# CONTROL OF TEXTURE IN POLYCRYSTALLINE THIN FILMS USED AS DATA STORAGE MEDIA

David E. Laughlin, Hua Yuan, En Yang, and Chun Wang
Materials Science and Engineering Department
Data Storage Systems Center
Carnegie Mellon University
Pittsburgh, PA 15213

## ABSTRACT

In current data storage systems the information is stored in polycrystalline thin film media which have a preferred crystallographic texture. The preferred texture is such that the easy axis of magnetization (or ferroelectricity) is either in the plane of the film or perpendicular to the plane of the film. The texture of the media is obtained through polycrystalline epitaxy on layers that are deposited beneath the thin film media. In this paper we review the various schemes that have been and are being used in our media group in the Data Storage Systems Center at Carnegie Mellon University to obtain preferred textures in magnetic and ferroelectric media. We will include descriptions of the control the texture of media made of close packed hexagonal Co based alloys, tetragonal FePt $L1_0$ phases and the tetragonal PZT perovskite phase.

## INTRODUCTION

The storage of information on computer hard drives and tape systems depends on the ability to write the information and read back the information at rates that are rapid in real time. The information also must be able to be stored for times up to tens of years. Most such storage devices rely on the permanent magnetic moments that exist in thin films of magnetic materials. If a uniaxial magnetic material is utilized to store the information, each magnetized region can be thought of as either a 0 or a 1, depending on the direction of magnetization. A similar arrangement could be used to store information on ferroelectric materials.

There are two basic geometries for the uniaxial materials: the unique axes may be in the plane of the film (longitudinal recording) or the axes could be out of the plane of the film (perpendicular recording). The unique axes are usually the soft magnetic or easy axes of magnetization, so it is important to be able to control the crystallographic texture of the magnetic thin films. This control of texture is performed by one or more layers of films that are beneath the magnetic layer. A schematic cross section of a vintage 1990's stack of films on a hard drive is shown in Figure 1.

Each of the layers have specific roles to play in the production of media. The <u>seedlayer</u> is a film layer which is deposited on the substrate and beneath the underlayer. The seedlayer acts to control the crystallographic orientation of subsequent layers, by "seeding" formation of crystals with certain orientations that are favorable for the formation of a magnetic film with the proper orientation. The seed layer also can act to control the grain size of subsequent layers, by the mechanism of grain to grain epitaxy. The <u>underlayer</u> is the layer under the magnetic layer that affects the characteristics and properties of the magnetic layer. It directly controls the crystallographic texture of the magnetic layer as well as its grain size. Another feature that it can contribute to is the isolation of the magnetic grains from each other by diffusion of some of its atoms through the grain boundaries of the magnetic film.

From the above it is clear that the role of crystallographic texture in the polycrystalline thin films utilized for recording is crucial. The texture of the polycrystalline recording layers is controlled by the careful selection and control of the texture the underlayers and seedlayers as described above. This control is usually obtained by means of a coherent or semi-coherent epitaxy across the interface of the layers. Thus, not only is the texture of the films important but so too are their respective lattice parameters.

In this paper some of the specific materials and epitaxial relationships utilized in recording media and investigated by us will be presented and reviewed.

## I. LONGITUDINAL MAGNETIC RECORDING MEDIA [1-3]

### 1. Co HCP alloy media with $(10\bar{1}1)$ texture

The earliest of the sputtered magnetic thin film media utilized Co based alloys that when sputtered yielded a more or less random orientation of the Co [0001] easy axis. This was of course non ideal, since many of the moments of the Co alloy were not oriented in the plane of the thin film. It did not take long for industry to find out that if Cr were sputtered before the Co alloy, the [0001] easy axes of the thin grains composing the thin film would be favored to occur at an angle of about $29^0$ from the plane of the film. This occurs when the $(10\bar{1}1)$ plane of the Co alloy is favored to lie parallel to the substrate surface.

