formation of crystallized CoSi_2 , possibly via liquid-phase regrowth with a complete mixing of Co into Si by liquid-phase diffusion resulting in a crystallized silicide thickness that is relatively large compared with the two-step RTA process, which typically forms $3.6\text{-}\text{\AA}$ CoSi_2 with 1 \AA of Co. The sheet resistance of the corresponding silicides formed using the multiple-pulse LTA is shown in Fig. 2. A well-intermixed Co and Si layer promotes Co-silicide formation after a 100-pulse LTA and has led to about $15 \text{ }\Omega/\text{sq}$.

The developed multiple-pulse LTA technique for the formation of silicide was implemented on perimeter-intensive junction leakage structures bounded with shallow trench isolation (STI). The junction leakage and forward-bias current of the p^+/n and n^+/p perimeter-intensive diodes after a 100-pulse LTA on 8-nm Co films are shown in Fig. 3(a) and (b). The corresponding sheet resistance of the narrow Si lines is about $20 \text{ }\Omega/\text{sq}$. The I - V characteristics of the LTA samples are measured, and similar silicided diodes formed using RTA process (i.e., control samples) are included for comparison. The reverse junction leakage current of the LTA Co-silicided junction is lower than that of the RTA Co-silicided junction. The forward-bias current diode characteristic has comparably good drive current compared to that of the RTA samples. The improved reverse junction leakage performance also indicates that there is no bridging across the STI regions between the narrow and long active regions on the perimeter-intensive structures, which was verified by other bridging tests as well. The TEM micrograph in Fig. 4(a) shows that Co-silicide of 43-nm thickness has been formed with 8-nm Co on the narrow-width junctions (i.e., $0.5\text{-}\mu\text{m}$ p^+ Si) after a 100-pulse LTA at 0.3 J/cm^2 . It is shown that silicide/Si interface is smooth and uniform, with no excessive overgrowth or diffusion near the STI corner. The detailed high-resolution TEM (HRTEM) and electron diffraction analysis (inset) in Fig. 4(b) depicted that the Co-silicide phase is CoSi_2 and fully epitaxial with the substrate. The (111) plane of the single-crystal Co-silicide is aligned to the (111) planes of the Si substrate, indicating that liquid epitaxial regrowth has taken place with the Si substrate as the regrowth template after the occurrence of melting. The

