JP0150561

JAERI-Conf 2001-002

ICANS-XV

15th Meeting of the International Collaboration on Advanced Neutron Sources

November 6-9,2000

Tsukuba, Japan

14.5
Neutron Mirror Development for VCN/UCN sources

Y.Kawabata[1*], S.Tasaki[1], M.Hino[1],
M.Suzuki[2], K.Somemiya[3#], A.Wakata[4], M.Nakayama[5]

[1] Research Reactor Institute, Kyoto Univ., Kumatori, Osaka 590-0494, Japan
[2] Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan
[3] Faculty of Engineering, Kyoto Univ., Sakyo-ku, Kyoto 606-8501, Japan
[4] R&D center, Mitsubishi pencil Co., Fujioka, Gumma 375-8501, Japan
[5] R&D center, TDK Co., Ichikawa, Chiba 272-8558, Japan
* E-mail:kawabata@rri.Kyoto-u.ac.jp
# Present address : The Japan Research Institute Limited, Chiyoda-ku, Tokyo 102-0082, Japan

Abstract

Several types of neuron mirrors and monocromator have been developed for VCN and UCN facilities. As the VCN guide tube must be set very close to the CNS cell, it will suffer a severe irradiation. Neutron mirrors enduring a hard environment are essential. Replica supermirrors and polished glassy carbon mirrors have been developed for VCN extraction. A wide band monochromator consisting of a stack of four multilayers on two Si wafers has been developed. One multilayer has 201 Ni/Ti layers. The layer thickness is gradually changed in order to extend the neutron reflection wavelength range similar to a supermirror. It is required as blades of a proposed new type UCN turbine. Development of deuterated diamond-like carbon mirrors is also in progress for the UCN transportation.

1. Introduction

Thermal or cold neutron guide tubes have been widely used in neutron scattering facilities. The irradiation effect on neutron mirrors of neutron guide tubes is not severe because they are not inserted into the high irradiation field. But they are installed deeply into the high doze field to extract very low energy neutrons, i.e. very cold neutron or ultracold neutrons. Neutron mirrors must endure the irradiation and the heat cycle. A replica Ni-mirror guide was developed and installed as the vertical guide tube in ILL[1]. The effectiveness of the guide tube introduced close to CNS and the soundness of a replica mirror in the severest environment were shown by this ILL guide tube. Replica mirror is improved to be a supermirror[2]. The surface roughness is quite well because it is the replica of the glass surface. However, it easily warps because it has the removing process in the production and also the base is not thick enough to prevent it. It is not a critical disadvantage for VCN because the critical angle of the total reflection is large, but the replica mirror is not used for cold or thermal neutrons. So it is expected to develop a new mirror with high smoothness, flatness and irradiation resistance. In addition, the mirror material is desirable not to disturb the neuron flux field when it is installed in the high flux region. To cope with these requirements, polished glassy carbon mirrors are developed[3].

When multiplayer mirrors or monochromators for short neutron wavelength are requires, a large number of very thin layers are expected. In a thin film production by the sputtering or evaporation method, it is a problem that minute crystals created in film production distort the multilayer structure[4]. Another problem is that a multilayer with a large number of layers comes off easily. Since these problems make a limit to the neutron reflection performance, the improvement of the technique in the stack of multilayers is developed. One of the proposed applications of the wide band monochromator is the blades of the mechanical neutron decelerators for the ultracold neutron generation[5].

Deuterated diamond-like carbon (D-DLC) was developed to use as a mirror material of UCN bottle for neutron electric dipole moment (EDM) experiment[6]. We also developed D-DLC from deuterated ethylene. It will be used as free shape mirror at junctions of guide tubes and experimental equipments. We will use it for UCN transportation.

There need several types of special mirros for UCN/VCN generation and transportation. Here, developments of replica supermirrors, polished carbon mirrors, wide band monochromators and deuterated diamond-like carbons for these purposes are reported in this paper.

2. Mirrors for VCN extraction used in high irradiation fields

2.1 Replica supermirror

To extract more very low energy neutrons, a neutron guide tube must be inserted much closer to a neutron source. The existing replica mirror is a copper based nickel monolayer mirror[1]. A replica-supermirror, which is a metal based mirror and resistant to a hard environment, is developed as a new neutron mirror technique. As it works well for a long time in a very hard irradiation field, copper is selected in this paper as a base material of the replica supermirror. Ni-Ti multilayers are evaporated as supermirrors because of the full experience in KUR[7]. A Ni-Ti supermirror is evaporated on a float glass and Cu is electroplated as the base material. When this surface layer is removed from a glass, a replica-supermirror is produced. They are 15 bi-layers and 2d is 40 nm. These parameters are selected to fabricate easily by the evaporation method. The base glass is a usual float glass of 10 cm × 10 cm × 6 mmt .

