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ABSTRACT

RBS and ellipsometric investigations were combined to separate the contribution of radiation damage and overlayer contamination. It is pointed out that disorder effects which were produced by silicon self-implantation are shielded without proper surface cleaning. For cleaning, plasma stripping proved to be an effective method. The change in ψ parameter could be correlated with the degree of amorphousness. It seems that Δ parameter "feels" crystalline-amorphous phase transition on low dose $^{31}P^+$ and $^{27}Al^+$ implants. No clear evidence was found for impurity effects on high-dose $^{75}As^+$ and $^{31}P^+$ implants.

АННОТАЦИЯ

Исследовано влияние радиационных повреждений и углеродных слоев, образующихся при ионном внедрении в кремний, на эллипсометрические параметры. Дополнительные измерения выполнены с помощью обратного рассеяния ионов и при использовании метода каналирования. Очистка от углеродных слоев проводилась путем плазменного травления. Изучена корреляция между эллипсометрическим параметром ψ и степенью аморфности. Изменение эллипсометрического параметра Δ, по-видимому, обусловлено переходом кристалл - аморфное вещество.

KIVONAT

Rutherford-visszaszórással és ellipszometriával vizsgáltuk az ionimplantáció által okozott sugárzási károsodást és hidrokarbon-lerakódást sziliciumkristályokon. $^{28}Si^+$-ionokkal implantált szilicium ellipszométeres vizsgálata során azt észleltük, hogy megfelelő felülettisztitás nélkül a sugárzási károsodás által okozott hatások torzulva jelentkeznek. A plazmamarás megfelelő felülettisztitási eljárásnak bizonyult. A ψ -paraméter változása az amorfitás fokával mutat korrelációt. A $^{31}P^+$- és $^{27}Al^+$ -ionokkal implantált sziliciumminták vizsgálata kis dózisok esetén azt valószinüsiti, hogy a Δ-paraméter változása a kristályos - amorf fázisátalakulás lezajlásával van korrelációban. A nagydózisu $^{75}As^+$- és $^{31}P^+$-implantációval készitett minták vizsgálata során nem találtunk egyértelmü szennyezőhatást.

ABSTRACT

RBS and ellipsometric investigations were combined to separate the contribution of radiation damage and overlayer contamination. It is pointed out that disorder effects which were produced by silicon self-implantation are shielded without proper surface cleaning. For cleaning, plasma stripping proved to be an effective method. The change in ψ parameter could be correlated with the degree of amorphousness. It seems that Δ parameter "feels" crystalline-amorphous phase transition on low dose $^{31}P^{+}$ and $^{27}Al^{+}$ implants. No clear evidence was found for impurity effects on high-dose $^{75}As^{+}$ and $^{31}P^{+}$ implants.

1. INTRODUCTION

Although the study of the optical properties of ion-implanted semiconductors has received great interest, the ellipsometric investigation of implanted silicon seems to be premature. Attempts were made to get correlation between implantation conditions and measured ellipsometric parameters /ψ and Δ/ and calculated ones /n and k/, respectively[1,2,3,4].

It was concluded that the disorder due to implantation is responsible for the modification of optical parameters in the first place and other effects, for example, surface overlayers, were regarded to be secondary importance or they were not mentioned at all.

This paper tries to emphasize all the implantation and other parameters that have contribution to ψ and Δ. Especially we will point out the importance of surface conditions of implanted samples, because small amount of hydrocarbon contamination /carbon build-up/ sometimes has an effect on ψ and Δ almost of the same order of magnitude than the radiation damage itself.

2. EXPERIMENTAL

Silicon wafers of both <111> and <100> orientation were subjected to room-temperature implantation. To study the effect of disorder on ellipsometric parameters, partly $^{31}P^+$ and $^{27}Al^+$ implantation partly $^{28}Si^+$ self-implantation were done in the energy range 40 - 80 keV. Trying to find impurity effects, $^{31}P^+$ and $^{75}As^+$ implantation were made with an energy which produces approximately the same depth distribution of disorder as the $^{28}Si^+$ implantation. The dose of arsenic and phosphorus was 10^{17} atom/cm^2.

