Fabrication and growth mechanism of one-dimensional Heusler alloy nanostructures with different morphology on anodized alumina oxide template by magnetron sputtering

Xiaoyu MA[1], Guifeng CHEN[1], Xiaoming ZHANG[1], Taoyuan JIA[1], Weiqi ZHAO[1], Zhaojun MO[2], Heyan LIU[1], Xuefang DAI (✉)[1], and Guodong LIU (✉)[1]

1 School of Materials Science and Engineering, Hebei University of Technology, Tianjin 300130, China
2 School of Materials Science and Engineering, Tianjin University of Technology, Tianjin 300384, China

E-mails: xuefangdai@126.com (X.D.), gdliu1978@126.com (G.L.)

Supplementary materials

The structure of Heusler alloy

Heusler alloys are a kind of intermetallic compounds with highly ordered arrangement of atoms. In some literature, Heusler alloy is also called Heusler compound and the structure of Heusler alloy is also called Heusler structure. Heusler alloy was first proposed in 1903 [S1]. However, at that time, people did not know exactly their structure and only the generic formula X_2YZ was proposed, where, X and Y denote some transition-metal elements, and Z an *s*-*p* element. In the 1960s and 1970s, the structure of Heusler alloy was determined [S2–S3]. But the concept of Heusler alloy is only limited to $L2_1$ structure as shown in the upper part of Fig. S1 until half-Heusler alloy appears ($C1_b$ structure). The general definition of Heusler alloy based on sublattice framework was proposed in 2008 [S4–S5]. In the general definition of Heusler alloy, it is considered that the Heusler structure is composed of four face-centered cubic (f.c.c.) sublattices crossing along the space diagonal as shown in the central part of Fig. S1. Four f.c.c. sublattices are labeled with A, B, C, and D, respectively. When all sublattices are occupied by atoms, this Heusler alloy is called full-Heusler alloy. When one of four f.c.c. sublattices is empty, this Heusler alloy is called half-Heusler alloy. When the fourth atom (X′) enters into Heusler alloy, that is, X_2YZ becomes XX′YZ, Heusler alloy is called quaternary Heusler alloy or LiMgPdSb-type Heusler alloy. When X and Y are the same atoms, that is, X_2YZ becomes X_2XZ, Heusler alloy is in DO_3 structure. When one of X atoms and Y are exchanged to occupy their sublattices in $L2_1$ structure, the fashion of atomic ordered arrangement will be changed, which is called inverse Heusler alloy or Hg_2CuTi-type Heulser alloy [S4]. In this work, we adapt the general definition of Heusler alloy, that is, Heusler alloys include the alloys with $L2_1$, DO_3 and $C1_b$ structures as well as quaternary Heusler alloy and Hg_2CuTi-type Heulser alloy.

The 1D-HA-NSs with various morphologies under different growth conditions

The one-dimensional nanostructures with various morphologies can be formed in different compositions, growth temperatures, and crystal axes, which indicate that the formation of 1D-HA-NS morphology is almost independent on these factors. Here, we show the nanowires with different shapes, AC nanowires and nanowires of different Heusler alloy (Fig. S2). The 1D-HA-NSs grow at different substrate temperatures or on AAO template with different apertures.

