

Self Aligned Double Pattern Method for the Definition Silicon Nanowires Using Ga⁺ Focused Ion Beam Milling Technique with Mask of Hydrogenated Amorphous Silicon Film

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This work presents the Ga⁺ focused ion beam (FIB) milling technique, with the protective layer of hydrogenated amorphous silicon (a-Si:H) film, and self aligned double pattern (SADP) method for obtaining sub-50 nm wide silicon nanowires (SiNWs), as is shown in Figure 1. In this case, the FIB milling technique is employed in the definition of Al mandrel (nanometric width), which are protected by the a-Si:H film, and, afterwards, used as sacrificial layer in the SADP method. Previous works, the FIB milling technique was used for the formation of 3D transistors.^{1,2} However, this technique had no control and high doses of the gallium ions in the conduction channel. In order to avoid this interaction of the gallium ions with the substrate during the FIB milling technique, a thin layer of a-Si: H (60 nm thick) was deposited by electron cyclotron resonance (ECR) – chemical vapor deposition (CVD) at room temperature, on the Al film which was on the Si substrate as shown in Figure 1. Afterwards, the Al mandrel formation, the steps of the SADP process (with a-Si: H film spacers) were performed as shown in Figure 1. Then all the process steps, SiNWs were formed on the sample surface at 35 nm in width and spaced at 170 nm as shown a cross section in Figure 2(a).

SiNWs was formed on *p*-type Si (100) substrate. The sequential process steps is shown schematically in Figure 1. The Al mandrel were defined using the Ga⁺ FIB, with energy of 30 kV and current of 30 pA.³ In this step, the ion beam was used only for a cut of the a-Si:H thin layer and Al film, as shown in Figure 1. The a-Si:H layer and Si substrate etch were done using SF₆/C₄F₈ inductively coupled plasma (ICP) after the FIB step. Figure 2(b) presents a cross section of 4 SiNWs with double SiNWs spaced at ~ 800 nm.

¹ Lima, L. P. B.; Santos, M. V. P.; Keiler, M. A.; Dekkers, H. F. W.; Gendt, S. D.; Diniz, J. A. ECS Transactions **66**, 61, (2015).

² Santos, M. V. P.; Lima, L. P. B.; Diniz, J. A.; Filho, J. G.; Journal Vacuum Science & Technology B **31**, 06FA01 (2013).