The mechanism for obtaining this crystallographic texture in Co alloy thin films is that of grain to grain epitaxy. When Cr is sputtered at room temperature, the resulting thin film has a strong (110) crystallographic texture. This is the texture one would expect since it is the close packed plane for BCC crystals. It can be seen from Figure 2 that this plane of atoms has a reasonably good match with the $(10\bar{1}1)$ plane of a Co alloy. Furthermore because the epitaxy is grain to grain control of the Cr grain size could also control the grain size of the magnetic film. This became a very important concept when in the later 1990's grain size of the media had to be decreased to keep up with the need to increase the magnetic storage density. Control of the Cr grain size can be obtained through the use of appropriate seed layers. See Figure 1.

### 2. Co HCP alloy media with $(11\bar{2}0)$ texture

Although the above texture was workable, it did not put the c-axis entirely in the plane of the film, which for longitudinal recording would be ideal. Thus ways to do this were explored in the 1990's. It was discovered that if the Cr underlayer were sputtered at elevated temperatures, a different texture of the polycrystalline film would obtain, namely the (002) texture. This texture allowed for the $(11\bar{2}0)$ planes of the HCP Co alloy to be parallel to the plane of the film allowing for the c-axis to lie in the film plane. See Figure 3 for the matching of the atomic structure in the plane of the film. While this texture put all the c axes of the grains in the plane of the film, it had the disadvantage of allowing for two crystallographic variants of the HCP phase to lie within a single (002) Cr grain as the c axis could lie parallel to the $[110]$ or $[1\bar{1}0]$ directions of the Cr underlayer.

### 3. Co HCP alloy media with $(1\bar{1}00)$ texture

One final crystallographic texture for longitudinal Co HCP alloy magnetic films has been utilized, namely the $(1\bar{1}00)$ of Co parallel to the (112) of Cr. This OR is displayed in Figure 4.

Although this OR is possible it has not been easy to obtain the (112) texture for Cr. Lee et al. discovered that the B2 structure often deposited with the (112) texture. NiAl was the intermetallic alloy that they used and the atomic arrangements for this OR are shown in Figure 5. It should be noted that if Cr is sputtered onto the NiAl it will by polycrystalline epitaxy have the (112) texture. Later, others found out that BCC Cr alloys such as CrW could be deposited with this (112) texture. This discovery of Lee et al. actually had other advantages as well. The sputtered grain size of the NiAl was less than that of BCC Cr alloys, thus enabling the magnetic layer to have smaller grain size because of grain to grain matching. This was a necessary feature in order to increase the density of information storage. Another consequence of the use of NiAl as a underlayer was that the sputtering process could be performed at ambient temperatures. Most of the thin film media sputtered on glass uses A B2 underlayer, the most popular being RuAl, which has a larger lattice parameter than NiAl and hence is better matching for good epitaxy with Co magnetic alloys that have large amounts of Pt in them.

The various OR that have been observed in Co/Cr thin films are noted in Table I.

## II PERPENDICULAR MAGNETIC RECORDING MEDIA

### 1. Co HCP alloy media with (0001) texture

Since the early years of the 21st century, magnetic media has been perpendicular, i.e. the magnetization has been perpendicular to the plane of the film. For HCP Co based alloys this is obtained by producing a strong (0002) texture of the Co films. This is the normal texture obtained for thin films of HCP alloys, but these alloys do not always start of with this texture. It is therefore still necessary to have a layer under the magnetic layer which will induce immediately the (0002) texture of the magnetic films. The layer of choice for this material is Ru. Ru has the HCP structure with lattice parameters $a = 0.270$ nm and $c = 0.420$ nm. The spacing of the atoms in the basal plane is larger than the spacing in the Co alloy basal plane. For coherent epitaxy this gives rise to an in plane tensile stress in the magnetic films which produces an out of plane compressive stress. Since most magnetic HCP Co alloys have a negative magnetostrictive coefficient this compressive stress produces an additional out of plane anisotropy which is beneficial for magnetic properties.

