IMPROVEMENT OF CO-BASED AMORPHOUS CORE FOR UNTUNED BROADBAND RF CAVITY

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Abstract

We have developed a cobalt-based amorphous core as a new magnetic-alloy (MA) core for the loaded RF cavity. Owing to its permeability found to be approximately 1.5 times higher than that of FINEMET FT-3M, this MA core is an excellent candidate for constructing a compact broadband RF cavity with less power consumption. In this report, we present our recent studies of the Co-based amorphous core concerning, its annealing temperature and insulating materials coated on the amorphous tape.

INTRODUCTION

In National Institute of Radiological Sciences(NIRS), radiotherapy by use of carbon-beam has been carried out since 1994 at Heavy Ion Medical Accelerator in Chiba (HIMAC)[1]. More than 2,000 patients were treated and the clinical results show its effectiveness. Considering the increasing requirements for dedicated treatment facility of carbon beam, design study and R&D of several components were performed[2]. In this design, compact synchrotron was proposed with circumference of 63 m. The injection energy is 4Mev/u, and required maximum energy is 400MeV/u. With these conditions, revolution frequency ranges from 0.4 to 3.5 MHz. To allow harmonic number of 1 and 2, necessary frequency for acceleration is from 0.4 to 7 MHz. Maximum acceleration voltage is 3.2 kV with margin for mixture of second and third harmonics in the acceleration wave form. Considering its easiness of maintenance, Untuned broadband rf cavity has been developed with rf power source of semiconductor. Cavity have two acceleration gaps, and each one consists of six cores and a gap in between forming a 1/4 λ coaxial resonator. The resonator was so designed that its impedance is about 400 Ω at maximum. To match it with an rf power supply of out-put impedance of 50 Ω, 1:9 impedance transformer has been attached at each resonator. To realize rf cavity of high impedance with compact size of less than 2 m, core material with high impedance is required[3]. To attain these requirements, Co based amorphous core with high permeability is attractive to construct compact cavity. In selecting core material, in addition to high inductance, core loss due to hysteresis and eddy currents must be taken into account. We therefore represent the magnetic permeability of a core in complex form, as follow

$$\mu = \mu' - j\mu'', \tag{1}$$

where the real and imaginary parts denote the inductance and core loss, respectively.

The core impedance is therefore expressed as

$$Z = j\omega\mu\ L_0 = \mu''\omega L_0 + j\mu'\omega L_0 \equiv R + jX\ . \tag{2}$$

Here, L_0 is the inductance of air-core.

This core inductance is realized as a cavity whose shunt impedance Z_0 is given by

$$Z_0 = \frac{R^2 + X^2}{R} = R\left(1 + Q^2\right) = 2\pi L_0\left(\overline{\mu}Qf\right) \tag{3}$$

with quality factor $Q = \mu' / \mu'' = X/R$ and $\overline{\mu} \equiv \mu''\left(1/Q + Q\right)$. The $\overline{\mu}Qf$ factor in the above equation is often used as a measure of the cavity performance.

Due to low-Q values (less than 1 for Cobalt-based amorphous and FINEMET) of a MA core, the MA-loaded cavity shows a broadband feature. This untuned broadband cavity makes the structure simpler with no needs for tuning loop.

FINEMET FT-3M was used in many cases of untuned cavities, because this is well known as core material. In the development of compact new cavity, we chose a Co-based amorphous as an effective alternative to FINEMET FT-3M, see Fig. 1, since it has high-permeability[4], though this feature is proven only in commercial frequency (less than 100 kHz) range.

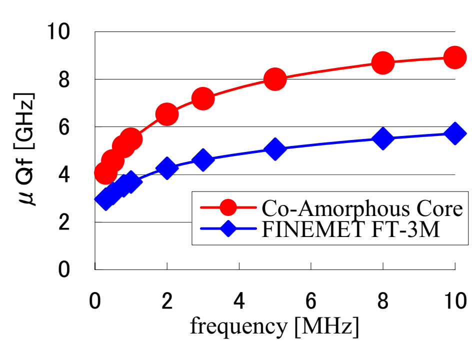

Fig. 1. Comparison of $\overline{\mu}Qf$ values between Co-based amorphous core and FINEMET FT-3M.

The developed rf cavity has good performance with enough rf voltage in the required frequency range, though there are several technical points to be improved to achieve better rf cavity. One is to look for the optimal annealing temperature to attain higher $\overline{\mu}Qf$ value in the frequency range in question. Another is to improve the insulation between amorphous tapes. In this paper, search of annealing temperature and test on several insulation materials of the amorphous tape are presented below.