The surface precision of the fabricated replica mirrors is measured by optical methods. The results of two replica mirrors are as follows. The values of surface roughness in peak to valley (PV) are 22 and 200 nm. The surface roughness (rms) are 1.5 and 2.3 nm. These values show that the surface of the replica mirrors is almost as good as that of float glass. It is good enough to be a good supermirror.

Neutron reflectivity is measured by the cold neutron time of flight (TOF) measurement system at the cold neutron guide port, CN2-3 in JRR-3M, JAERI. The neutron reflectivity of the replica supermirror, the supermirror on the glass plate and the nickel mirror are shown in Fig.1.

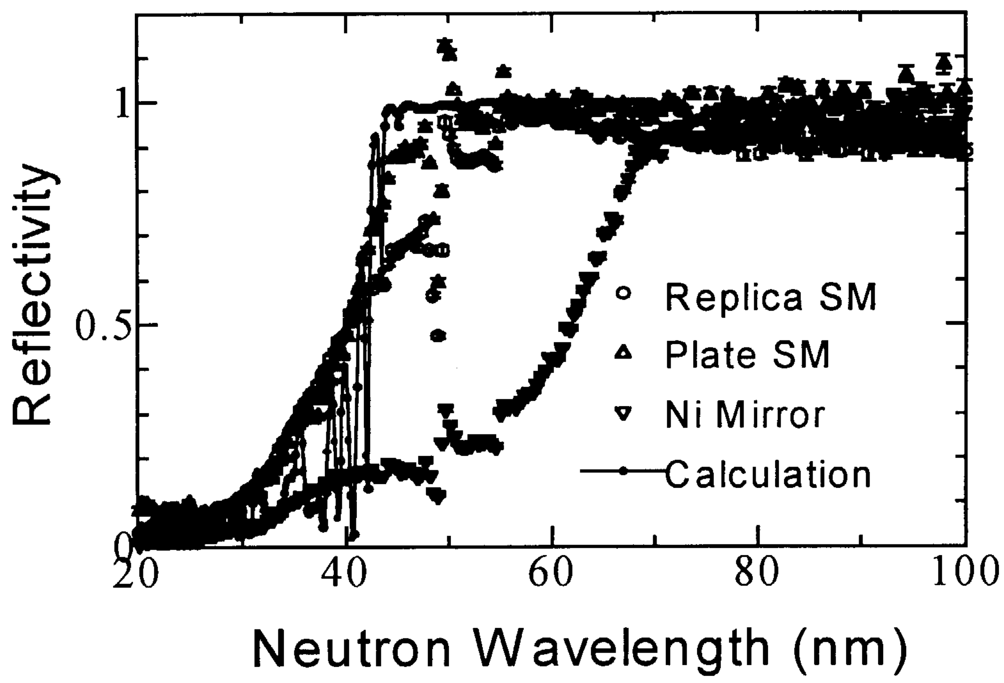

Fig.1. Neutron reflectivity of replica supermirror

The calculated reflectivity of the deposited layers is also shown in the same figure. The parameters presenting the mixture of the layer materials in this calculation are estimated according to the characteristics of the supermirror production facility[8]. The migration of adjoining layers and the interface roughness are not considered in this calculation. The wavelength in the figure is the neutron wave component perpendicular to the mirror surface. The reflectivity of the replica supermirror is almost the same as that of the supermirror on the plate and also similar to the design that is calculated from the evaporated layer thickness.

Though the roughness of replica supermirrors is very good, the flatness is not so good because of the thinness of the base metal. So it is important to support it correctly to keep it flat for the practical use. The measurement in this paper shows that it is possible to keep flat. As the critical angle of the VCN on the supermirror is much larger than the order of the flatness, the effect of surface flatness is relatively small for VCN extraction.

2.2 Carbon mirror

Though the roughness of the surface of Ni film or Ni-Ti supermirror is quite smooth, it easily warps. In case of installing a neutron guide tube near to a reactor core, effects of the installing should be as small as possible, i.e. the effects must not decrease neutron flux in the neutron source. To cope with these requirements, we have developed a polished carbon mirror as a new substrate for VCN guide tube.