For silicon implants isothermal annealing at 550 ^{o}C in nitrogen ambient was also carried out. The ellipsometer used for this work was a manual LEM-2 in the polarizer, compensator, sample, analyzer /PCSA/ configuration and a He - Ne 632.8 nm laser as a light source. The ellipsometric parameters ψ and Δ were measured for an angle of incidence $\varphi = 70^{o}$. To get direct information about disorder and the overlayer impurities produced during implantation process, channeling measurements with 1.2 MeV $^{4}He^{+}$ beam were done in a vacuum of 5×10^{-5} Pa.

As the surface cleaning before and after implantation proved to be a crucial point, both standard chemical cleaning and plasma stripping were done. The later process was carried out with 200 W power in gas-mixture type DS-300 typically to 20 - 25 minutes. The etching time was optimized experimentally and details will be reported elsewhere.

3. RESULTS AND DISCUSSION

3.1 Effect of solid phase epitaxial growth and surface films

There are two major contributing factors to the optical parameters of surface region due to ion implantation:

i/ radiation damage,

ii/ carbon build-up, especially, for high-dose processes /$\Phi = 5 \times 10^{15} - 10^{17}$ atom/cm^{2}/.

Silicon self-implantation produces both contributions without any possible impurity effect. Fig. 1 shows channeling spectra of 80 keV $^{28}Si^{+}$ implants. After implantation 150 nm thick disorder was found. Subsequently, isothermal annealing at 550 ^{o}C was applied to get thinner amorphous layers. Fig. 2 contains the corresponding ellipsometric parameters. It is known that the ψ parameter characterizes the degree of amorphousness [5]. Up to 40 min annealing, while RBS spectra exhibit 50 nm regrowth, the ψ values are practically constant. At the 60 min annealing, however, the channeling still shows a fully amorphous layer, but ψ suggests a partially recrystallized zone. At further annealing both RBS and ellipsometric measurements exhibit almost perfect crystalline structure. The question that arises from Fig. 2 is, what ellipsometric parameters characterize as-implanted amorphous layers?

Several authors dealt with the mechanism of carbon build--up during implantation. M. Yamaguchi and T. Hirayama[6] observed approximately 6 nm carbon at 10^{16} atom/cm^2 implanted dose and 60 nm thick contaminant film at 10^{17} atom/cm^2 in good vacuum ($\sim 10^{-5}$ Pa). This overlayer consisting of polymerized hydrocarbon molecules, to our knowledge, was disregarded at earlier studies. For example Kucirkova took only account of a maximum 1 nm native oxide which was measured on the virgin part and this oxide was considered as being identical on the implanted part, too[7]. K. Nakamura et al. made only a 2 nm correction for surface oxide layer[8]. The hydrocarbon film, however, causes a slight change in ψ and drastic decrease in Δ which is in correlation with the thickness of disordered layer and surface film together. This could cause problems for ellipsometric investigations of liquid--nitrogen temperature implants, where the probability of carbon deposition increases. Oxygen plasma was used by K. Watanabe et al. to remove possible contaminations during implantation[9]. Fig. 2 shows a drastic change in Δ after a plasma stripping of the surface contamination on as-implanted samples. K. Nakamura et al. investigated $^{31}Pa^{+}$ implanted samples as a function of implantation temperature[8]. A direct comparison of ours and their results is impossible, because of different wavelength used but the tendency in Δ was similar after low temperature irradiation compared to our samples without plasma stripping.

The drop of Δ at the beginning of heat treatment, to our belief is not a contamination effect, the onset of epitaxial growth is a probable cause of the change in Δ. To decide what really takes place, using other structure sensitive methods, for example TEM, is necessary. It is clear, however, from our experiments that this kind of effect is shielded without proper surface cleaning.

3.2 The effect of dose of ion-implantation

The effect of the degree of amorphousness as a function of increasing dose for $^{31}P^{+}$ implantation has also been investigated. Fig. 3 shows RBS spectra taken along channeling direction and Fig. 4 the measured ellipsometric parameters, respectively.

