Supporting Information
Controlled Silicidation of Silicon Nanowires using Flash Lamp Annealing

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Annealing involves the heating of wafers to change their properties. Additionally, it can also be used to change the structure of materials. Over the past several decades, annealing has evolved from several minutes to days based furnace annealing to picoseconds laser annealing (LA). Shorter time annealing, namely rapid thermal annealing/processing (RTA/RTP), came under focus towards the late 20^{th} century due to the advancements in complementary metal-oxide-semiconductor (CMOS) technology[1,2]. This shift of focus was mainly driven by the processing of source-drain electrodes for advanced CMOS technology. However, to overcome the problem of transient enhanced dopant effects, the need to develop an annealing technology with sub-second times emerged, which led to the production of advanced annealing techniques. Today, RTA, FLA, and LA are widely used annealing techniques. They are compared in table S1. In RTA, energy is typically supplied by halogen lamps. It is an isothermal process in which the front (T_{FS}) and the backside (T_{BS}) of the wafer are at the same temperature. The annealing times are typically in the range of 1 s to 100 s. In FLA, the energy is supplied by Xenon lamps. This process occurs in the thermal flux regime, a regime where power density is high enough to induce local heating but not so high to nullify heat transfer completely. The annealing times are in the range of 10 µs to 100 ms. In LA, there are two modes of operation: continuous and pulsed mode. In the former, either the laser beam scans the wafer or the wafer is moved under the laser. The resulting dwelling times are in the ms-range, which depends on the speed of the movement and spot size of the laser. This process also takes place in the thermal flux regime. In the pulsed mode operation, a narrow region of the wafer surface is heated depending on the penetration depth of the light used. It is an adiabatic process, where only local heating occurs. The processing times in this type of annealing are up to several tens of ns.[3]

RTA is a commonly used technique in research and development. It has been employed widely for various applications, including silicidation. However, the homogeneous and reproducible intrusion of silicide into the nanowires has remained an issue using this technique. Flash lamp and laser annealing processes enable precise thermal treatments of materials at a reduced thermal budget of the bulk. Therefore, the surface being annealed is cooled down rapidly compared to the RTA process.

FLA is also known as intense pulsed light processing, flashlight sintering, or photonic curing. The setup consists of a chamber, a wafer holder, a bank of Xenon flash lamps, a pre-heating system, reflectors, and a quartz window. The pre-heating system can be used to heat the sample before initiating the flash. This reduces the thermal stress of the substrate and mitigates the effects of metastable annealing.[3,4] It can also be used if higher processing temperatures are required. Typically, the pre-heating system consists of a bank of halogen lamps. As this system is similar to the one used for RTA, it is also referred to as flash-assisted RTA.[5] In some setups, hot-plate based pre-heating is used. The reflector directs the light towards the substrate and ensures the homogeneity of temperature on the substrate surface. The quartz windows prevent the deposition of substrate material on the flash lamps and the pre-heating system.

Table S1: Comparison of different annealing techniques[3]

Parameters	RTA	FLA	cw LA	Pulsed LA
Annealing times	1-100 s	10 µs-100 ms	µs-100 ms	1-1000 ns
Light source	Halogen lamps	Xe flash lamps	Laser	Laser
Material dependence of temperature	No	Yes	Yes	Yes
Heating rates (Ks^{-1})	10-10^3	10^4-10^7	-	$>10^8$
Annealing regime	Isothermal	Thermal flux	Thermal flux	Adiabatic
Backside temperature	$T_{BS} \approx T_{FS}$	$T_{BS} < T_{FS}$	$T_{BS} < T_{FS}$	$T_{BS} \approx T_{FS}$

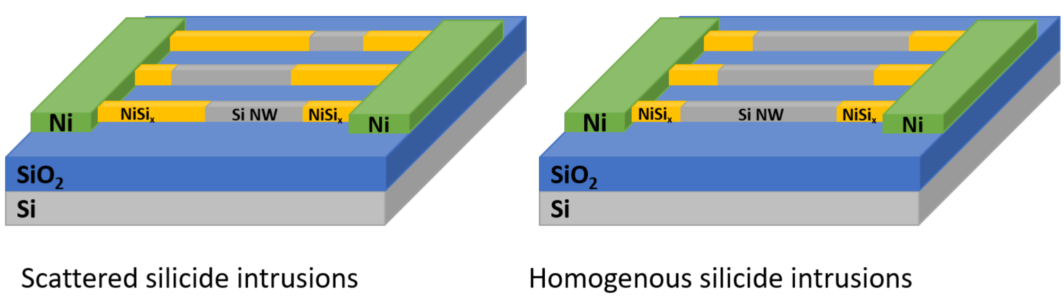

Figure S1: (a) Schematic illustration of the silicided nanowires (a) with uncontrolled silicide lengths (b) with homogeneous and symmetric silicide lengths.

