Metallic nanowires on SmSi interface

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Abstract. The manufacture of nanowires and the exploitation of their specific properties are the great fields of fundamental and industrial research. Some nanostructuration can be obtained with the help of conventional lithography technics; nevertheless these technics are limited by the optical resolution, the introduction of many defects and the residual damage related to engraving. A new approach, which consists to create nanowires in-situ on pre structured SmSi(111) interface has been investigated by scanning tunneling microscopy (STM). This interface is known to permit the creation of many different 1D templates in the submonolayer range. We show in this study, the possibility to create Fe nano-objects of well-defined size distributed in an ordered array.

1. Introduction
Low-dimensional structures such as quantum wires and quantum dots have attracted intensive study in the past both for their potential in building up new optoelectronic and microelectronic devices and for their physical and chemical properties compared with the bulk material. One-dimensional (1D) metal nanowires may build up 1D electron systems, which are expected to show unique transport behavior. But, the realization of nanostructure on a surface raises problems particularly complex to solve and depend of the nature and interaction of the element with the surface [1]. To understand all these properties of low dimensional structures and utilize them for device application, it is essential to fabricate periodic arrays of such structures with controllable sizes over large sample areas. For the rare earth atoms adsorption, an epitaxial disilicide hexagonal type can be formed around 500 °C. Resulting of an anisotropic lattice mismatches along two perpendicular directions, these disilicide exhibit well defined nanowires.

We investigate in this work the possibility to elaborate Fe self-assembled atomic nanowires on a Si(111) surface. For that, we have used pre-structured surfaces formed by anistropic reconstructions, the (7×1) known on rare earth Si(111) interface. In this case, we can minimize the interactions adsorbate-silicon and obtain the realization of Fe nanowires on the interface Sm/Si(111)7×1 with a great thermal stability [2, 3].

2. Experimental procedure
The samples were prepared and analysed in a ultrahigh vacuum chamber equipped with a STM and a Low Energy Diffraction analyser (DEL). The silicon wafers, oriented (111), were heated resistively by DC current. A clean surface is obtained by repeated cycles of heating at 1200 °C and a slow cooling down at room temperature. The high degree of cristallinity of the surface is checked by a STM observation of the (7×7) structure in atomic resolution. Sm was evaporated
from a Mo crucible and deposited onto the Si(111) substrate held at 550 °C at a rate about 0.63 monolayer (ML) per minute in a pressure better than 3 × 10^{-10} mbar. The monolayer scale is referred to the Si(111) surface atomic density (7.8 × 10^{-14} atoms/cm²). Once the Sm/Si interface elaborated, Fe atoms are evaporated from a Mo crucible at a rate about 0.008 ML per minute onto the sample held at temperature in the 300 °C – 400 °C range. The STM observations were made at room temperature and the STM images were acquired in the usual constant current mode.

3. Results and discussion
The (7×1) Sm/Si(111) is based on the HCC model of the (3×2) reconstruction previously described in the literature. This structure is obtained for a Sm coverage of 0.42 of monolayer. The structural model (Fig. 1) is formed by a honeycomb chain added to two parallel zigzag Si chains. These Si chains are called Seiwatz model. Added to the honeycomb chain, these zigzag Si chains give a ×7 periodicity to the structure. Each free T4 site is recovered by a Sm atom (black atoms). This is corresponds to three Sm atoms by (7×1) unit cell (0.42 of ML) [4].

Figure 1. Structural model for the 7×1 Sm/Si(111) surface

A typical positive STM image of the (7×1) is shown Fig. 2. The structure appears like 3 parallel rows separated by a larger dark channel. The empty state STM images of the (7×1) acquired around +2V, don’t show the Si atoms. So the Si HCC and the Si Seiwatz chains cannot be atomically resolved and the dark channels are assigned respectively to the HCC position for the widest and to the Si Seiwatz for the narrowest. By positionning the structural model of the (7×1) on the empty state STM image, we show that the three parallel rows correspond the Sm atoms.

The iron atoms deposition on the (7×1) Sm/Si(111) shows a quite different interface of the one observed on the pre-structured (3×2). The Fig. 3 shows a large view of this interface for a 1/10 of ML iron coverage. The three domains of the (7×1) Sm/Si initial substrate are
Figure 2. Empty state STM image of the (7×1) Sm/Si(111) surface for a sample bias voltage of $V_s = +1.7$ V, $I_t = 0.45$ nA, size=8×8 nm$^2$. The Si Seiwatz chains, Sm atoms and Si HCC positions are indicated in white ($a = a_0 \sqrt{3/2}$ and $a_0 = 0.384$ nm).

still present and a clean surface formed by large bright parallel rows is observed. A prolonged annealing shows interesting results. Indeed, after a one hour 500 °C annealing, a modification of the surface is observed.

Figure 3. STM image of the Fe/(7×1) Sm-Si interface for a 1/10 of ML iron coverage for a sample bias voltage of $V_s = +2.09$ V, $I_t = 0.55$ nA, size=80×80 nm$^2$. Self-assembled nanowires are visible along the equivalent [110] direction.

The Fig. 4 is a zoom-in on the Fig. 3. This figure shows a homogeneous interface with bright parallel rows attributed to the iron atoms. The distance measured between the rows is 2.3 nm.
corresponding to \( \times 7 \) the unit lattice spacing \( i.e. \) exactly the same periodicity that the \((7 \times 1)\) reconstruction in this direction. The width of each bright row is typically of 1nm and their length about tens of nanometers. At this stage, we can reasonably think that the iron atoms don’t destroy the initial reconstruction and that they are simply adsorbed on the substrate.

![Figure 4.](image)

Each row is separated one of the other and due to this particular one dimensional geometry the rows induced by iron atoms are called ”nanowire”. Just some parts of the surface, induced by a local weak coverage, are uncovered and appear more dark. In these zones, the samarium rows of the \((7 \times 1)\) reconstruction are less visible. Images STM show the presence of nanostructures distributed and directed according to the same direction as the lines of the structure \((7 \times 1)\). By increasing the rate of the iron coverage, we have noted that these 1D nanostructures grow preferentially in the direction \([1\overline{1}0]\) and that the structure \((7 \times 1)\) is destroyed to the benefit of the structure SmSi \((3 \times 2)\). The interaction Fe-Si seems in our results not very important and one can suppose that the nanostructures observed are made up mainly of iron atoms.

4. Conclusion
We have demonstrated that the pre-structured SmSi\((111)\) \(7 \times 1\) interface is a good candidate for a 1D nanowire on semiconductor substrate. Taking into account the morphology of the deposit, we show that the iron atoms are adsorbed preferentially along chains of Seiwatz. Interactions between the iron atoms and the SmSi surface at room temperature are sufficiently strong to block the formation of an iron disilicide.

References
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