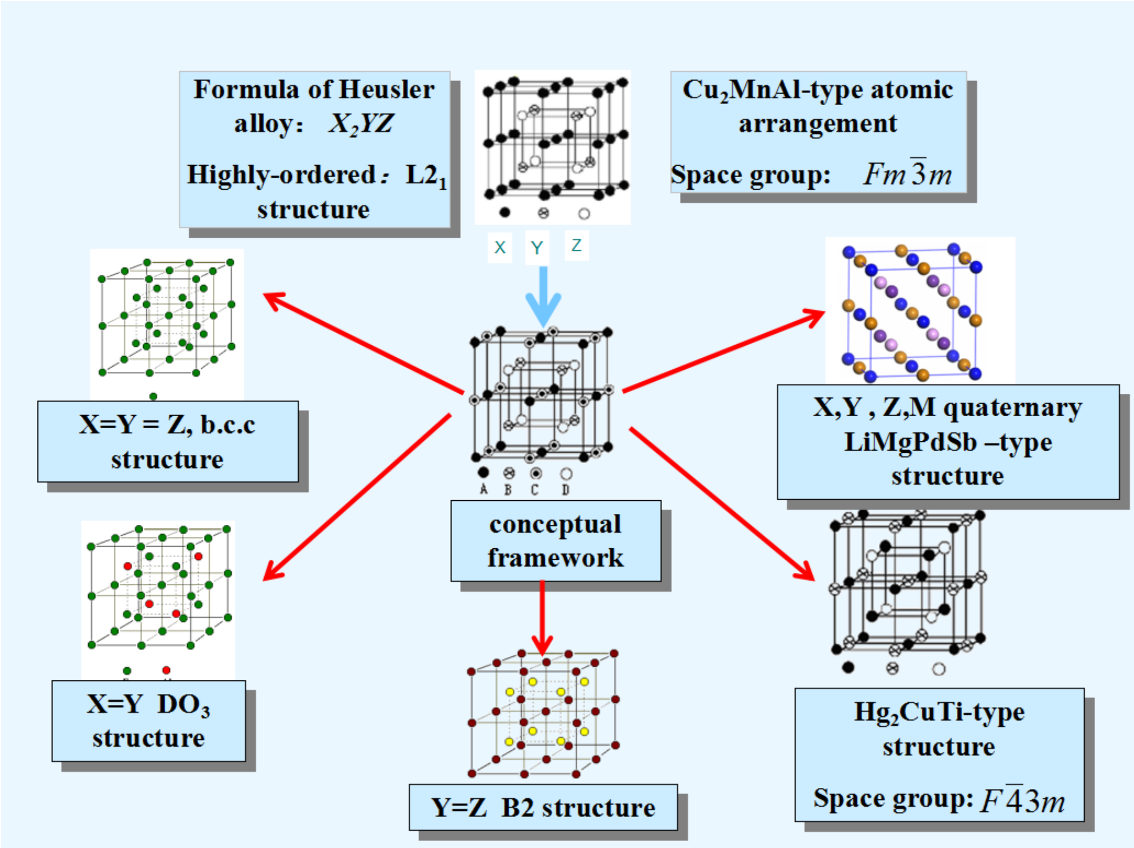

Fig. S1 The structure schematic diagram of Heusler alloy and the concept evolution topological diagram of Heusler alloy.

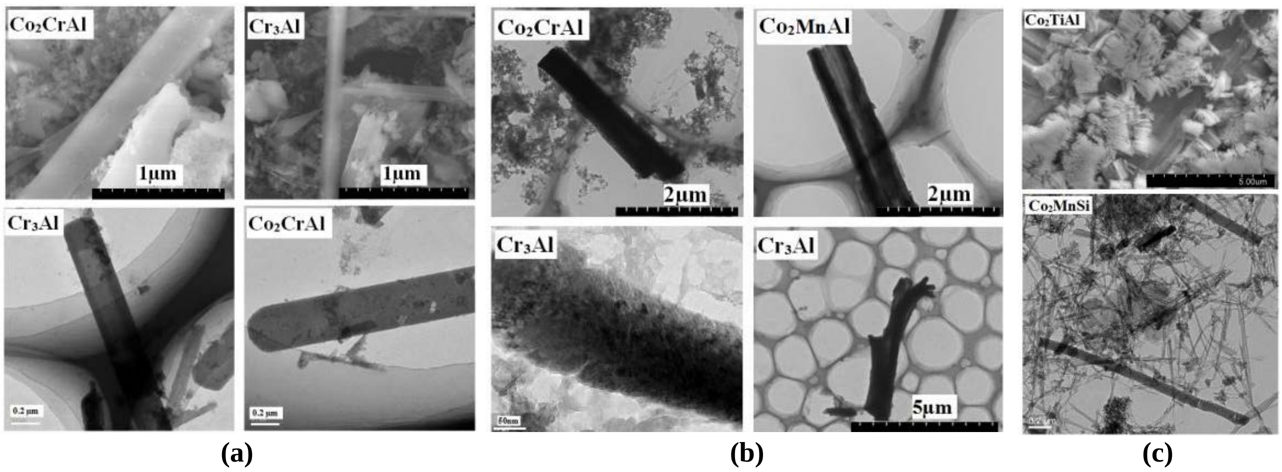

Fig. S2 (a) The nanowires with different shapes. The substrate temperature is 300 °C. The aperture of AAO is 80–100 nm for the nanowire in the upper left corner and 30–40 nm for the nanowire in the upper right corner. The lower part is the hexagonal nanowires found in Heusler alloys with different composition. The substrate temperature is room temperature and the aperture of AAO is 40–70 nm. **(b)** The upper part is the nanotubes found in Heusler alloys with different compositions. The substrate temperature is 400 °C and the aperture of AAO is 40–70 nm. In the lower left corner, we show an AC nanowire with smaller diameter than that reported in text. The substrate temperature is 400 °C and the aperture of AAO is 40–70 nm. In the lower right corner, several nanowires are stuck together due to the higher substrate temperature than 400 °C. The aperture of AAO is 40–70 nm and the actual temperature of the substrate is 450 °C. **(c)** Two kinds of nanowires not mentioned in the text. The substrate temperature is room temperature and the aperture of AAO template is 40–70 nm. Their diameter is similar to the Heusler alloy nanowires grown on the AAO template with the same aperture, which are reported in text. The upper image is nanowires that have been separated from the AAO template but have not yet been ultrasonically separated into individual. The upper image is individual nanowire. All nanowire compositions are labeled in the upper left corner of the images.