The source material of carbon mirrors is a blended polymer of furan and phenol resin. By baking the source material in an atmosphere of nitrogen at two kinds of temperature, 1000 and 2000 degrees, it becomes a glassy carbon of which the grain size is less than about 5nm. The sample disk is 77mm in diameter and 0.8mm in thickness. Surfaces are polished mechanically by abrasive diamond grains in three stages. The sizes of grains in each stage are 2, 0.5 and 0.1 μ m

The surface roughness of a carbon mirror was measured by the scanning optical interferometer. The measured average PV value which indicate distance between maximum peak and valley height for these samples was almost within 10 nm. The average surface roughness(rms) was within 1.0 nm. We measured another elements in these carbon mirrors up to lower limit of an inductively coupled plasma atomic emission spectroscopy. Total impurity for all elements was less than 5ppm, and then neutron absorption materials (B, Cd and Gd) were less than 1ppm.

We measured neutron reflectivity by the carbon mirror with the neutron reflectometer in C3-1-2 beam port of JRR-3M in JAERI[9]. The measured neutron reflectivities of a carbon mirror and a silicon wafer are shown in Fig.2. The critical wavelength of Si was 123nm. It corresponded to the known potential of 54neV and showed the reliability of this measurement. The reflectivity of a carbon mirror was 0.998 ± 0.004 in the total reflection range (90 - 145 nm) and the critical wavelength was 79 nm. It also corresponded to the potential of 130neV and the carbon density of 1.50 g/cm^3. This density was exactly same with the measured value of this carbon mirror. The high reflectivity shows that this carbon mirror has a good performance as the neutron mirror.

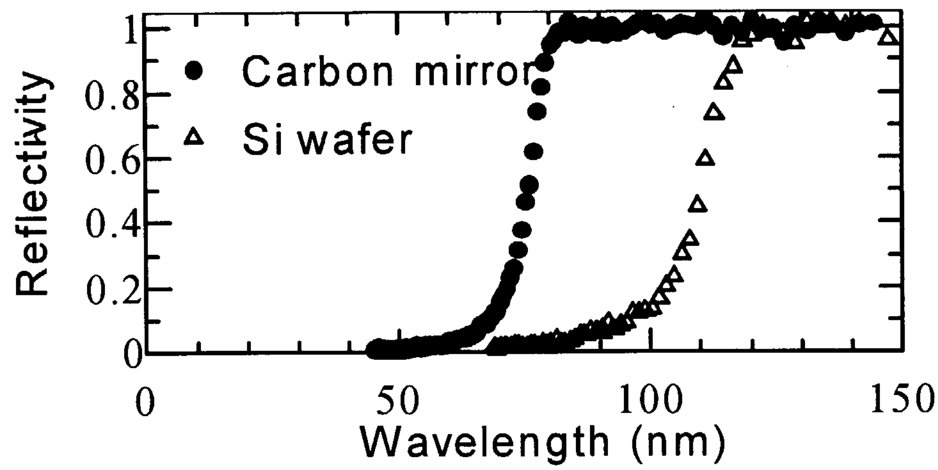

Fig.2 Reflectivity of glassy carbon mirror

Carbon mirror has the irradiation resistance, since it is made of pure carbon which has small neutron absorption cross section. A carbon neutron guide tube can be inserted into the reflector of the reactor core or the accelerator target area because carbon materials have been used as the reflectors in the nuclear reactor core for a long time. A void in the reflector area will be minimized with a carbon neutron guide, because the void will be limited only to the beam extraction size. It also could be minimize the disturbance of the neutron flux. The calculation results shows the neutron flux increases about 20%, when the distance between the inlet of the guide tube and the reactor core is 30cm in the reference core using low enrichment fuel and heavy water reflector.

3. Mirrors for UCN generation and transportation

3.1 wideband monochromator

The multilayer neutron mirror technology is highly advancing as the slow neutron control technique to cope with the demand from the neutron scattering experiments. A multilayer for short neutron wavelength requires a large number of very thin layers. In a thin film production by the sputtering or evaporation method, it is a problem that minute crystals created in film production distort the multilayer structure[4]. When such distorted thin layers are piled up, the structure of the multilayer with a pile of such distorted thin layers is not suitable for neutron reflection. Another problem is that a multilayer with a large number of layers comes off easily. Since these problems make a limit to the neutron reflection performance, the improvement of the technique in the stack of multilayers is required.

