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Structural Characterization of Co/Cr Superlattices

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Abstract

This study focuses on the structural characterization of Co/Cr superlattices. Co/Cr superlattices have attracted significant interest due to their exceptional magnetic and electronic properties, which are highly sought after in technological applications such as high-density data storage, magnetic sensing, and spintronics. The synthesis and comprehensive analysis of these superlattices are critical for unlocking their potential and tailoring their properties for specific applications. Molecular Beam Epitaxy (MBE) is a sophisticated technique for the fabrication of Co/Cr superlattices, offering unparalleled control over material deposition at the atomic level. This precision facilitates the creation of superlattices with distinct interfaces and tailored thicknesses, crucial for modulating their physical properties. X-Ray Diffraction (XRD) serves as a cornerstone technique for structural characterization, providing detailed insights into the crystalline structure and orientation of the superlattices. This study considers the detailed characterization through XRD of Co/Cr superlattices grown by using the MBE technique, aiming to highlight the potential of Co/Cr superlattices in future technological applications.

Keywords: Co/Cr superlattice, magnetoresistance, X-ray diffraction, structural characterization

1. Introduction

The pursuit of materials with novel and enhanced properties for technological applications has been a key driver in the advancement of material science and nanotechnology [1, 2]. In this context, Co/Cr superlattices have garnered significant interest due to their exceptional magnetic and electronic properties, which are highly sought after in high-density data storage, magnetic sensing, and spintronics [3, 4]. The fabrication and comprehensive analysis of these superlattices are critical for unlocking their potential and tailoring their properties for specific applications [5-7].

Molecular Beam Epitaxy (MBE) stands out as a sophisticated technique for the fabrication of Co/Cr superlattices, offering unparalleled control over material deposition at the atomic level [8, 9]. This precision facilitates the creation of superlattices with distinct interfaces and tailored thicknesses, crucial for modulating their physical properties [10]. The versatility and precision of MBE have been instrumental in exploring the limits of material synthesis, enabling the engineering of superlattices with desired characteristics. Following the synthesis, the structural characterization of Co/Cr superlattices becomes imperative to understand their properties and performance [11, 12]. X-ray Diffraction (XRD) is a cornerstone technique in this regard, providing detailed insights into the crystalline structure and orientation of the superlattices. Through XRD analysis, researchers can glean information on lattice parameters, strain profiles, and the overall quality of the superlattice structure (Doe et al., 2019). This information is vital for correlating structural attributes with the magnetic and electronic behaviors of the superlattices, thereby guiding the optimization process for their application in advanced devices [13, 14].

Current study considers the detailed characterization through XRD synthesis of MBE grown Co/Cr superlattices. By examining the processes involved in their fabrication and the insights gained from XRD analysis, this study aims to shed light on the potential of Co/Cr superlattices in future technological applications. Emphasizing the importance of precise fabrication and characterization techniques, this paper will contribute to the ongoing discourse in the field, highlighting the role of Co/Cr superlattices in advancing material science and nanotechnology.

2. Materials and Method

The molecular beam epitaxy (MBE) technique was employed to grow the sample, a process detailed by the parameters outlined in Table 1. Initially, the substrate temperature was raised to 590 °C within 20-30 minutes, a step essential for removing the oxide layer on the substrate surface and purifying it from oxygen. The intent behind the growth of the superlattice structure was to closely match the lattice constants of the subsequently grown layers with that of the superlattice, thereby inducing giant magnetoresistance through the formation of magnetic structures. This was achieved by

incorporating a Ge buffer layer and Co and Au bridge layers; the Au layer, in particular, facilitated the nucleation of the subsequent Co layer in the hexagonal close-packed (hcp) phase.

The growth rates for the Co/Cr superlattice were fine-tuned by experimenting with various parameters such as layer thickness, growth rates, and temperature, to determine the optimal conditions for growth, as specified in the table. Upon completion of the superlattice growth, a 20 Å thick Au cap layer was added. This layer serves a dual purpose: it prevents the oxidation of the superlattice and preserves the integrity of the structure. The architecture of the grown multilayer crystal, as presented schematically in Table 1, reflects the meticulous planning and execution of the growth process, highlighting the precision achievable with MBE in the development of complex superlattice structures.