XRD patterns of 1D-HA-NSs

The XRD patterns show all the nanostructures reported in this paper crystallize in Heusler structure (Fig. S3). For Cr_3Al alloy, the space between (1 1 0) planes achieved from XRD results is 0.209 nm, which is in good agreement with the result of electron diffraction pattern (0.208 nm).

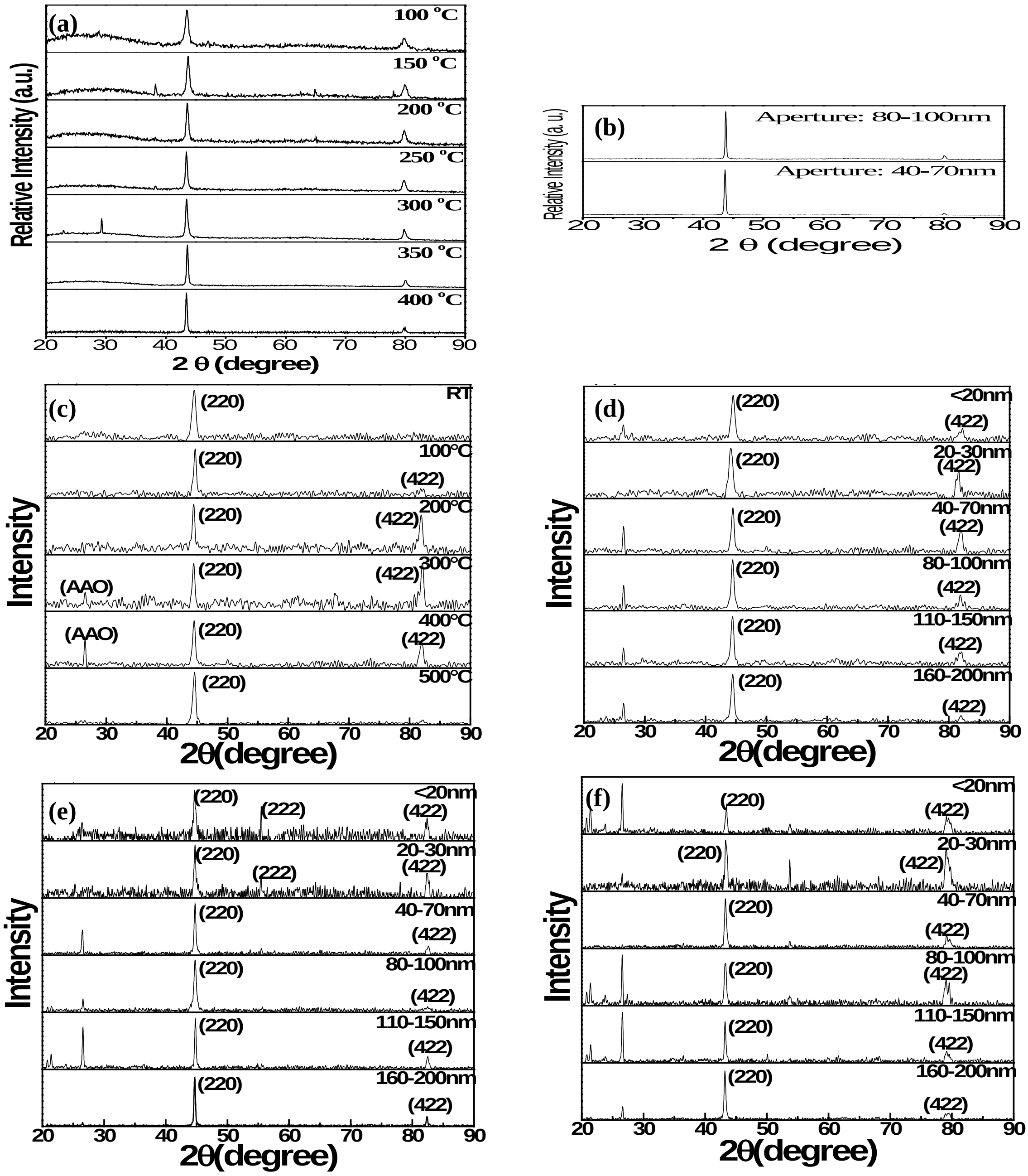

Fig. S3 (a) The XRD patters for Cr_3Al nanowires grown on the AAO template with the aperture of 40–70 nm at different substrate temperatures. **(b)** The XRD patters for Cr_3Al nanowires grown on the AAO template with the different apertures at the substrate temperature of 400 °C. **(c)** The XRD patters for Co_2MnAl nanowires grown on the AAO template with the aperture of 40–70 nm at different substrate temperatures. **(d)** The XRD patters for Co_2MnAl nanowires grown on the AAO template with the different apertures at the substrate temperature of 400 °C. **(e)** The XRD patters for Co_2CrAl nanowires grown on the AAO template with the different apertures at the substrate temperature of 300 °C. **(f)** The XRD patters for Co_2TiAl nanowires grown on the AAO template with the different apertures at room temperature.

The composition of all grown 1D-HA-NSs detected by EDS

Here, we listed all the grown 1D-HA-NSs in Table S1. The corresponding real compositions detected by EDS were also shown.

Table S1 Compositions of all grown 1D-HA-NSs and their corresponding morphology

Nominal composition	Actual composition	Substrate temperature/°C	Aperture of AAO template/nm	Nanostructure morphology
Cr_3Al	$Cr_{2.98}Al$	100	40–70	Triangular, square and hexagonal nanowires
	$Cr_{3.04}Al$	150	40–70	Triangular, square and hexagonal nanowires
	$Cr_{2.98}Al$	200	40–70	Triangular, square and hexagonal nanowires
	$Cr_{2.96}Al$	250	40–70	Triangular, square and hexagonal nanowires
	$Cr_{3.01}Al$	300	40–70	Triangular, square and hexagonal nanowires
	$Cr_{2.95}Al$	350	40–70	Triangular, square and hexagonal nanowires; nanotubes
