HgTe/CdTe superlattices grown on CdZnTe(211)B by MBE

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HgTe-CdTe superlattices have received much interests over the last several years as a potential material for its applications for detecting devices and optoelectronics. We have grown the HgTe-CdTe superlattice using MBE in our lab. We have carried out DCRC spectroscopy after growth of HgTe-CdTe superlattice with varying the superlattice periods and controlling the barrier thickness and we have known that the presence of the main peak and the satellite peaks. We obtained 20 arcsec of FWHM, over 100 periods of superlattice. We also note that high peak intensity shows the high quality of the sample and each layer of superlattice has abrupt interfaces. The angular separation between the main peak(m=0) and the first satellite peak($m=\pm 1$) is increased when the barrier layer thickness in superlattice layers are decreased. The separation between the first satellite peak(($m=\pm 1$) and the second satellite peak($m=\pm 2$) is increased similarly. The number of the satellite peak is a qualitative measure of the interfacial abruptness of the superlattice.

Ⅰ. Introduction

HgTe-CdTe superlattices have received a great deal of interests over the last several years as a potential material for long wave length infrared detecters and high-speed avalanche photodiodes for fiber optic communications among others[1]. HgTe-CdTe superlattice structure make it possible to reduce the structural defects by spacing between HgTe layers and CdTe layers to form a bulk-like layers by its superlattice structure, Because of the large equilibrium vacancy concentration normally present in the HgCdTe system it is anticipated that interdiffusion of the layers of HgTe-CdTe interfaces. One can obtain the more stable Hg-based thin film, comparing with the unstable $Hg_{1-x}Cd_xTe$ alloy structure[2-4]. Since the controling of the energy band gap of $Hg_{1-x}Cd_xTe$ alloy can be possible only by the controlling of Cd molefraction, which forms its mother material, but the energy band gap of $Hg_{1-x}Cd_xTe$ superlattice can be controlled by the thickness of each layer which forms the superlattice structures, therefore, it is much easier that the band gap controlling of $Hg_{1-x}Cd_xTe$ superlattice than that of $Hg_{1-x}Cd_xTe$ alloy's.

Interests in HgTe-CdTe superlattice system arises for two reasons, (i) its potential as a material for infrared detector, (ii) its creation of a new type of superlattice structures which contains a semiconductor, CdTe, and a semimetal, HgTe. The Γ_8 light hole band in CdTe becomes the conduction band in HgTe. There exists a quasi-interface state as a consequence of the matching up of bulk states belonging to the conduction band in HgTe with the light -hole valance band in CdTe.

In this study, in order to investigate the structural and the optical properties if the superlattice, we have carried out DCRC after growth of the HgTe-CdTe superlattices by MBE.

Ⅱ. Experiment

The $Hg_{1-x}Cd_xTe$ films used for these experiments were grown by MBE in a RIBER 32P(ISA Riber Co., France), and the samples was loaded into the introduction chamber after mounted to 3" molyblock by DAG and were treated thermally at 120℃ for 2 hours to remove residual impurities.

Growth was carried out at 186℃ with the growth rate of 5Å/sec on (211)B oriented CdZnTe substrate. The substrate temperature was calibrated by dotting In(m.p.:156℃), Sn(m.p.:232) and PbAg(m.p.:304℃) on the moliblock near the sample.

HgCdTe epi-layer surface were examined by in-situ reflection high energy electron diffraction(RHEED). During the HgTe/CdTe superlattice growth, the individual layer thickness of HgTe well layers were fixed as 100Å and CdTe barrier layers are controlled as 100Å, 60 Å, 30Å, 20Å systematically.

The period for the HgTe-CdTe superlattice was experimentally determined by measuring the angular separation between the satellite peaks of their DCRC spectrum.

III. Results and Discussions

Fig. 1 shows an simulated data fitted by semikinematic approximation about an DCRC spectrum of a (100Å/100Å) period for HgTe-CdTe superlattice grown by MBE.

As a result from fitting with the diffraction angle, $\triangle\theta$ from -3500 arcsec to 3500 arcsec, the superlattice main peak is dominated. We note that the presence of several satellite peaks as shown in figure 1.