Table 1. The conditions for sample growth.

Layer (from top to bottom)	Material	Thickness	Lattice Constant	Orientation	Growth rate and source
Cap layer	Au	20 Å	4.07 Å	(111) face-centered cubic (fcc)	K-cell, 0.08 Å /sn
Superlattice	Co/Cr	(32Å/4Å)*27 1000 Å	Co (hcp)=4.07 Å Co(bcc) = 2.51 Å Cr (hcp) = 4.57 Å Cr (bcc) = 2.8 Å	(0001) hexagonal close-packed (hcp)	MBE 0.25-0.35 Å/s
Bridging layer	Au	20 Å	4.07 Å	(111) face-centered cubic (fcc)	K-cell, 0.08 Å /s
Bridging layer	Co	25 Å	2.80 Å	(110) body-centered cubic (bcc)	E-beam, 0,2-0,4 Å /s
Buffer layer	Ge	500 Å	5.66 Å	(110) zinc blende (zb)	E-beam, 0.3 Å /s
Substrate	Semi-insulating GaAs	>1mm	5.65 Å	(110) zinc blende (zb)	---

3. Results and Discussion

The X-ray Diffraction (XRD) analysis has been utilized as a critical method for the structural characterization of Co/Cr superlattices. XRD provides valuable information about the crystal structure and phases, determining the quality and arrangement of the material. In this study, the findings from XRD analysis offer significant insights into the crystalline structure, orientation, and phase transitions of the superlattices. Our goal here is, after a long time, has the hcp Cr phase observed for the first time in this structure turned into the bcc phase and has there been a deterioration in the structure quality? Possible peaks/phases and XRD result for sample are given in Table 2 and Figure 1, respectively.

The XRD results indicate that the superlattice incorporates both hexagonal close-packed (hcp) and body-centered cubic (bcc) phases. In particular, the different crystal structures of Co and Cr layers (Co in both hcp and bcc phases, and Cr in hcp

and bcc phases) highlight the structural complexity of the superlattices. This diversity in phases plays a crucial role in influencing the magnetic and electronic properties of the superlattices.

Another notable point from the XRD analysis is the alignment of measured peaks and calculated 2θ values with the expected crystal phases, demonstrating the high crystal quality and orderly structure of the synthesized superlattices. For example, the clear observation of the Au (111) phase at a specific 2θ angle indicates the successful growth of the protective Au layer on top of the superlattice structure, serving to prevent oxidation. In this contex, the XRD analysis has provided critical information on the structural integrity and phase composition of the superlattices, laying the foundation for understanding and optimizing the material's magnetic and electronic properties. The importance of structural characterization in evaluating the potential use of Co/Cr superlattices for specific technological applications is clearly underscored in this study.

Table 2: Possible peaks and phases of the sample.

Material	Phase	Peak (hkl)	2θ Degree	2θ Xrd
GaAs	Zinc blende	(110)	45.36	45.35
Ge	Zinc blende	(110)	45.35	45.34
Co	bcc	(110)	45.31	44.42
	hcp	(0001)	44.46	
Au	fcc	(111)	38.48	38.46
Cr	hcp	(0001)	43,67	44.42
	bcc	(110)	44.44	