It is important that the Co films start off with the correct texture as their thickness is approaching 10 nm so that any misoriented grains in the film would be detrimental to the magnetic anisotropy. This is an additional benefit of the Ru underlayer.

### 2. High Anisotropy $L1_0$ Media With (001) Texture [4]

As the grain size of the magnetic media decreases, the probability of the grains becoming superparamagnetic increases. Eventually Co based alloys will not be able to be used in perpendicular media. Research has begun on alternative alloys and the ones with the most promise are FePt alloys that have been atomically ordered to exist as the $L1_0$ tetragonal phase. The [001] axis of this phase is the easy axis: hence the texture which is must obvious to be developed is the (001) texture of the tetragonal phase. This texture places the easy [001] axis of the $L1_0$ phase perpendicular to the plane of the film.

We have been able to do this by using underlayers that have four fold symmetry and whose lattice parameters are such as to place the growing FePt film in tension. This makes the perpendicular axis of the $L1_0$ film unique and biases the growth of the [001] texture of the atomically ordered $L1_0$ phase.

Figure 6 shows that both the MgO and Cr underlayers or seedlayers wil place the $L1_0$ film in tension. This allows the $L1_0$ film to obtain the correct texture for perpendicular recording. The OR is $(001)_{L1_0}$ //$(200)_{Cr}$ and $[200]_{L1_0}$ //$[0\bar{1}1]_{Cr}$

## III PEROVSKITE COMPOUNDS FOR PERPENDICULAR FERROELECTRIC RECORDING

The ferroelectric material lead zirconium titanate ($Pb(Zr,Ti)O_3$ or PZT), is a promising medium for scanning probe based high density data storage[5]. Epitaxially grown PZT thin films with controlled orientation are of interest for probe storage applications. Though researchers have already obtained good epitaxial PZT thin films on some single crystal substrates such as $SrTiO_3$, MgO, and $LaAlO_3$ using different deposition methods such as sputtering, pulsed laser deposition, and metal-organic chemical-vapor deposition,[6-8] fabrication on single crystal silicon is preferred for industrial applications.

The scheme presented here is shown in Figure 7 [9]. Essentially one sputters a layer of Ag on single crystal of Si which has been HF etched to obtain a highly oriented Si film [10]. This arises from the matching of 4 lattice parameters of Ag to three lattice parameters of Si. This Ag film is used as an epitaxial layer for Pt which in turns produces an epitaxial relationship with the perovskite PZT. Using this scheme Wang et al. were able to obtain highly oriented PZT films for ferroelectric recording.

## SUMMARY

It can be seen that over the years the storage industry has utilized the careful choice of buffer layers, seedlayers and underlayers to obtain the texture of the recording layers that is desired. As the industry continues to progress we expect that more types of epitaxial relationships will be developed and that the engineering of recording layers will continue.

## ACKNOWLEDGMENTS

This work has been supported by Seagate Research and the Data Storage Systems Center of Carnegie Mellon University.

## REFERENCES

1. Li-Lien Lee, David E. Laughlin and David N. Lambeth: "Seed layer induced (002) crystallographic texture in NiAl underlayers," *J Appl. Phys.*, 79 (8) 4902-4904 (1996).

2. David E. Laughlin, Li-Lien Lee, Li Tang, and David N. Lambeth: "The control and characterization of the crystallographic texture of longitudinal thin film recording media," IEEE Trans. on Magn., 32(5) 3632-3637 (1996).

3. David E. Laughlin, B. Cheong, Y. C. Feng, D. N. Lambeth, L. L. Lee and B. Wong, "The Control of Microstructural Features of Thin Films for Magnetic Recording", Scripta Met. et. Mat. **33**, no.10/11, 1525-1536 (1995).

4. D.E. Laughlin, S. Kumar, Y. Peng and A.G. Roy, "Engineering the microstructure of thin films for perpendicular recording," *IEEE Transactions on Magnetics*, 41(2), 719-723 (2005).