The thickness of one pair of HgTe-CdTe superlattice can be valuated from this spectrum. From Bragg's diffraction condition,[5]

$$L_m = 2\Lambda\sin\theta_m, \qquad m=0,\pm1,\pm2,\cdots$$

where L_m is m-th x-ray diffraction for the superlattice, presents at satellite peaks of $m=0,\pm1,\pm2,\cdots$, and $\Lambda(\Lambda_A+\Lambda_B)$ is the periodicity of the superlattice, ie. the thickness of a well layer(Λ_A) and a barrier layer(Λ_B). It is straightforward to show that the thickness of one periods of the superlattice can be determined from the angular separation between the main peak and the satellite peaks of the superlattice in the form of,

$$L_0 = 2\Lambda\sin\theta_0\ , \quad L_0=0\cdot\lambda \ : \ 0th\ diffraction\ signal$$

$$L_1 = 2\Lambda\sin(\theta_0+\Delta\theta)\ , \quad L_1=1\cdot\lambda \ : \ +1th\ diffraction\ signal$$

From this relation, one pair of thickness, Λ can be calculated by,

$$\Lambda = \frac{\lambda}{2[\sin(\theta_0+\Delta\theta)-\sin\theta_0]}$$

where λ is x-ray's wavelength. Then, the total thickness of the HgTe-CdTe superlattice was experimentally determined by using one pair of thickness and growth periods from experimental data.

Fig.2 shows the FWHM of main peak from DCRC data for the periods of HgTe-CdTe superlattice. The FWHM of all peaks decreased as increasing of the periods of superlattice,

We obtained 20 arcsec of the FWHM over 100 periods of superlattice. In general, very few data has small the FWHM as 20 arcsec in many reported papers for the superlattice thin film growth.

We also note that high peak intensity shows the high quality of the sample and each layer of superlattice has abrupt interfaces. The simulated DCRC spectrum by approximation for HgTe well layers were fixed as 100Å and CdTe barrier layers are changed from 100Å, to 10Å is shown in fig. 3. The cut-off wavelength is closely related with the thickness of HgTe well layer in superlattice, we fixed the HgTe layer as 100Å, because 100Å of well layer thickness is exactly correspond to 10 to 12 ㎛ of the cut-off wave length and also it is applicable to infrared detecting devices which detect 8~12㎛ wavelength region. The relation

between HgTe layer thickness and band gap of superlattice in HgTe-CdTe superlattice can be written in the form by Reno at el.[6].

$$\lambda_c(\mu m) = [0.3666\exp(-0.0034d_2^2)+0.118]d_1+0.78$$

Where λ_c the cut-off wavelength, d_1, d_2 are thickness of CdTe and HgTe.

For example, when the CdTe layer thickness varies 30 Å to 100Å with the HgTe layer thickness is 100Å, the cut-off wave length can be determined by the region of 4.3~12.5 ㎛. In other word, it is possible to make the detecting device which detects either 3~5㎛ or 8~12㎛ of cut-off wave length region as well. As decreasing of the barrier layer thickness in superlattice layer, the angular separation between the main peak(m=0) and the first satellite peak(m=±1) is increasing as same as the separation between the first satellite peak((m=±1) and the second satellite peak(m=±2) is increasing.

It has been reported the presence of 7 satellite peaks the maximum number of the satellite peak[7] for HgTe/CdTe superlattice by literature, while it is not uncommon to see 12 or more orders in the case of GaAs/AlGaAs superlattice system. These results may be explained by a lowering in crystal quality due to unstable Hg-based thin film for temperature, the diffusion problem at interface, and so on.

In fig. 4 (a) shows DCRC spectrum for 100 periods of HgTe/CdTe(100/100Å) superlattice grown at 186℃, (b) represents an simulated data fitted by approximation.

As a result from fitting with the diffraction angle, $\triangle\theta$ from -2500 arcsec to 2500 arcsec, the superlattice main peak is dominated and the presence of several satellite peaks are shown.

The thickness of one pair of HgTe/CdTe superlattice can be valuated from this spectrum.

Ⅳ. Conclusion

In summary, we have carried out DCRC spectroscopy after growth of HgTe-CdTe superlattice by MBE with varying the superlattice periods and controlling the barrier thickness and we have known that the presence of the main peak and the satellite peaks. We obtained 20 arcsec of FWHM over 100 periods of superlattice.

The period for the HgTe/CdTe superlattice was experimentally determined by measuring the angular separation between the satellite peaks of their DCRC spectrum and in all cases agreed well with periods calculated from film growth. The FWHM of all peaks decreased as increasing of the periods of superlattice. We also note that high peak intensity shows the high quality of the sample and each layer of superlattice has abrupt interfaces.