For low dose implants $\leq 3.1 \times 10^{14}$ atom/cm^2, channeling shows buried disorder and the corresponding ψ values are insensitive to the partially amorphized layer. The Δ parameter, however, decreases to a minimum. At higher doses, where the layer becomes fully amorphized, the ψ reaches a saturation value and the corresponding Δ values increase again indicating the presence of a new, amorphous phase. For even higher doses, where only the thickness of amorphous layer increases according to RBS, the Δ decreases simultaneously. Comparing these data with the ones of the annealing of self-implantation, we think that the Δ parameter "feels" the optical inhomogeneity due to crystalline - amorphous phase transition and vice versa and seems to be a good measure of layer thickness in optically homogeneous materials, for example, in a fully amorphized layer. We have to emphasize that this effect was also shielded by thin surface films on samples which were not subjected to plasma stripping.

Similar behavior was observed on aluminum-implanted silicion too /Fig. 5/.

3.3 The role of impurities for high-dose implantation

High-dose implantation causes the following difficulties:

i/ increasing number of recoil-implanted carbon and oxygen,

ii/ sputtering of implanted layer. The measured implanted dose does not characterize the quantity of implanted specimen. Moreover the lower the energy, the higher amount of sputtering takes place,

iii/ the degree of amorphousness strongly depends on the implantation condition /for example ion-beam induced annealing might occur[10,11]/.

Trying to clarify the role of impurities, $^{31}P^+$ and $^{75}As^+$ ions were implanted at room temperature with doses of 3.1×10^{15} or 1×10^{17} atom/cm^2. Some wafers were mounted into the implanter with good thermal contact between wafer and holder and others were thermally isolated. Besides, the ion current during implantation varied between 1 - 10 μA/cm^2.

Unfortunately, no regular behavior was observed. For As implants, the ψ values were between 14.5° - 17.5° and Δ values between 145° - 165° for both doses depending on the conditions of implantation. Similarly for high-dose P implants /$\Phi = 10^{17}$ atom/cm^2/ we could produce ψ values between 11.3° - 15.7°, so there is a difference between range of ellipsometric parameters but it might be the consequence of beam induced annealing. In our opinion the present experiments are not suitable to decide whether impurity effect exists or not. If exists it is hard to separate its contribution from other damage effects. It is clear that more extended experiments are necessary in the future in this respect.

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FIGURE CAPTIONS

Fig. 1 Channeling spectra taking along <100> direction on Si self-implanted sample to follow the isothermal annealing sequence.

Fig. 2 The change in the ellipsometric parameters at self-implanted silicon for isothermal annealing at 550 ^{o}C.

Fig. 3 Backscattering spectra of $^{31}P^{+}$ implanted silicon as a function of dose.

Fig. 4 The change in the ellipsometric parameters at $^{31}P^{+}$ implanted silicon as a function of dose.

Fig. 5 The change in the ellipsometric parameters at $^{27}Al^{+}$ implanted silicon as a function of dose.