	$Cr_{2.99}Al$	400	40–70	Triangular, square and hexagonal nanowires; nanotubes; AC nanowires
	$Cr_{2.94}Al$	450	40–70	The stuck nanostructures
	$Cr_{3.03}Al$	400	80–100	Triangular, square and hexagonal nanowires; nanotubes; AC nanowires
Co_2MnAl	$Co_{2.02}Mn_{0.99}Al$	RT	40–70	Triangular, square and hexagonal nanowires
	$Co_{1.98}Mn_{0.98}Al$	100	40–70	Triangular, square and hexagonal nanowires
	$Co_{2.02}Mn_{0.98}Al$	200	40–70	Triangular, square and hexagonal nanowires
	$Co_{2.01}Mn_{0.97}Al$	300	40–70	Triangular, square and hexagonal nanowires; nanotubes
	$Co_{1.96}Mn_{0.97}Al$	400	40–70	Triangular, square and hexagonal nanowires; nanotubes
	$Co_{1.97}Mn_{1.01}Al$	500	40–70	The stuck nanostructures
	$Co_{2.01}Mn_{0.97}Al$	400	< 20	Triangular, square and hexagonal nanowires
	$Co_{1.98}Mn_{0.99}Al$	400	20–30	Triangular, square and hexagonal nanowires
	$Co_{2.03}Mn_{0.95}Al$	400	80–100	Triangular, square and hexagonal nanowires; nanotubes
	$Co_{2.01}Mn_{0.99}Al$	400	110–150	Film
	$Co_{1.97}Mn_{0.94}Al$	400	160–200	Film
Co_2CrAl	$Co_{1.98}Cr_{0.95}Al$	300	< 20	Triangular, square and hexagonal nanowires
	$Co_{1.99}Cr_{1.04}Al$	300	20–30	Triangular, square and hexagonal nanowires
	$Co_{2.04}Cr_{0.96}Al$	300	40–70	Triangular, square and hexagonal nanowires; nanotubes
	$Co_{1.96}Cr_{1.05}Al$	300	80–100	Triangular, square and hexagonal nanowires; nanotubes
	$Co_{2.0}Cr_{1.03}Al$	300	110–150	Film
	$Co_{1.98}Cr_{0.99}Al$	300	160–200	Film
Co_2TiAl	$Co_{1.99}Ti_{0.98}Al$	RT	< 20	Triangular, square and hexagonal nanowires
	$Co_{1.97}Ti_{1.04}Al$	RT	20–30	Triangular, square and hexagonal nanowires
	$Co_{2.03}Ti_{1.0}Al$	RT	40–70	Triangular, square and hexagonal nanowires
	$Co_{1.97}Ti_{0.98}Al$	RT	80–100	Triangular, square and hexagonal nanowires
	$Co_{1.95}Ti_{1.02}Al$	RT	110–150	Triangular, square and hexagonal nanowires
	$Co_{2.02}Ti_{0.99}Al$	RT	160–200	Film

Note: RT, room temperature.

References

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