The angular separation between the main peak(m=0) and the first satellite peak(m=±1) is increased when the barrier layer thickness in superlattice layers are decreased. The separation between the first satellite peak((m=±1) and the second satellite peak(m=±2) is increased similarly. The number of the satellite peak is a qualitative measure of the interfacial abruptness of the superlattice.

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Reference

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Figure Captions

Fig. 1. The calculated DCRC data for the HgTe(100Å)/CdTe(100Å) SL which have several SL periods.

Fig. 2. FWHM of the principle peaks for HgTe(100Å)/CdTe(100Å) SLs as a function of the SL periods from DCRC

Fig. 3. The calculated DCRC data for the 100Å thick-HgTe layers SLs which have several CdTe layer thickness.

Fig. 4. Experimental (a) and simulated (b) DCRC spectra of a HgTe/CdTe superlattice. The structure, grown at 186℃ on a (211)B $Cd_{0.96}Zn_{0.04}Te$ substrate, has 50 periods of CdTe-100Å and HgTe-100Å

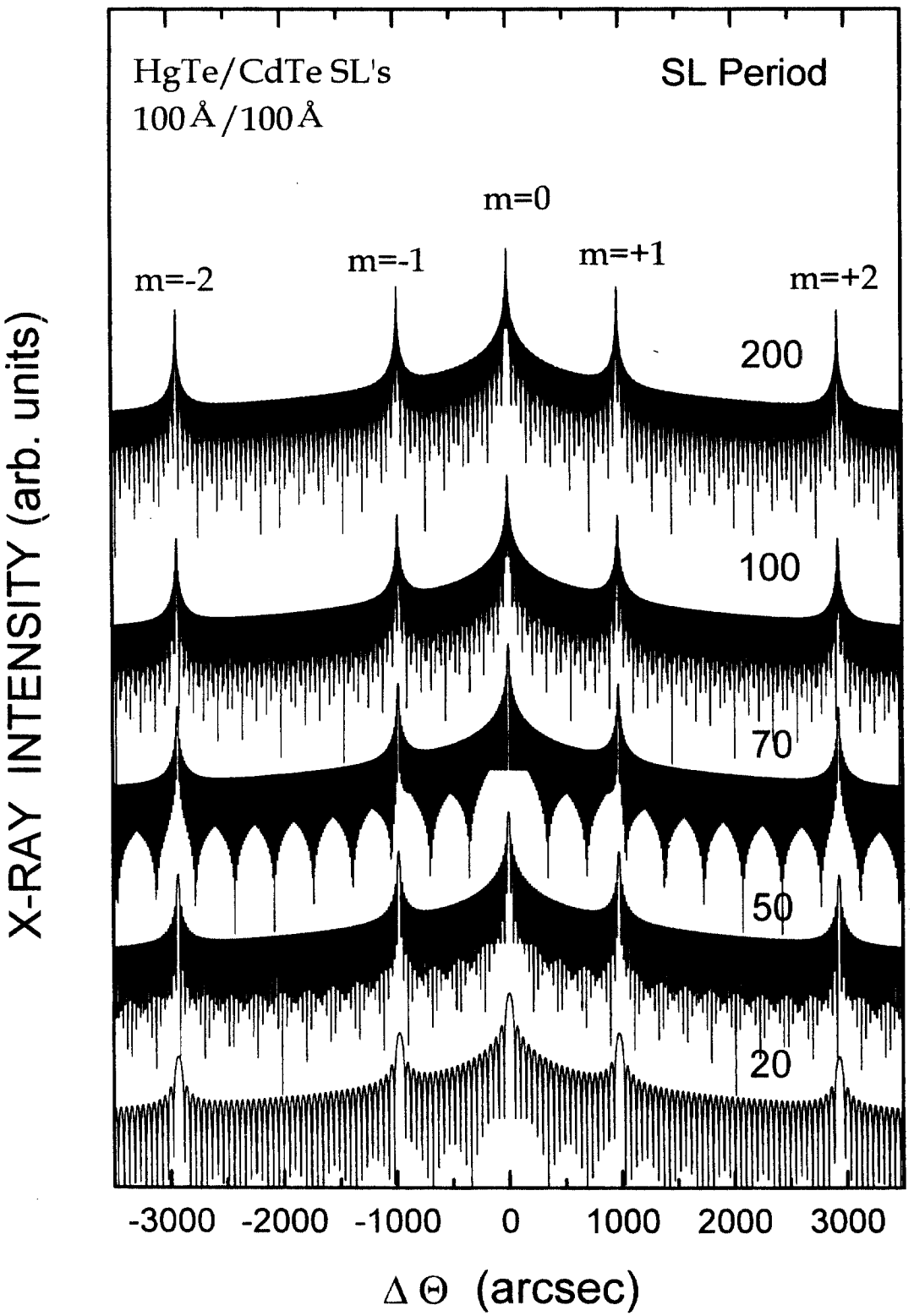
HgTe/CdTe SL's
100 Å / 100 Å
SL Period
m=0
m=-1
m=+1
m=-2
m=+2
200
100
70
50
20
X-RAY INTENSITY (arb. units)
-3000
-2000
-1000
0
1000
2000
3000
Δ Θ (arcsec)