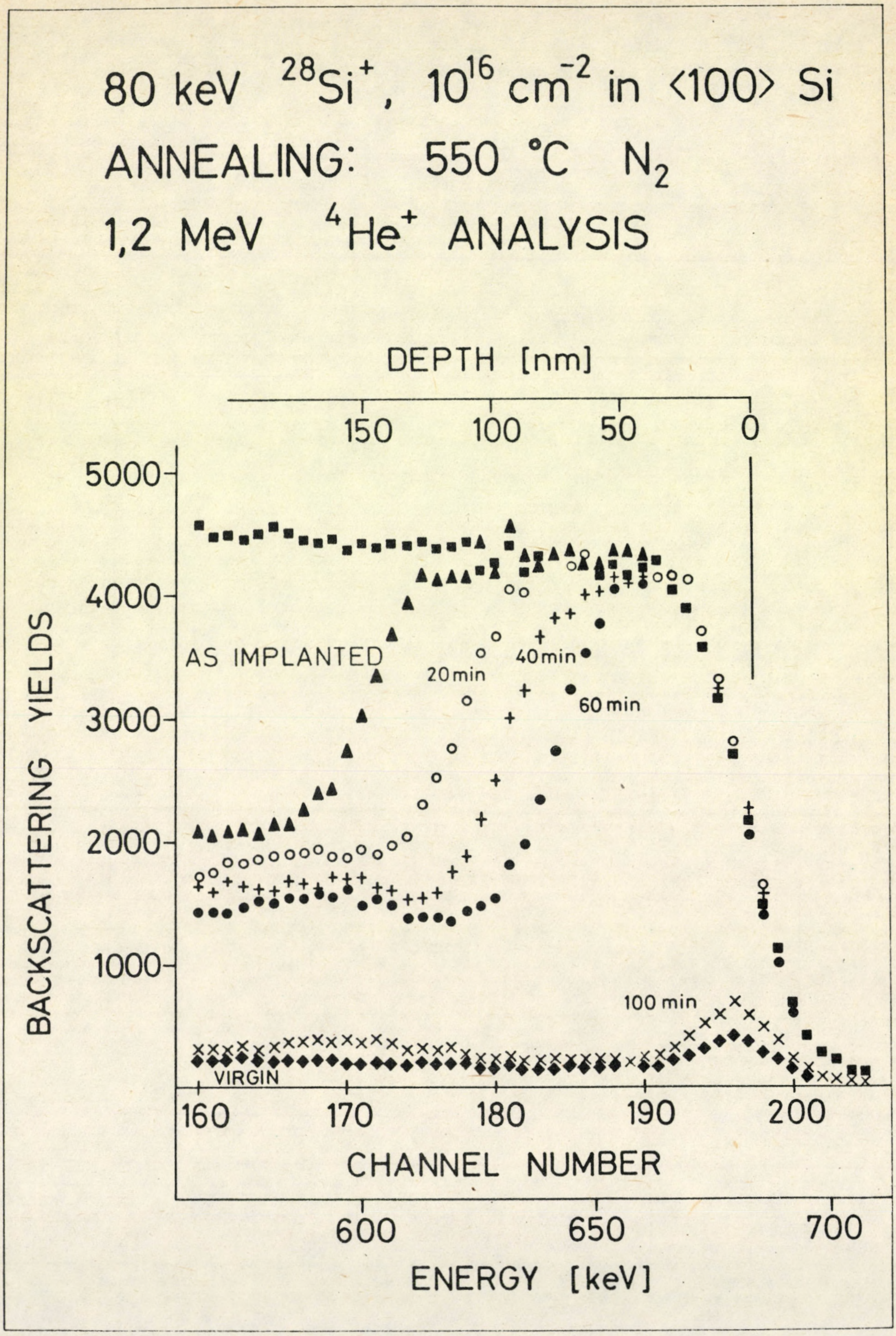

80 keV ²⁸Si⁺, 10¹⁶ cm⁻² in <100> Si
ANNEALING: 550 °C N₂
1,2 MeV ⁴He⁺ ANALYSIS
DEPTH [nm]
150
100
50
0
5000
4000
3000
2000
1000
BACKSCATTERING YIELDS
AS IMPLANTED
20 min
40 min
60 min
100 min
VIRGIN
160
170
180
190
200
CHANNEL NUMBER
600
650
700
ENERGY [keV]

Fig. 1.