In the development of the present wide band multilayer monochromator, Ni and Ti were used as materials of multilayers. These metals were alternately piled up by the vacuum evaporation method on a Si wafer. The thickness of Si substrate is 225 μ m. A wide band neutron monochromator consisting of a stack of four multilayers on two Si wafers has been developed. The structure is shown in Fig 3. One multilayer has 201 Ni/Ti layers. The layer thickness is gradually changed in order to extend the neutron reflection wavelength range similar to a supermirror.

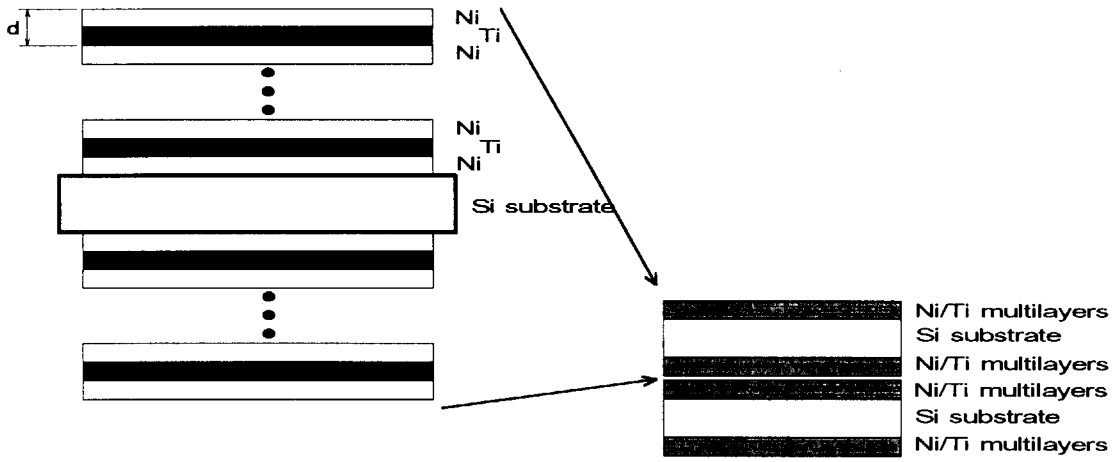

Fig.3 Structure of wide band monochromator

Figure 4 shows the measured and calculated reflectivities measured by the $\theta - 2\theta$ reflectometer. This stacking method enhances widely the neutron wavelength to 19 – 40 nm from 26 – 40 nm of one multilayer. These measurements suggested that Ni/Ti multilayers made by the vacuum evaporation method have a difficulty in increasing more thin layers. It has been shown that NiC/Ti multilayers made by the sputtering method have the better interface because the grain size of Ni becomes smaller[10]. This fabrication technique may improve the reflectivity in the shorter wavelength, though it usually has the sample size limitation.

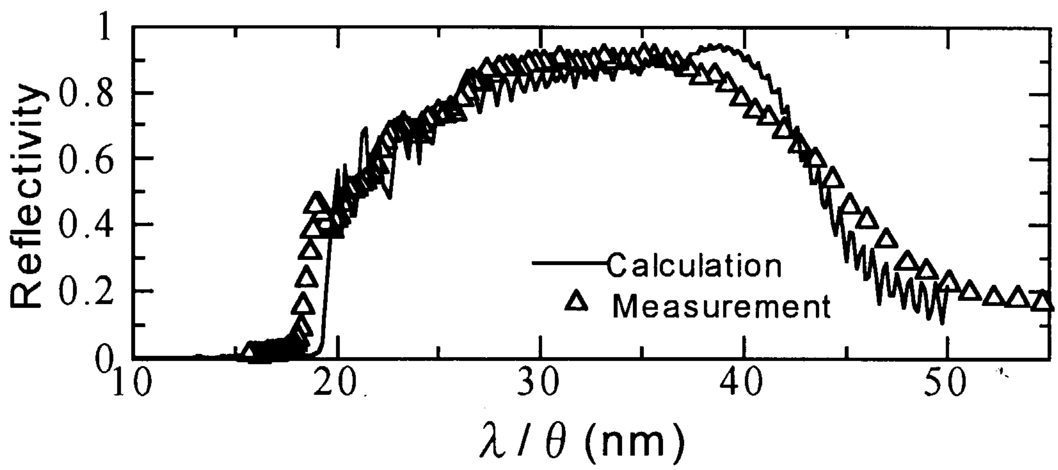

Fig.4 Neutron reflectivity of wide band monochromator

3.2 Deuterated diamond-like carbon (D-DLC)

As gaps of reflection walls make significant losses in storage and transmission of UCN, neutron mirrors of complicated shapes are required for UCN experimental equipments. D-DLC mirrors were developed as free shape mirrors. Usually a lot of hydrogen are contained in normal DLC when it is deposited by RF plasma chemical deposition. Deuterated hydrocarbon gas was used as a source material to eliminate hydrogen in DLC.