5. Y. Cho, K. Fujimoto, Y. Hiranaga, Y. Wagatsuma, A. Onoe, K. Terabe, and K. Kitamura, Nanotechnology **14**, 637 (2003).

6. L. Roytburd, S. P. Alpay, L. A. Bendersky, V. Nagarajan, and R. Ramesh, J. Appl. Phys. **89**, 553 (2001).

7. C. B. Eom, R. B. Van Dover, Julia M.. Phillips, D. J. Werder, J. H. Marshall, C. H. Chen, R. J. Cava, R. M. Fleming, and D. K. Fork, Appl. Phys. Lett. **63**, 2570 (1993).

8. Junichi Ishida, Takatoshi Yamada, Atsuhito Sawabe, Kumi Okuwada, and Keisuke Saito, Appl. Phys. Lett. **80**, 467 (2002).

9. C. Wang, D. E. Laughlin, and M. Kryder, "Epitaxial growth of lead zirconium titanate thin films of Ag buffered Si substrates using rf sputtering," *Applied Physics Letters* **90**(17), 172903 (2007).

10. W. Yang and D. N. Lambeth, J. Appl. Phys. **81**, 4370 (1997).

**Table 1. Orientation Relationships in Co/Cr Thin Films**

| | |
|---|---|
| $(10\bar{1}1)_{Co} // (110)_{Cr}$ | $[\bar{1}\bar{1}20]_{Co} // [\bar{1}11]_{Cr}$ |
| $(11\bar{2}0)_{Co} // (002)_{Cr}$ | $[0002]_{Co} // [\bar{1}10]_{Cr}$ |
| $(10\bar{1}0)_{Co} // (112)_{Cr}$ | $[\bar{1}\bar{1}20]_{Co} // [\bar{1}\bar{1}1]_{Cr}$ |
| $(10\bar{1}0)_{Co} // (113)_{Cr}$ | $[0002]_{Co} // [\bar{1}10]_{Cr}$ |

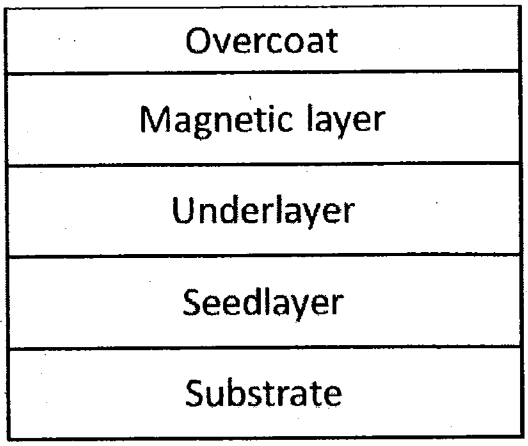

Figure 1. A schematic display of the sequence of various layers in longitudinal magnetic recording media of the 1990's.

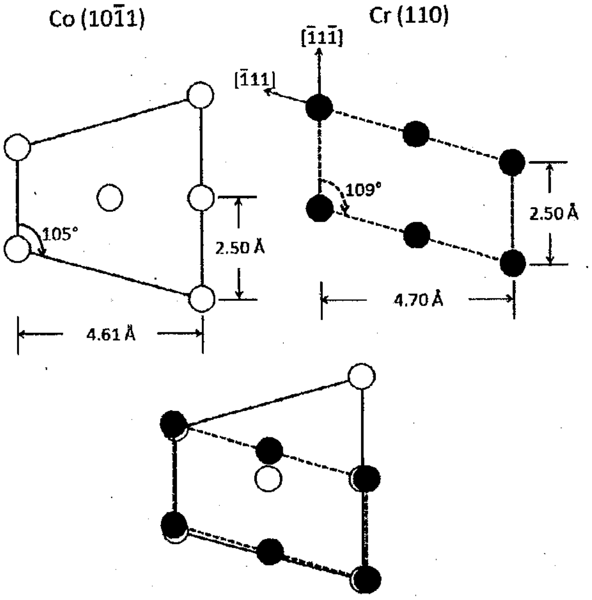

Figure 2. Schematic of the atomic positions of the $(10\bar{1}1)$ planes of HCP Co alloys along with the (110) planes of BCC Cr and their match. Here the $[\bar{1}\bar{1}20]_{Co}$ // $[\bar{1}11]_{Cr}$ After [3].