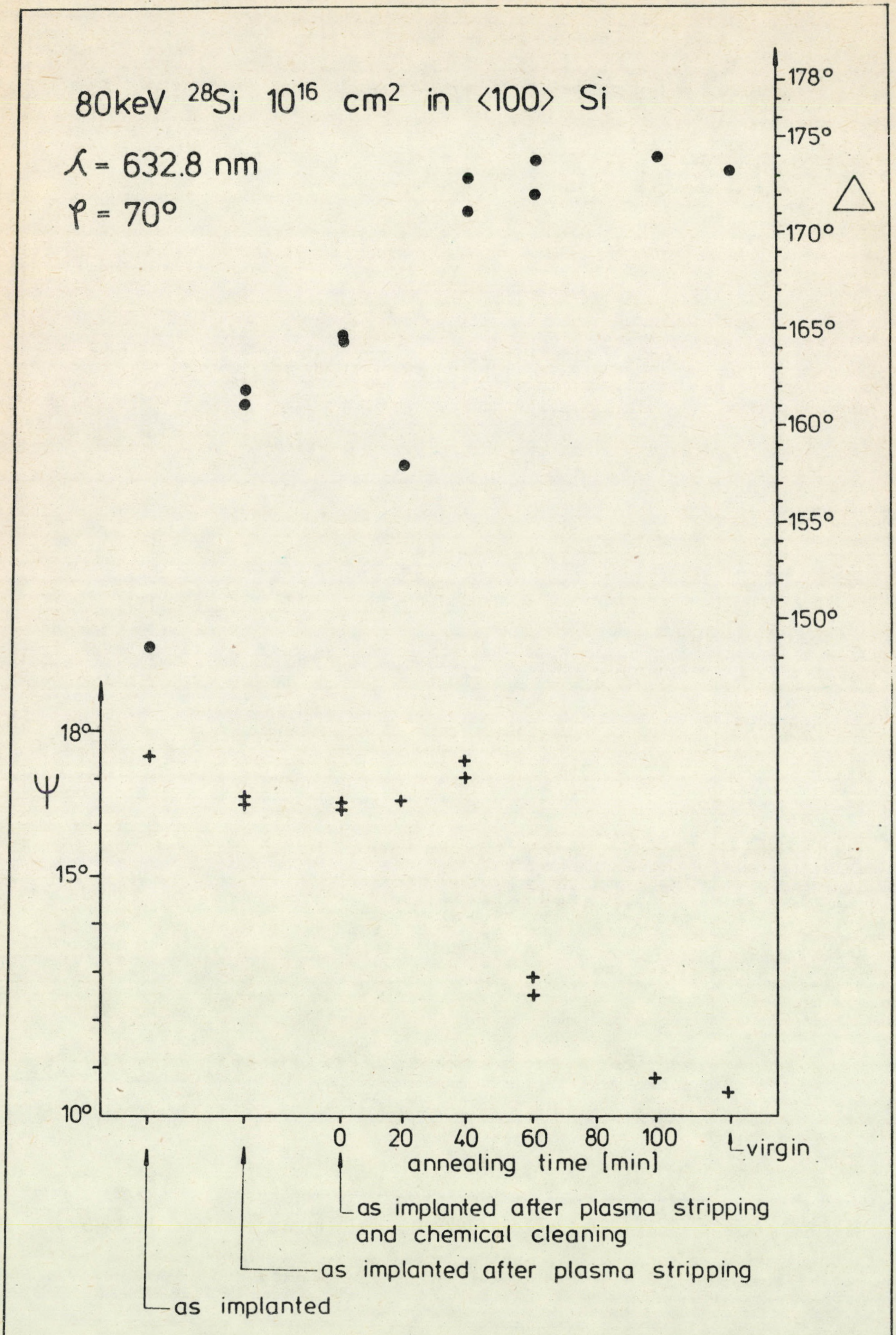