Fig.1

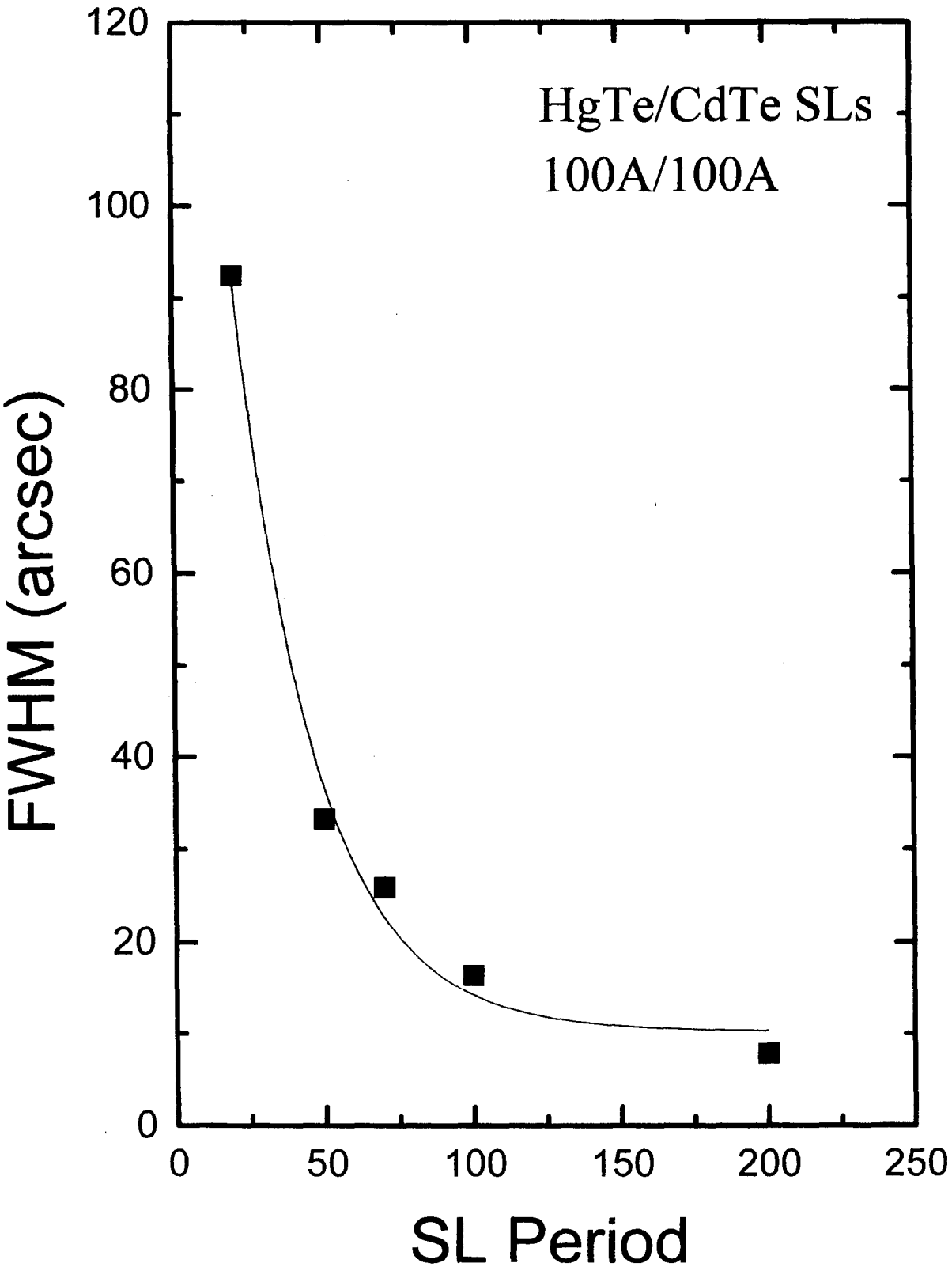
HgTe/CdTe SLs
100A/100A
FWHM (arcsec)
SL Period
120
100
80
60
40
20
0
0
50
100
150
200
250