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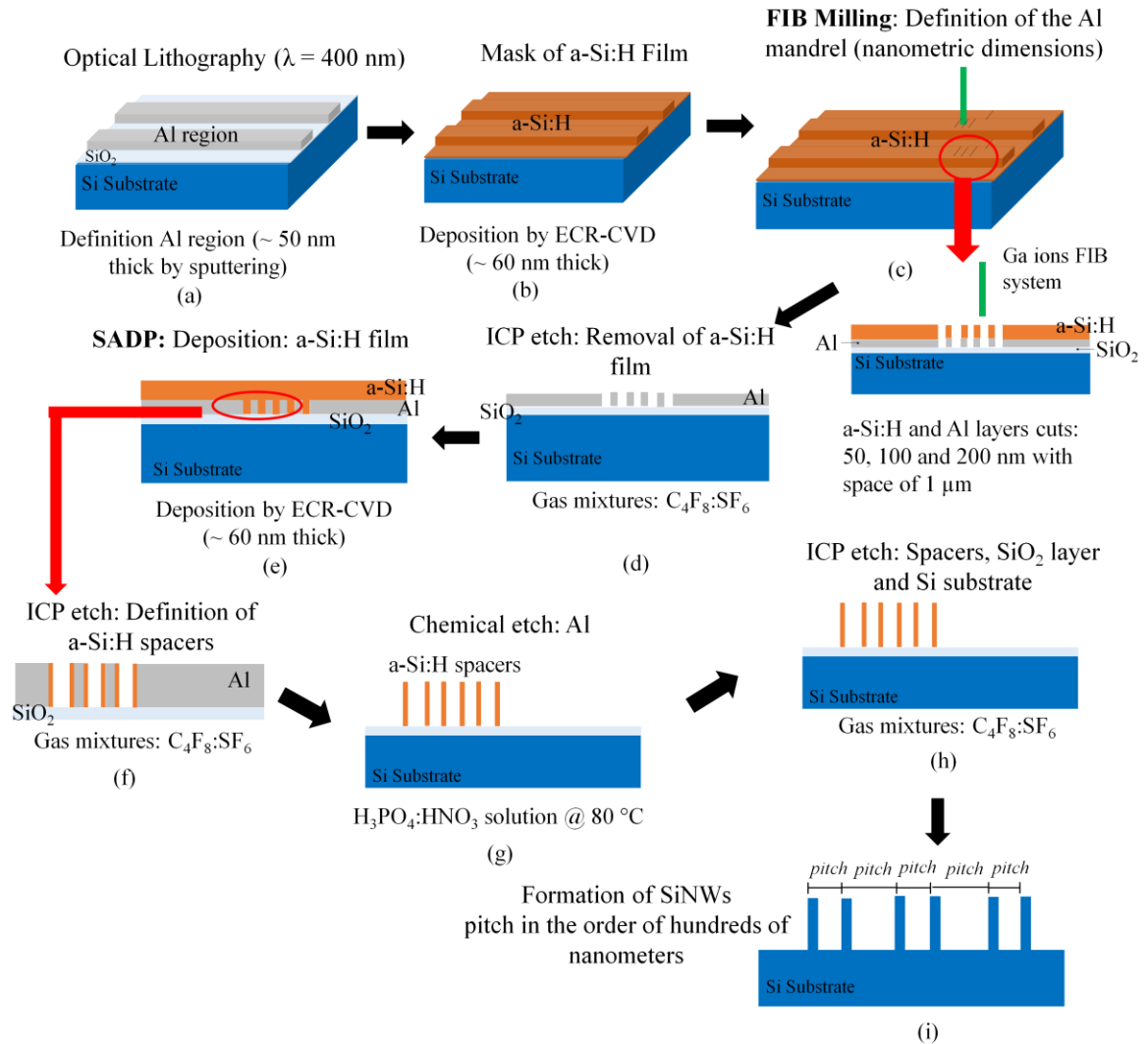


Figure 1: The sequential process steps to produce of SiNWs by the FIB milling, with the protective layer of a-Si:H film, and SADP method.

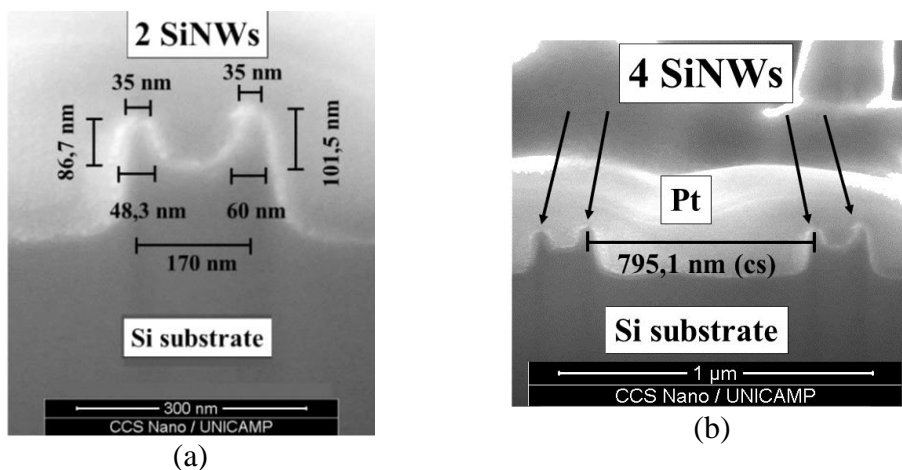


Figure 2: (a) 2 SiNWs with 35 nm in width and spaced at 170 nm. (b) 4 SiNWs with double SiNWs spaced at ~ 800 nm.