MANUFACTURING PROCESS

To manufacture large Co-based amorphous core, first, amorphous is taken out from alloy and metal of thin film is obtained by rapid cooling. The film is fed from the drum to liquid insulation material and the coated tape is rolled up on another drum again. The tape is annealed at around 420°C, and then is heated again to 200°C in the magnetic field to achieve higher permeability as shown in Fig. 2. Typical core impedance is shown in Fig. 3 for both real and imaginay parts.

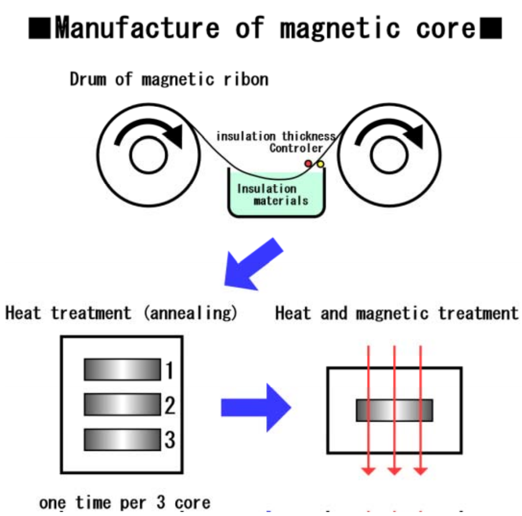

Fig.2. Manufacturing process of Co-based amorphous core.

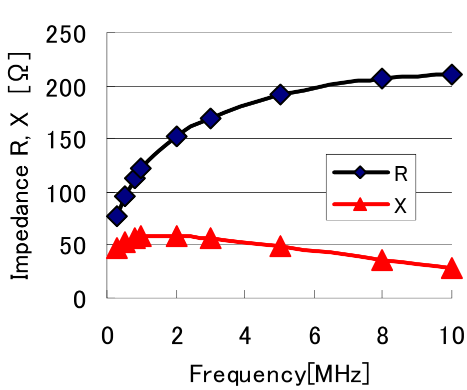

Fig.3. Impedance of large Co-based amorphous core (outer diameter: 555mm, inner diameter: 310mm, thickness: 30mm).

DEPENDENCE ON ANNEALING TEMPERATURE

We have investigated the dependency of permeability on the annealing temperature in MHz frequency region. We have prepared six sets of small Co-based amorphous cores (outer diameter: 21mm, inner diameter: 14mm, thickness: 4.5mm) and each set has ten core samples in it. Tested temperatures were from -60 degrees to 40 degrees in 20 degrees step. Measured $\overline{\mu}Qf$ values are shown in Fig. 4 and forms broad peaks. The operating temperature of -10°C may be recommended to make some allowance to the temperature setting.

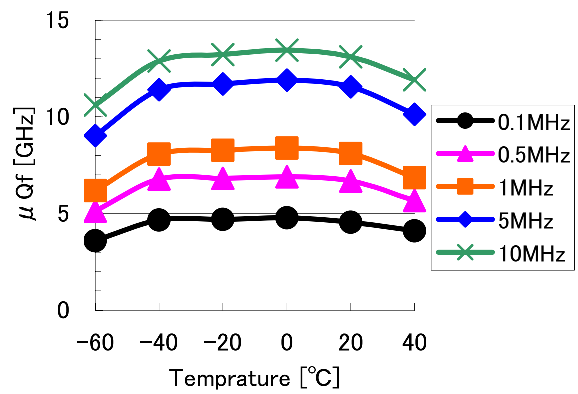

Fig.4. $\overline{\mu}Qf$ value as a function of annealing temperature.

DEPENDENCE ON INSULATION MATERIALS

We have experience about drop of $\overline{\mu}Qf$ value during the fabrication process of large cores for use in the acceleration cavity. The cause of this drop was speculated to poor insulation between the Co-based amorphous tapes. To improve the insulation, we have tested the 4 types of insulation materials. We prepared Co-based amorphous core of small size (outer diameter: 50mm, inner diameter: 34mm, thickness: 30mm) with 4 type of insulation materials as follows and their $\overline{\mu}Qf$ values are shown in Fig. 5.