Fig.2

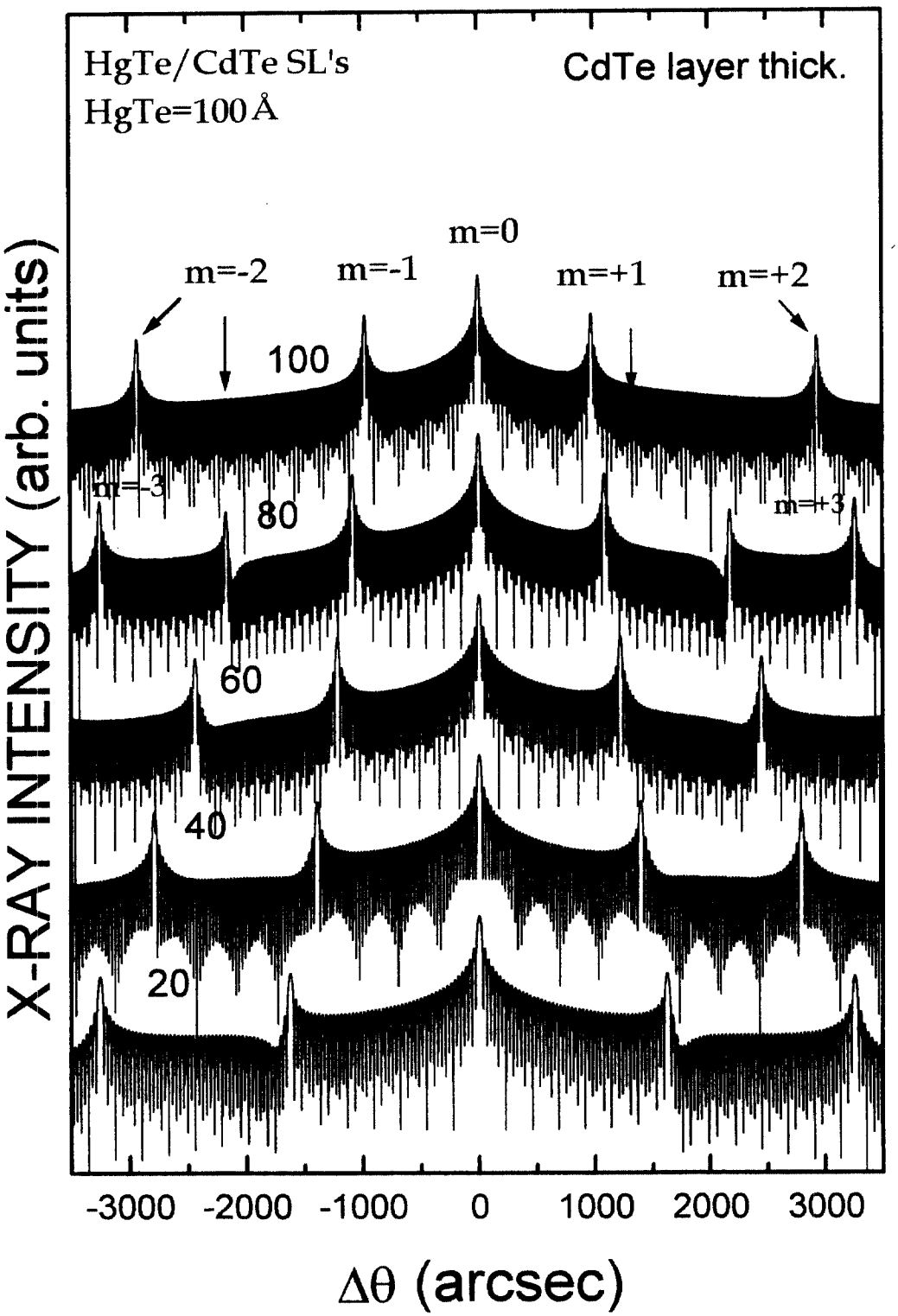
HgTe/CdTe SL's
HgTe=100 Å
CdTe layer thick.
m=0
m=-2
m=-1
m=+1
m=+2
100
m=-3
80
m=+3
60
40
20
X-RAY INTENSITY (arb. units)
-3000
-2000
-1000
0
1000
2000
3000
Δθ (arcsec)