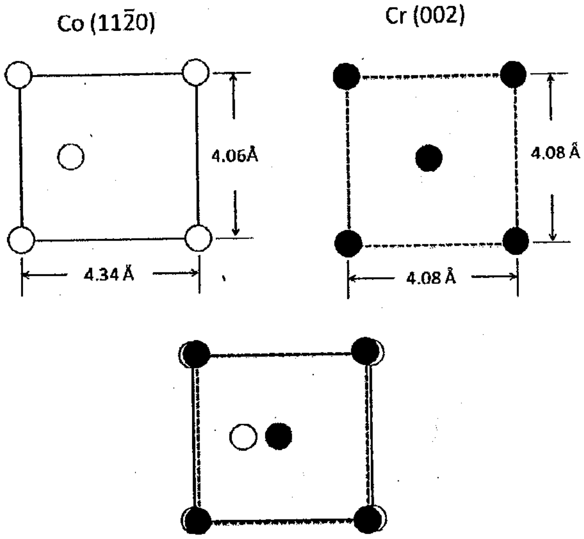

Figure 3. Schematic of the atomic positions of the $(11\bar{2}0)$ planes of HCP Co alloys along with the (2000) planes of BCC Cr and their match. Here, the $[0002]_{Co}$ // $[\bar{1}10]_{Cr}$. After [3].

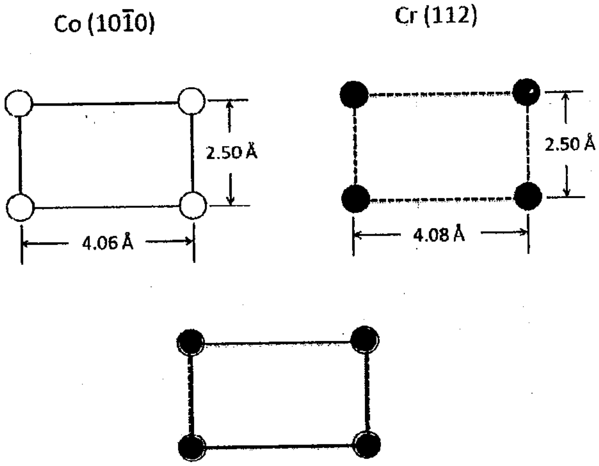

Figure 4. Schematic of the atomic positions of the $(10\bar{1}0)$ planes of HCP Co alloys along with the (112) planes of BCC Cr and their match. Here, the $[\overline{11}20]_{Co}$ // $[\overline{11}1]_{Cr}$ After [3].

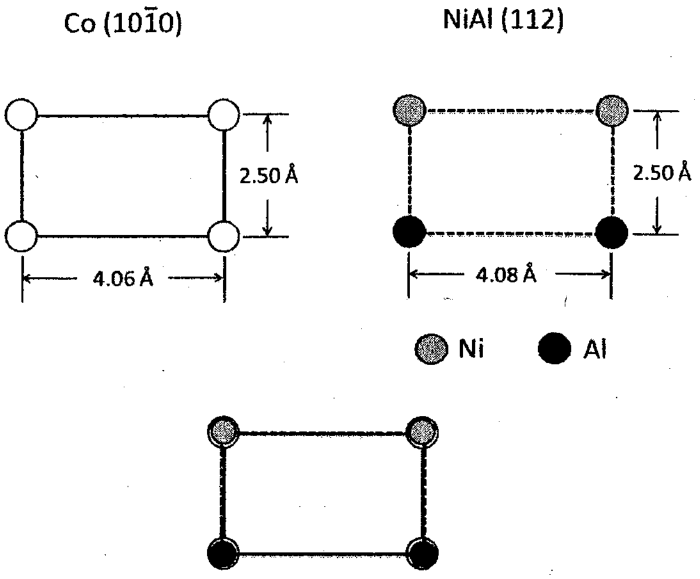

Figure 5. Schematic of the atomic positions of the $(10\bar{1}0)$ planes of HCP Co alloys along with the (112) planes of B2 NiAl and their match. Here, the $[\overline{11}20]_{Co}$ // $[\overline{11}1]_{NiAl}$ After [3].