We coated D-DLC layer on a Si wafer using deuterated ethylene as source gas. The neutron reflectivity is shown in Fig.5. The thickness of the layer is 71.1nm and the potential is 207neV. The critical wavelength is 62.9nm similar to natural nickel. It shows that D-DLC layer can be a good neutron mirror. The hydrogen on the surface of D-DLC may be a significant problem for UCN bottle experiment. An experiment to measure the hydrogen on D-DLC by ERDA is in preparation.

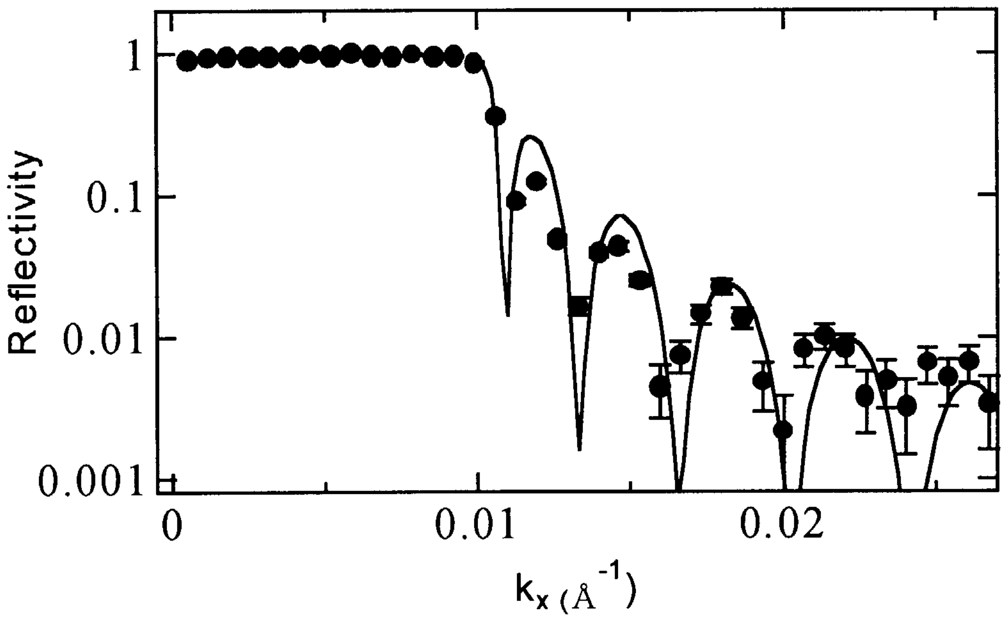

Fig 5 Neutron reflectivity of D-DLC layer

4. CN-3 development

The neutron cold beam line CN-3 in Kyoto University Reactor (KUR) is improving for dedicating the development of neutron optical devices. The arrangement of the cold neutron facilities in KUR is shown in Fig.6. CN-3 has a supermirror guide tube with cross-sectional dimensions of 20mm in width and 90mm in height, and wide band neutron spectrum is available. New beam lines are prepared for both time-of-flight (TOF) and monochromatic experiments including a neutron reflectivity measurement. It has a polarized neutron option with a very low magnetic field to cope with polarized neutron devices. Especially, TOF mode will be made for full use of developing devices which are suitable for pulsed neutron sources. The cold neutron radiography is also available with the space of 1m x 0.8m. A neutron imaging plate system and the combination of a converter and a CCD system are prepared for neutron imaging detection.