1. Fine SiO_2 particles of mean diameter of 10 nm and the insulator thickness of 1-2μm. The one used in the large size core for R&D cavity .
2. Large SiO_2 particles of mean diameter of 100 nm and the insulator thickness of 1-2μm.
3. Chained particle insulator of 200nm long made from SiO_2 of 10nm dia. and the insulator thickness of 1-2μm.
4. Polyimide film insulator and the insulator thickness of 7.5 μm.

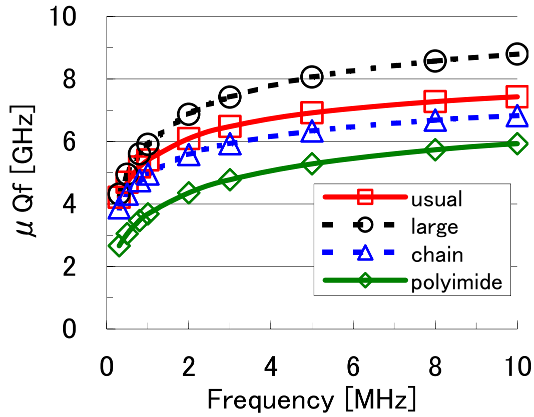

Fig.5. Frequency dependences of $\overline{\mu}Qf$ values with 4 types of insulation materials.

In the case of insulation with Polyimide film, the $\overline{\mu}Qf$ values were low. This comes from the lowest filling factor of Co-based amorphous core by 20%. There was no large difference between chain particle and small particle insulation and the core with large particle insulation showed the highest values.

We adopted the use of aluminium plate on one side of the core. We have measured its effect on $\overline{\mu}Qf$ values. The measured results are shown in Fig. 6 and Fig. 7.

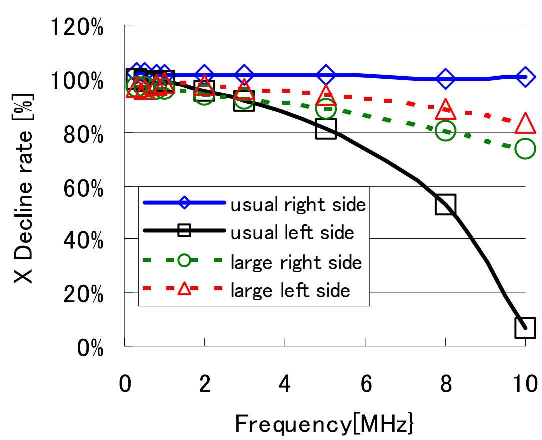

Fig.6 Inductunce ratio (X) of the tested core contacted with aluminium plate on right or left side of the core.

In the case of 10nm particle (SiO_2) for the insulation, large decrease of X was observed as in the large core for the R&D cavity. In the case of insulation with Polyimide, there is no decrease of inductance indicating good insulation characteristics of amorphos tape. In the cases of large particle and chained particle insulations, there are not large decreases of X values with contact of aluminium plate on right- or left-side.

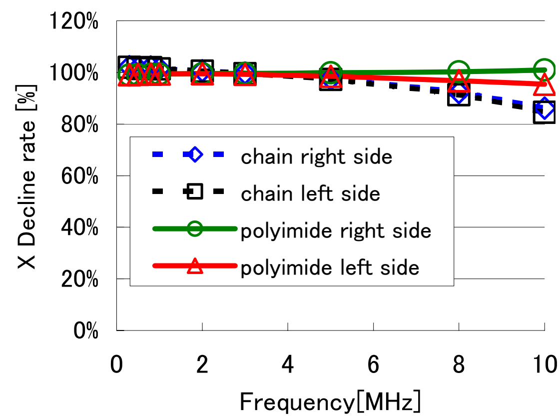

Fig.7 Inductunce ratio (X) of the tested core contacted with aluminium plate on right- or left- side of the core.

SUMMARY

- To know better annealing temperature to obtain higher $\overline{\mu}Qf$ value of the Co-based amorphous core, we have checked the dependence on the annealing temperature. Lower temperature than the commonly used value with 10 degree seems to be better.
- With 10nm particle SiO2 insulation of the amorphous tape have large reduction of X value with contact of aluminium plate on right or left side of the core. Insulation with 100nm particle SiO2 and chained 10 nm SiO2 particles show no large change of inductance (X) with contact of aluminium plate on right or left side of cores. With 100nm particle size of SiO2 insulation, we have highest $\overline{\mu}Qf$ value in the tested four insulation materials.

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