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## The thickness dependence of IR-reflectance from Al quantum wells

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The first report on the optical properties of metallic quantum wells (MQWs) in the IR-region appeared in 1991 [1]. The quantum sized effects (QSEs) in MQWs are usually studied in 0.1–4 nm thickness range due to small wavelength for electrons on Fermi surface for almost all metals. In this report the room temperature measurements on the IR (9.201  $\mu\text{m}$ ) linear p-polarized reflectivity ( $R_p$ ) of Al-QWs deposited on  $\text{SiO}_2$  and Si substrates are presented for thickness range from 0.5 nm to 112 nm [2]. Two type of ( $R_p$ ) oscillations in depend from Al-layer thickness in two thickness range (0.5–3.4 nm and 6–11 nm) are observed.

All Al-QWs was prepared with the help of RF-sputtering. The crystalline Si and amorphous  $\text{SiO}_2$  substrates were carefully selected to obtain a surface roughness as small as possible and symmetric QWs were made using barrier layers of  $\text{Al}_2\text{O}_3$ . The thickness of barrier layer was 2 nm for all structures. The change of Al thickness from sample to sample was made with step of near 1 monolayer. The Al-QWs on Si and  $\text{SiO}_2$  substrates were prepared simultaneously in just the same technological process. Our experimental set-up allow us to make IR reflectance of He-Ne laser radiation on 9.201  $\mu\text{m}$  wavelength with an accuracy better then 2%. The angle of incidence were fixed to 7°.

The dependence of  $R_p$  from Al-thickness  $d$  for Al-QWs is presented on Fig. 1, where the circles represent the data for  $\text{SiO}_2$  substrates and the diamonds — for Si substrates.

Let us first consider the  $R_p(d)$  for Al-QWs on  $\text{SiO}_2$  substrates. For a small film thickness ( $d$  less then 4–5 nm) it appears that  $R_p$  decreases slightly and almost monotonously with  $d$ . Qualitatively,  $R_p$  exhibits a parabolic dependence on  $d$  in this region, see Fig. 2, instead of giving any quantitative correlation with an existing theory. We believe that this parabolic decreasing can be due to the kind of substrate and its crystallinity because all Al-QWs were prepared on both substrates simultaneously. When the Al-thickness is increased beyond  $\approx 5$  nm, one still observed a slight decrease in the reflectivity before it finally passes through a flat minimum located in the region  $d$  near 7–8 nm for our QW system. For some metallic films grown by sputtering technique there exist a critical thickness  $d^*$  after which the mechanism of film grown is changed. The value of  $d^*$  strongly depends on the substrate physical condition, i.e. its crystallinity, surface cleanliness and technological condition during the sputtering process (substrate temperature, vacuum condition, metal rate deposition, etc.). For  $d < d^*$  the metallic layer will be in amorphous state while for  $d > d^*$  a crystalline layer begin to grow on the already amorphous layer giving as a result that the packing distance of the Al changes due to possible crystallites formation starting from this ( $d^*$ ) thickness value. Although (quantum) oscillation are observed in  $R_p$  in the range  $d \sim 5$ –8.5 nm and these are stronger than the weak oscillation appearing for  $d$  approximately less than 5 nm (Fig. 2), the overall thickness dependence of  $R_p$  is still rather smooth, but for film thickness in the range

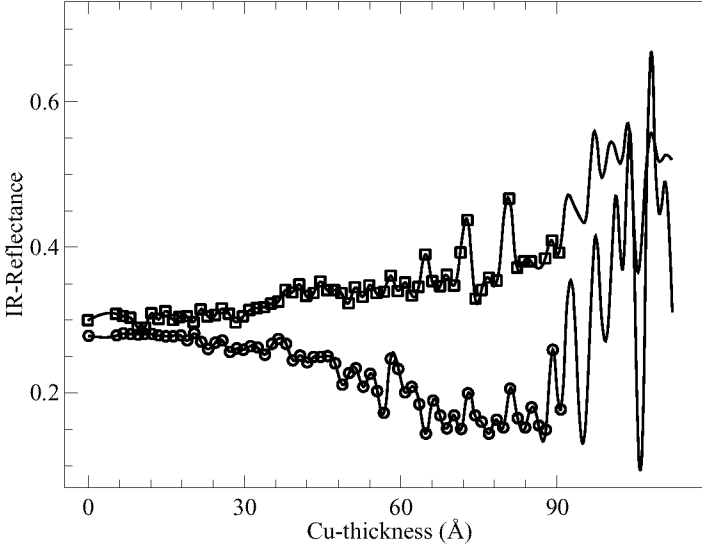


Fig 1.