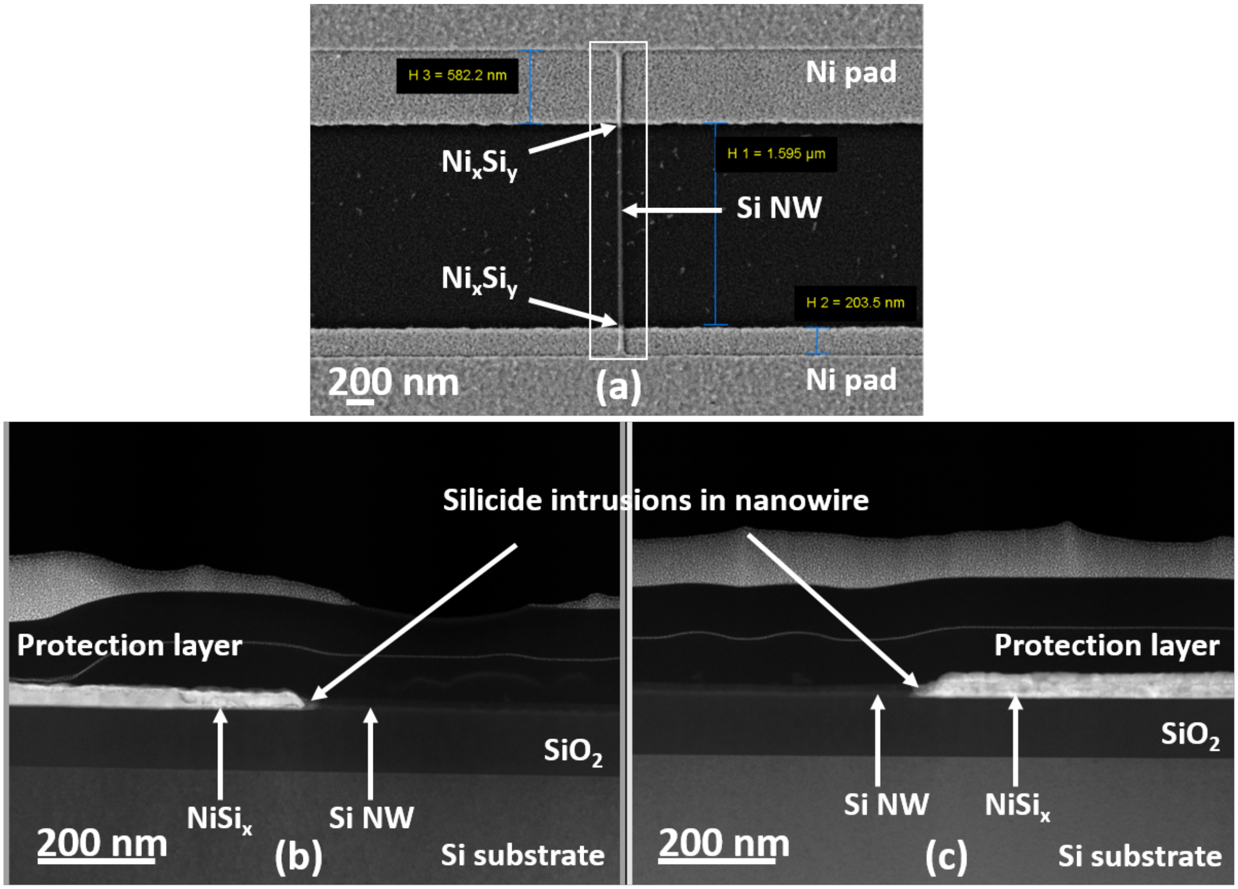

Figure S2: (a) Top-view SEM micrograph of a silicided single nanowire: annealing parameters are: N_2 environment, $70.4\,\mathrm{Jcm^{-2}}$ flash energy density, and 3 ms pulse duration. (b, c) STEM micrographs of the cross-section of the Si/Ni-silicide interfaces: nanowire is sectioned along its long axis, indicated by the rectangular box in (a). Silicidaion in the complete nanowire cross-section is seen, indicated by the bright regions.

References

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