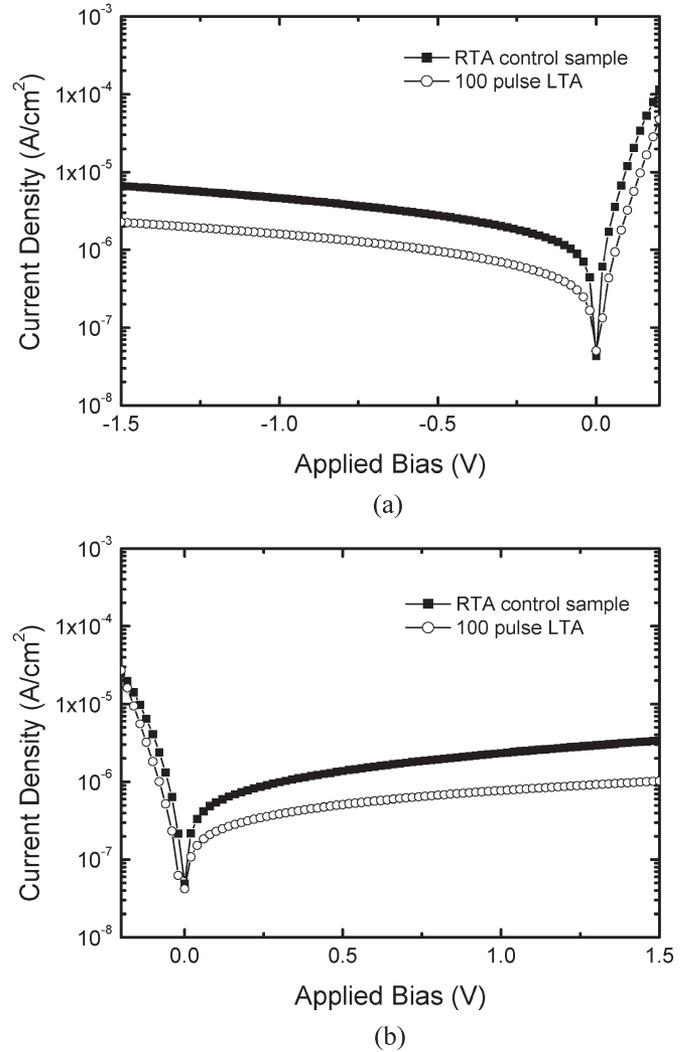


Fig. 3. Reverse- and forward-bias currents of (a) a p^+/n perimeter-intensive diode and (b) an n^+/p perimeter-intensive diode for 100 pulses of LTA at 0.3 J/cm^2 . RTA diode is included for comparison.

formation of good-quality liquid-phase epitaxial interface has been demonstrated previously using the single-pulse annealing followed by the conventional annealing [5]. In this letter, it is noticeable that the multiple-pulse LTA at low fluence has removed twinning defects or cellular structures found in single-pulse LTA samples caused by constitutional supercooling [6].

The absence of an amorphous layer of Co-silicide in Fig. 4(a) is attributed to heat confinement effects resulting from the STI. Laser annealing generally leads to fast solidification of supercooled liquid, which can result in rapid quenched amorphous structures. This can happen when the temperature of the supercooled liquid falls rapidly below the solidification temperature for amorphous Co-silicide. In the current study, the STI regions, which have a thermal conductivity that is about two orders of magnitude lower than that of Si [7], tend to trap a large amount of heat during excimer pulsed laser irradiation. This is coupled with the heat trapping due to the decreased reflectivity of Co on the STI region after multiple pulses. Co-Si adjacent to the STI would stay hotter for a longer time and would therefore possibly be kept from being rapidly quenched

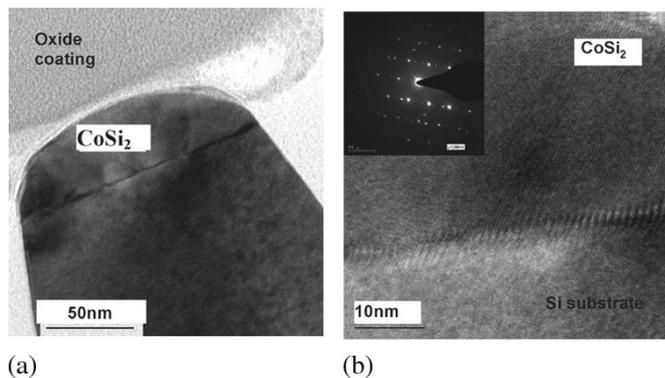


Fig. 4. (a) Cross-sectional TEM and (b) HRTEM of a Co-silicided $0.50\text{-}\mu\text{m p}^+$ active line after a 100-pulse LTA at 0.3 J/cm^2 . The inset in (b) shows the microdiffraction analysis at the Co-silicide/Si interface. The oxide layer shown in (a) is due to a TEM sample preparation.

to form an amorphous solid. Staying hotter for a longer time would prevent the supercooled liquid from being quenched into an amorphous phase with fast propagation of the solidification front. This inhibition of rapid quenching results in a completely crystallized Co-silicide phase in these narrow-width Si active lines bounded by STI.

IV. CONCLUSION

The use of multiple-pulse low-fluence laser annealing has resulted in a melt of desirable compositional ratio and the formation of crystallized CoSi_2 over narrow-width Si lines. A smooth and abrupt silicide/Si interface is achieved via liquid-phase epitaxial regrowth, together with the formation of the desired silicide phase. These occur as a result of fast laser melt-

ing and recrystallization of deposited elemental films. Excellent junction leakage performance of LTA silicided narrow-width junctions confirms that the multiple-pulse LTA technique is able to effectively remove defects that commonly result from rapid quenching of melt zones.

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