Fig.3

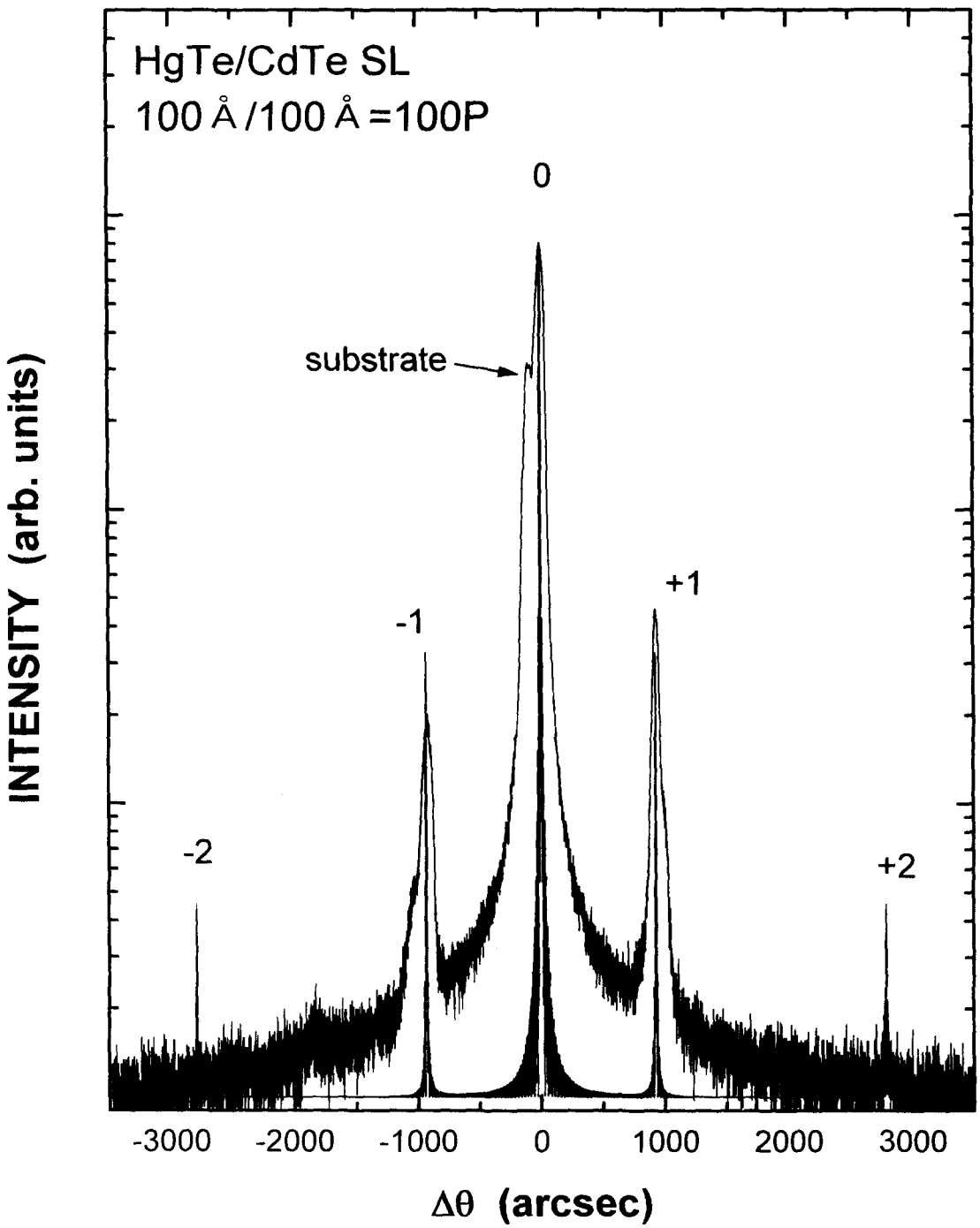
HgTe/CdTe SL
100 Å /100 Å =100P
0
substrate
-1
+1
-2
+2
INTENSITY (arb. units)
-3000
-2000
-1000
0
1000
2000
3000
Δθ (arcsec)

Fig.4