$d \sim 8.5\text{--}11.2$  nm pronounced oscillations are observed in the thickness dependence of the reflectivity. In this range, the change ( $\Delta R_p$ ) in the reflectivity can be as much as  $\Delta R_p \sim 0.4$  when  $d$  is increased by just one monolayer. Smearing out the oscillations by averaging  $R_p$  over a few monolayers, the overall tendency shows a significant increasing in  $R_p$  with  $d$  in the range  $d \sim 8.5\text{--}11.2$  nm. At  $d \sim 11.2$  nm the reflectivity is still far from the bulk value ( $R_{\text{bulk}} \sim 0.98$ ) for Al, and we expect that a thickness of at least  $d \sim 15\text{--}20$  nm is needed before one would be able to characterize an Al film by its macroscopic (complex) refraction index. Though the physical nature why this oscillations appear is not clear by the moment, it is necessary to notice that for some metal films such as Al, Cu, Pb, In and other the existence of the critical thickness  $d^*$  is a fact. On another hand, the strong oscillations observed in the thickness dependence of the p-polarized reflectivity cannot be explained on the basis of the simple quantum well picture even with interband and intraband transitions in Al-QW taken into account. If one consider as a fact that formation of Al-crystalline layer is grown on the surface of an amorphous Al-Layer as the film grows and therefore we have a double metallic system consisting of a quantum crystalline Al-layer and an  $\ll$  almost  $\gg$  non-quantum amorphous layer, it is likely to think that these are responsible for a strong oscillations observed in the thicker films. We confident that the oscillations measured in the thickness dependence of  $R_p$  for Al-QWs on  $\text{SiO}_2$  substrate are due to electronic quantum confinement effects.

For Al-QWs on Si-substrates the measured thickness dependence of the reflectivity, to some extent, resembles that of the Al-QWs on  $\text{SiO}_2$  substrates. Though the reflectivity shows an overall monotonous increasing and  $R_p$  does not start with a  $\ll$  parabolic  $\gg$  decrease as it was the case for the Al-QWs on  $\text{SiO}_2$  system, the oscillations are still present and more pronounced for the larger thickness. The reason why the reflectivity does not set-out with a  $\ll$  parabolic  $\gg$  decrease is not known at the moment. Although

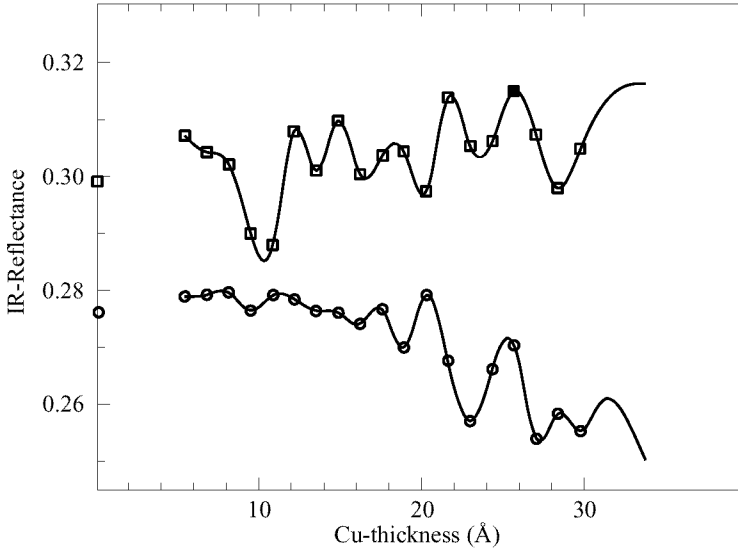


Fig 2.

we cannot predict the peak positions of such oscillations in Al-QWs on Si neither in Al-QWs on SiO<sub>2</sub> cases, it is worth noticing that a experimental correlation exists between the peak (or valley) position in both Al-QWs on SiO<sub>2</sub> and Al-QWs on Si, in our experimental measurements, as we can see in Fig. 1. A Fourier analysis of the experimental data gives a prominent spatial period of  $\sim 2.6$  nm for range  $d \sim 0.5$ – $3.4$  nm and  $3.4$  nm for range  $d \sim 3.4$ – $11.2$  nm.

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