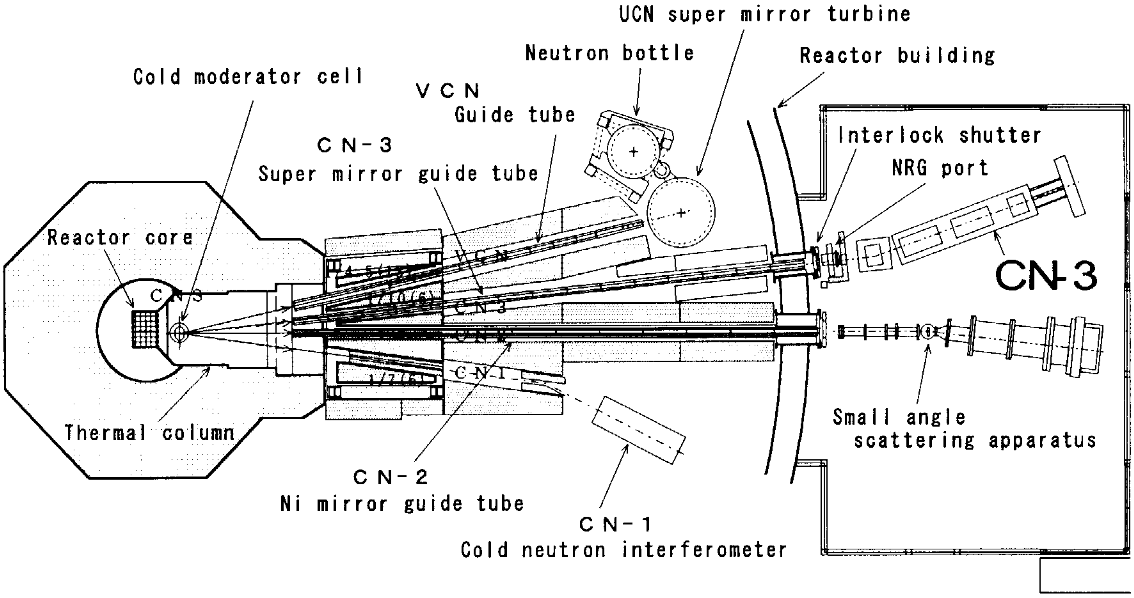

Fig.6 Arrangement of cold neutron facility in KUR

5. Conclusion

Replica supermirrors and polished glassy carbon mirrors have been developed for VCN extraction to be used in high irradiation fields. Replica supermirrors are superior in high Q reflectivity and carbon mirrors have good flatness and the reliability in safety used in the core area of neutron sources. Wide band monochromators and deuterated diamond-like carbons are also developed for UCN experiment. A wide band monochromator is a stack of four multilaysers on two Si wafers. A stacking method enables to increase total number of layers and widens the neutron reflection range practically to the shorter wavelength. The neutron cold beam line CN-3 in Kyoto University Reactor (KUR) is also improving for dedicating the development of neutron optical devices,

References

[1] A.Steyerl, H.Nagel, F.-X.Schreiber, K.-A.Steinhauser, R.Gähler, W.Gläser, P.Ageron, J.M.Astruc, W.Drexel, R.Gervais and W.Mampe., Phys. Lett. A116(1986)347.

[2] Y.Kawabata, M.Suzuki, S.Tasaki and K.Somemiya, Nucl. Instr. and Meth. in Phys. Res.

A420(1999)213.
[3] Y.Kawabata, M.Hino, H.Unesaki, M.Suzuki and A.Wakata, Proc. ASR-2000, Tokai, (2000)p165, in print.
[4] K.Soyama, M.Suzuki, Y.Kawabata, T.Ebisawa and S.Tasaki, J. Nucl. Sci. Technol., 35 (1998) 750.
[5] Y.Kawabata, Nucl. Instr. and Meth. in Phys. Res. A440(2000)685.
[6] M.G.D.van der Griten, J.M.Pendlebury, D.Shiers, C.A.Baker, K.Green, P.G.Harris, P.S.Iadjiev, S.N.Ivanov and P.Geltenbort, Nucl. Instr. and Meth. in Phys. Res. A423(1999)421.
[7] T.Ebisawa, N.Achiwa, S.Yamada, T.Akiyoshi and S.Okamoto, J. Nucl. Sci. Technol., 16 (1979) 647.
[8] S.Tasaki, T.Ebisawa, T.Akiyoshi, T.Kawai and S.Okamoto, Nucl. Instr. and Meth. in Phys. Res. A355(1995)501.
[9] T.Ebisawa, S.Tasaki, Y.Otake, H.Funahashi, K.Soyama, N.Torikai and Y.Matsushita, Physica B213&214(1995)901.
[10] K.Soyama, Doctoral thesis, Dept. of Phys., Kyushu Univ.(1999).