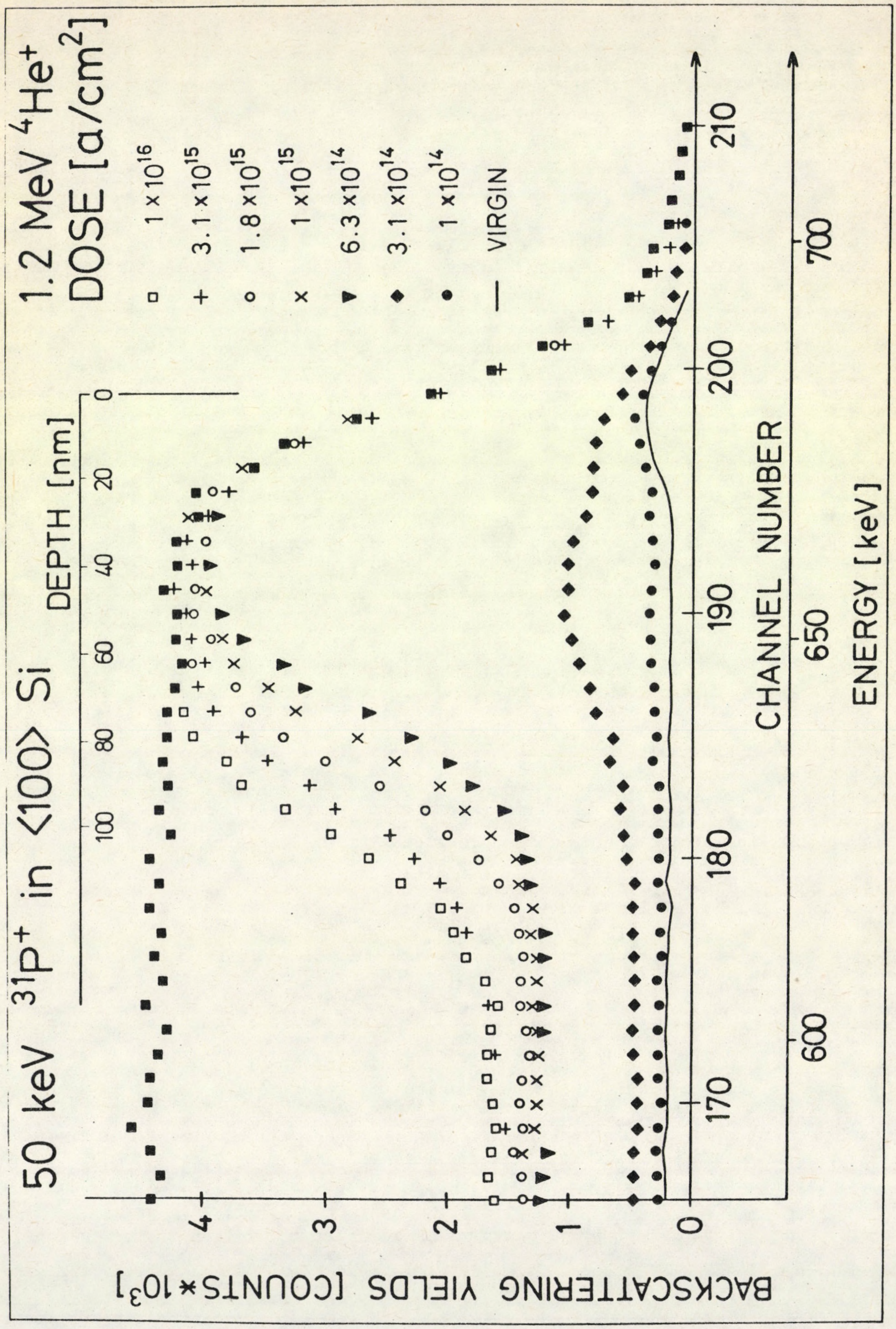