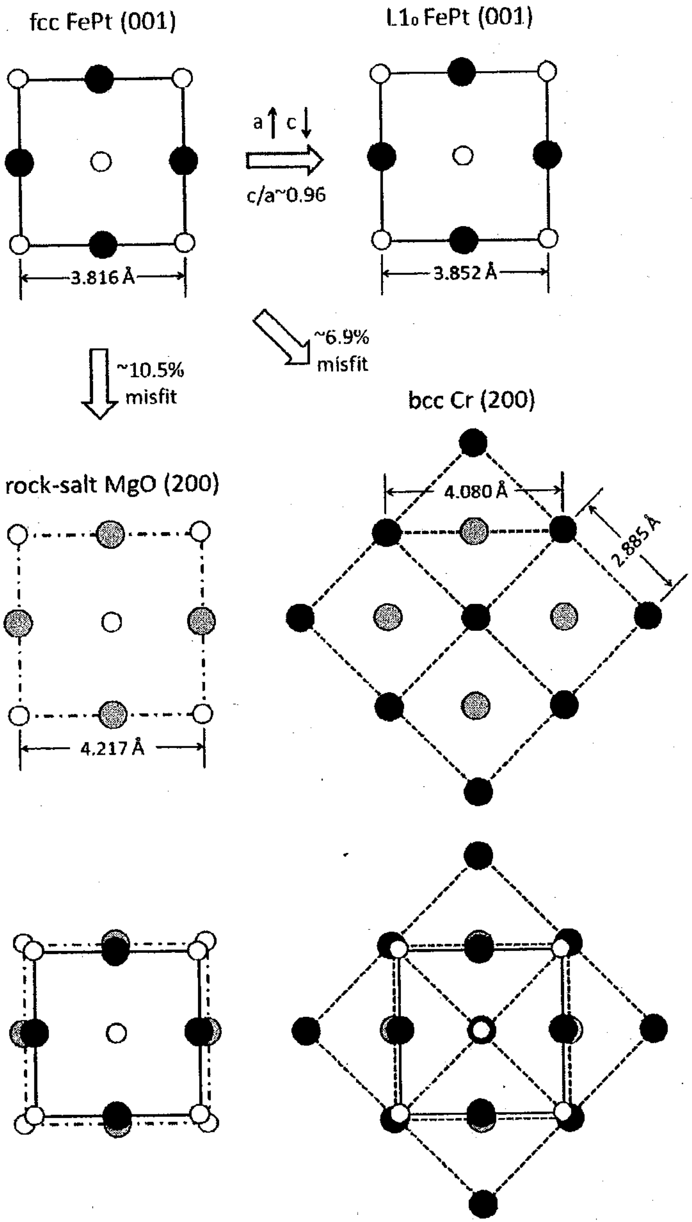

Figure 6. The epitaxial matching of FePt thin films with MgO and Cr seedlayers/underlayers. For the case of FCC FePt (disordered) / MgO the cube directions are parallel. For the $L1_0$ // Cr, $[110]_{L1_0}$ //$[100]_{Cr}$

