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# A—3—4 Resistivity Reduction of Polycrystalline Silicon Films by Laser Annealing

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Poly-Si films are widely used as gate and interconnecting electrodes in MOS LSI's. Lowering the sheet resistivity is still a key requirement to improve the high-speed performance. However, the resistivity seems to have reached almost to its minimum in the standard process, under the limited thickness and line width conditions. Utilizing a laser annealing technology, a drastic reduction in poly-Si sheet resistivity, from 40Ω/□ to 10Ω/□, has been observed. The technology was successfully applied in MOS fabrication process steps, and practically no degradation in device characteristics was observed. Physical mechanism of poly-Si laser annealing is also presented.

An accoustically Q-switched Nd:YAG laser (1.06μm) system with numerical control X-Y stage was used in this experiment. The laser pulse width, repetition rates, and spot diameter on a sample were 200 nsec, 10KHz and 50μm, respectively. Fig.1 shows the results of thermal anneal of Arsenic (As) ion implanted poly-Si films with and without laser annealing. The film thickness was 5300Å, and ion dose was $1 \times 10^{16} cm^{-2}$ at 230KV, i.e. $R_p$ was about 1300Å. By 30 min. thermal annealing after laser irradiation, low sheet resistivity obtained by laser annealing, gradually increased and then showed Lambda-shaped change around 700°C. Comparing with the data for "not laser annealed" samples, the change in resistivity can be explained as follows; i) The laser irradiation incorporated the implanted As atoms into substitutional sites during recrystallyzation, ii) the subsequent thermal annealing cause precipitation of As atoms at grain boundaries, then iii) thermal diffusion process dominates at higher temperature than 700°C, driving As atoms into deeper region from the surface, thus results in resistivity reduction again. TEM photographs in Fig.2 also support the model, since there found no remarkable grain growth. The above results suggest that with heavily doped poly-Si and laser annealing can result in very low sheet resistivity which is not achievable in conventional thermal diffusion process.

The sheet resistivity of As-diffused poly-Si, both before and after laser anneal, is shown in Fig.3 as a function of diffusion time. It should be noted that the sheet resistivity shows a saturation for prolonged diffusion time, but about 40% reduction by the laser annealing. Fig.4 shows the results of subsequent 450°C and 1000°C thermal anneal. At 1000°C the resistivity rapidly increases slightly higher than that of "not laser annealed" sample. However, 450°C shows only a modest increase during 2 hours of annealing.

The results of a laser annealing for patterned poly-Si in an MOS structure are shown in Fig.5. Compared with the results with unpatterned poly-Si, further reduction, down to almost one quarter, in sheet resistivity was observed. The pattern sensitivity in the resistivity reduction can be explained by different degree of grain regrowth due to the film edge stress.

In order to evaluate laser irradiation damages on actual MOS devices, relatively higher laser power, roughly 50% more than required to obtain low enough resistivity, was applied on MOS capacitors and self-aligned poly-Si gate MOS transistors after Al metallization. As shown in Fig.6, practically no degradation in C-V, $V_{th}$, and $g_m$ were observed. Junction leakage current, junction breakdown voltage, and leakage current between gate and source, drain or substrate were also tested without any noticeable change.

The technique was successfully applied to an actual NMOS LSI chip, and the expected speed improvement was confirmed. Dependence on poly-Si film thickness, doping level or ion implanted dose level dependence are also studied. More detailed discussion on the annealing mechanism will be presented.

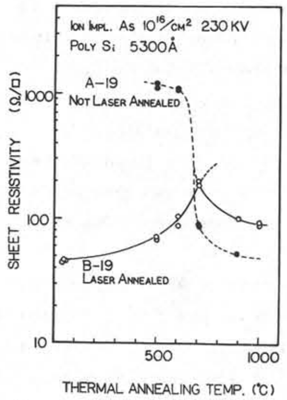


Fig.1 Sheet resistivity of laser annealed and unannealed poly-Si as a function of subsequent thermal annealing temperature. As-ion dose is $1x10^{16}cm^{-2}$.

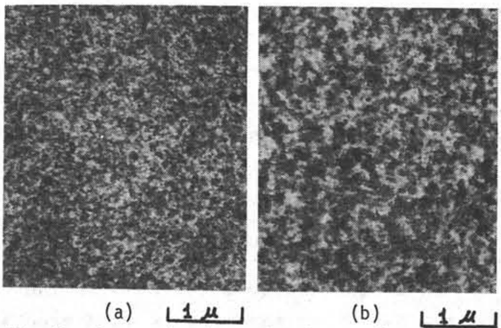


Fig.2 Transmission electron micrographs of As-ion implanted, and subsequently laser annealed poly-Si. (a) before and (b) after subsequent thermal anneal at 1000°C.

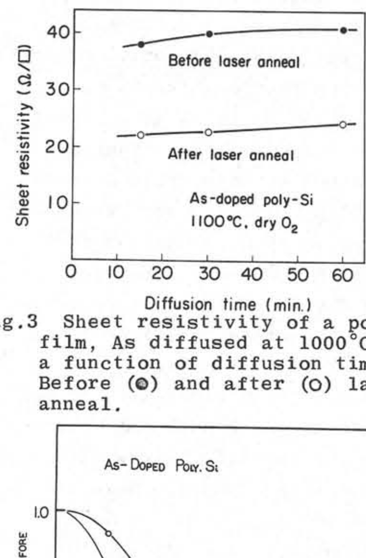


Fig.3 Sheet resistivity of a poly-Si film, As diffused at 1000°C, as a function of diffusion time. Before (◉) and after (O) laser anneal.

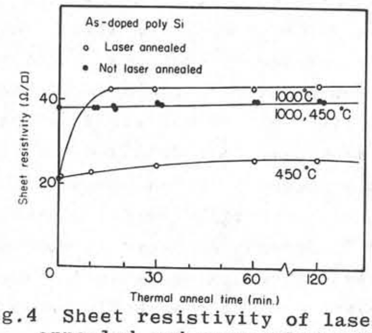


Fig.4 Sheet resistivity of laser annealed and unannealed poly-Si as a function of subsequent annealing time, at 450°C and 1000°C.

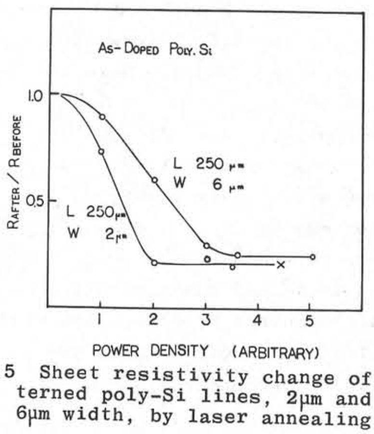


Fig.5 Sheet resistivity change of patterned poly-Si lines, 2μm and 6μm width, by laser annealing.

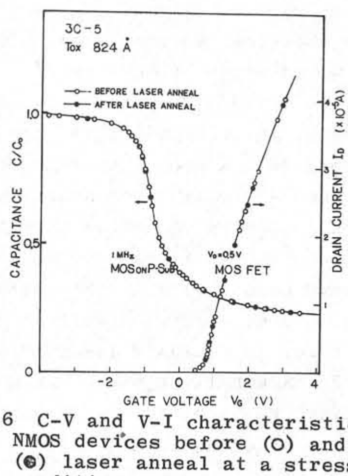


Fig.6 C-V and V-I characteristics of NMOS devices before (O) and after (◉) laser anneal at a stressed condition.