80keV 28Si 10^16 cm2 in ⟨100⟩ Si
λ = 632.8 nm
φ = 70°
178°
175°
170°
165°
160°
155°
150°
Δ
Ψ
18°
15°
10°
0
20
40
60
80
100
virgin
annealing time [min]
as implanted after plasma stripping and chemical cleaning
as implanted after plasma stripping
as implanted

Fig. 2.



50 keV $^{31}P^+$ in ⟨100⟩ Si
1.2 MeV $^4He^+$
DOSE [a/cm^2]
□ 1 x 10^{16}
+ 3.1 x 10^{15}
o 1.8 x 10^{15}
x 1 x 10^{15}
▼ 6.3 x 10^{14}
◆ 3.1 x 10^{14}
● 1 x 10^{14}
— VIRGIN
DEPTH [nm]
0 20 40 60 80 100
BACKSCATTERING YIELDS [COUNTS × 10^3]
0 1 2 3 4
CHANNEL NUMBER
170 180 190 200 210
ENERGY [keV]
600 650 700

Fig. 3.

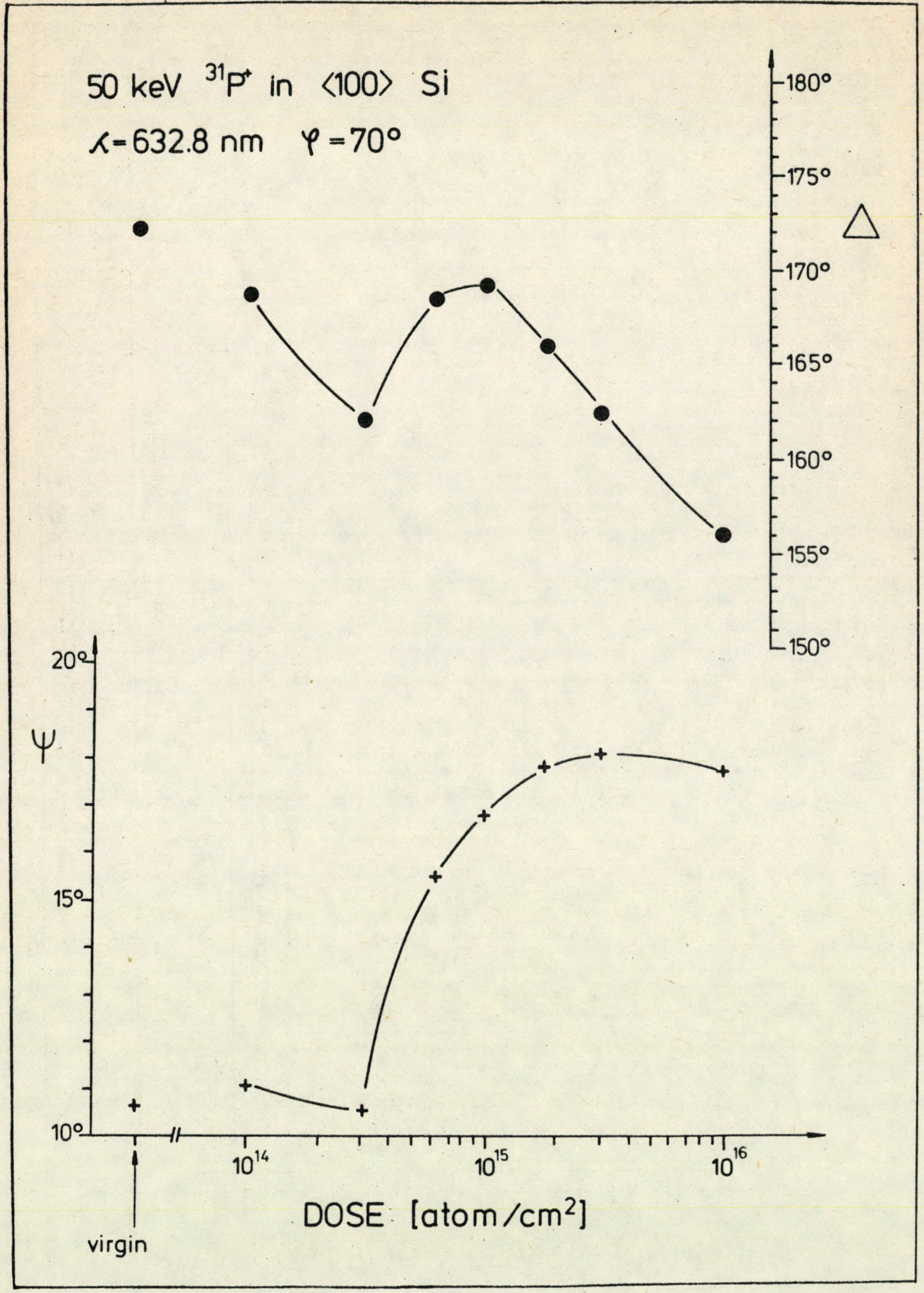
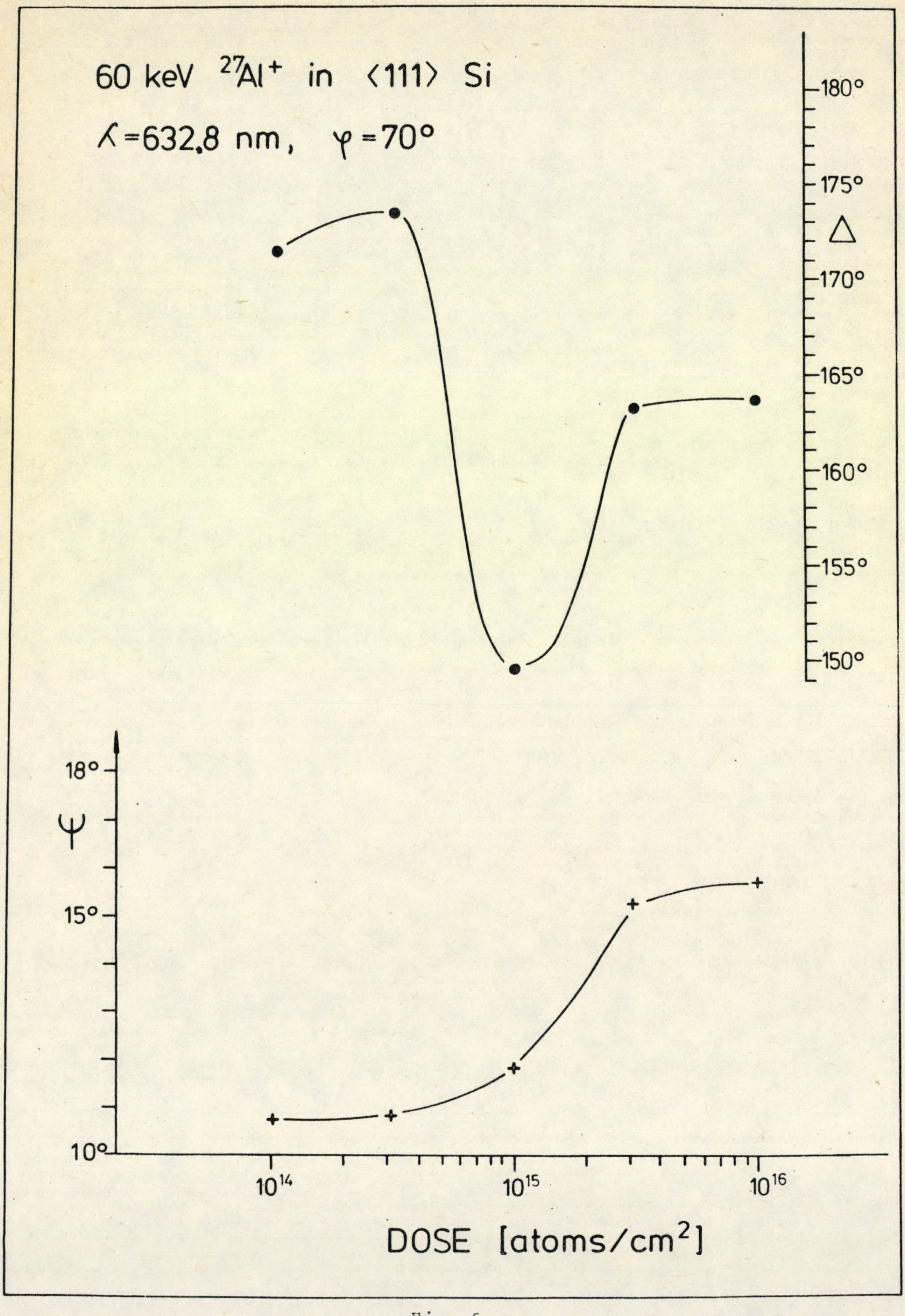

50 keV 31P+ in <100> Si
λ=632.8 nm φ=70°
180°
175°
170°
165°
160°
155°
150°
Δ
20°
15°
10°
Ψ
10^14
10^15
10^16
DOSE [atom/cm2]
virgin

Fig. 4.



60 keV $^{27}Al^{+}$ in ⟨111⟩ Si
λ=632.8 nm, φ=70°
180°
175°
Δ
170°
165°
160°
155°
150°
18°
Ψ
15°
10°
10^{14}
10^{15}
10^{16}
DOSE [atoms/cm^2]

Fig. 5.

Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Bencze Gyula
Szakmai lektor: Pócs Lajos
Nyelvi lektor: Gyulai József
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