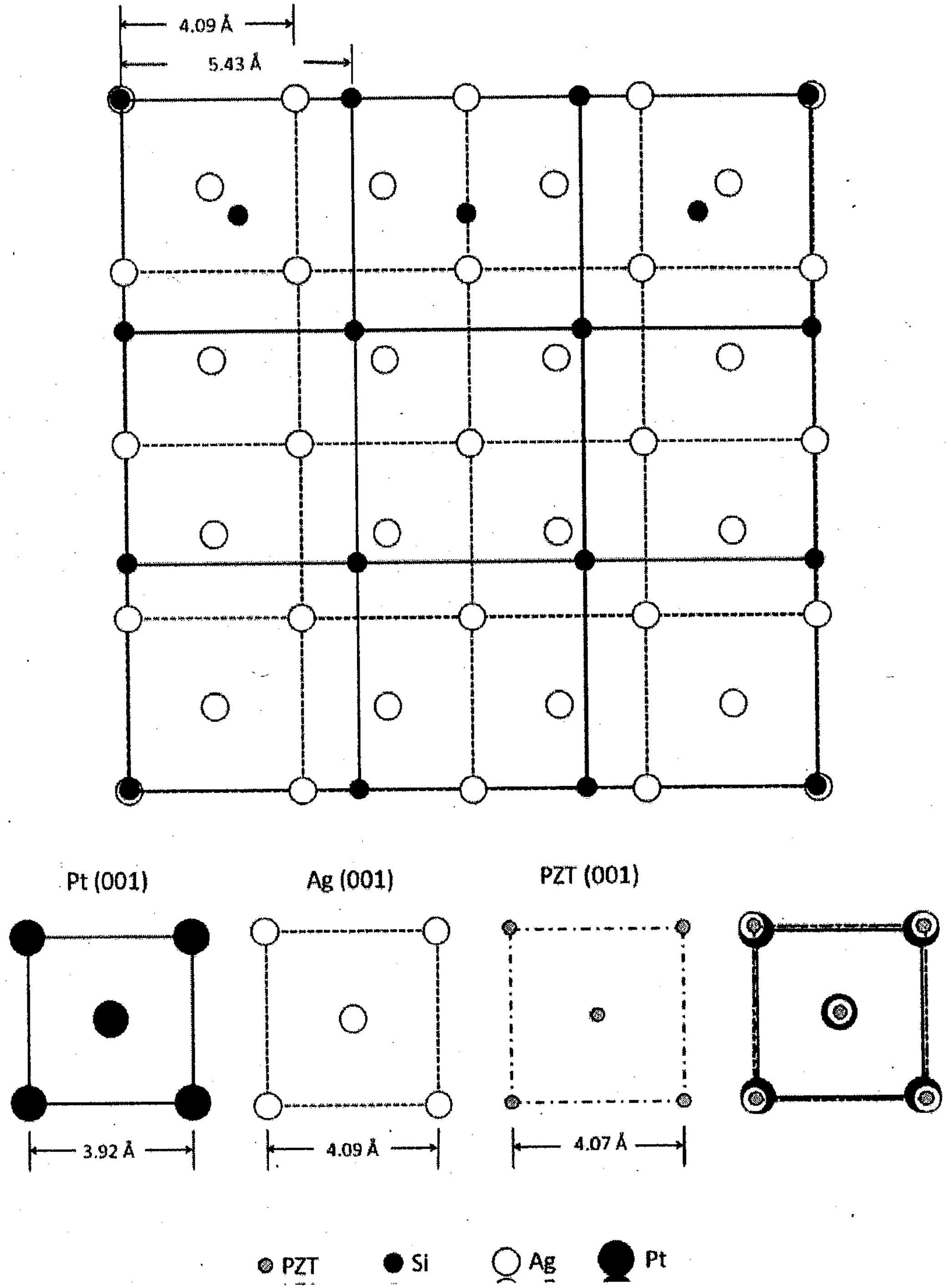

Figure 7. Orientation relationships between Si (001)/Ag(001), Ag(001)/Pt(001), and Pt(001)/PZT (001)planes. The lattice parameters of these phases are: Si: 0.543 nm; Ag: 0.409 nm; Pt: 0.392 nm and PZT: 0.407 nm. The cube directions are parallel in each case. After [9]