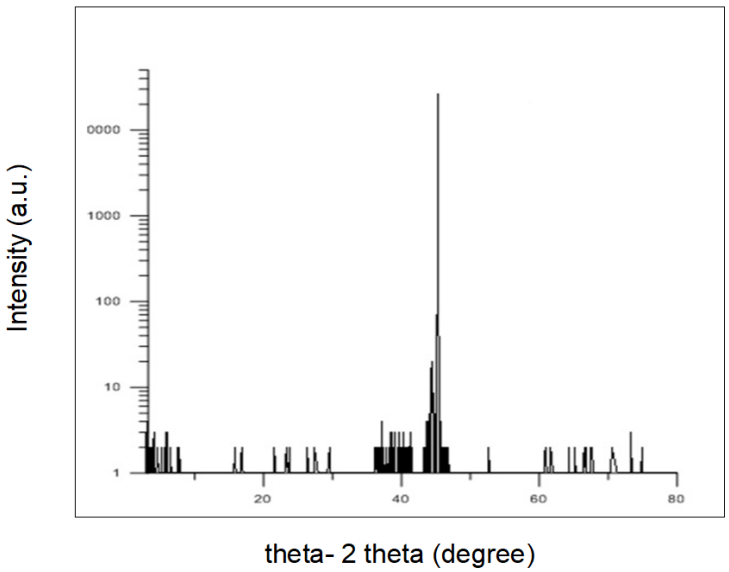

Figure 1. X-ray diffraction of the sample between 3°-80°

Following the initial analysis, a more detailed scan was conducted within the 36° - 46° range to closely examine the main peaks of the structure, as illustrated in Figure 2. This scan revealed the broad Au peaks and the more distinctly localized Co/Cr peaks within the structure, providing clearer insights into the material composition and structure. The lattice constants of Ge and GaAs compounds are very similar, leading to overlapping peaks that make the Ge (110) peak difficult to discern clearly. However, the comparison of the calculated lattice constants with their known real values shows minimal deviation, indicating the high quality of the crystal structure. The thickness calculations derived from these angle values, detailed in Table 3, demonstrate consistency among the measured values, which closely align with the actual thicknesses. This level of precision in the thickness measurements further confirms the exceptional quality of the crystal grown.

Table 3. The thickness calculations derived from XRD result.

Successive peaks	Thickness(Å)
5-4	899
4-3	897
3-2	895
2-1	893

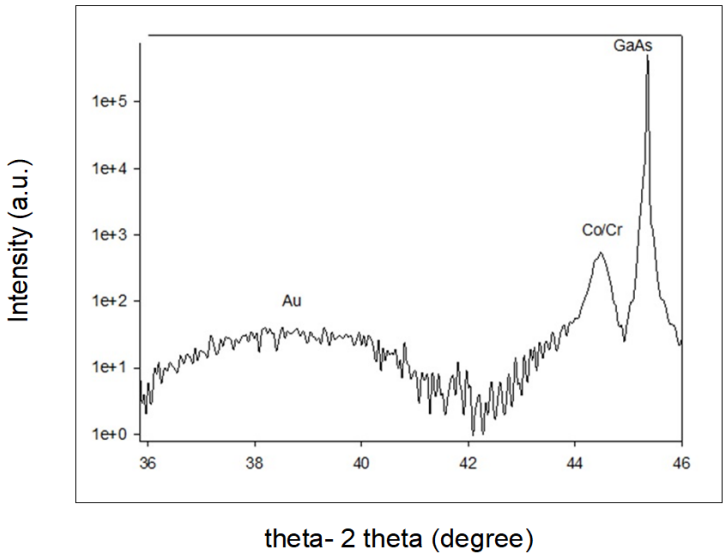

Figure 2. XRD patterns of the sample between 36°-46°.

4. Conclusions

This study on the structural characterization of Co/Cr superlattices presents findings obtained through X-Ray Diffraction (XRD) analysis. The XRD results indicate that the superlattices incorporate both hexagonal close-packed (hcp) and body-centered cubic (bcc) phases. Specifically, the different crystal structures of Co and Cr layers (Co in both hcp and bcc phases, and Cr in hcp and bcc phases) underscore the structural complexity of the superlattices. This diversity in phases plays a crucial role in influencing the magnetic and electronic properties of the superlattices. The data obtained from XRD analysis demonstrate the high crystal quality and orderly structure of the synthesized superlattices. This study emphasizes the importance of structural characterization in assessing the potential use of Co/Cr superlattices for specific technological applications, underscoring that precise fabrication and characterization are key factors in advancing material science and nanotechnology.

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