Superconducting transition edge sensor for heavy ion detection

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Heavy ion cancer therapy

Absorbed dose distribution

Carbon ion  X-ray

Higher dose convergence  Minimal damage to normal tissues

Heavy ions penetrate into the body to a specific depth, and the dose is concentrated in the very small volume in which the ions come to a stop.

The penetration depth can be adjusted precisely to the tumor area.

Precision measurement of the absorbed dose in heavy ion beam is required.
Background

- Regulation of the tumor tissue
- Adverse event

Probability of cancer recurrence

Uncertainty in dose rate measurement

Negative influence on the therapeutic effect
Objective

Minimizing of the uncertainty in dose rate measurement of heavy ion beam
- less than 5 % of the conventional measurement

Measurement of the absorbed dose in water

\[ D[\text{Gy}] = \frac{\text{Energy}[\text{J}]}{\text{Mass}[\text{kg}]} \]

Directly detection of the absorbed energy in heavy ion beam

Precision calorimetry

TES (Transition Edge Sensor)

Measurement by the ionizing chamber

\[ D[\text{Gy}] = \frac{\text{Charge}[\text{C}]}{\text{Mass}[\text{kg}]} \cdot \frac{\text{Energy}[\text{J}]}{\text{Charge}[\text{C}]} \]

W-value

Sensitivity fluctuation of ionizing chambers
- temperature, volume, recombination etc.

Uncertainty of W-value
- substituted the W-value of \( \gamma \)-ray from \(^{60}\text{Co} \) source for W-value of heavy ion
Sensor for heavy ion detection

We use the Ir/Au-TES coupled to a tin absorber.

Ir/Au bi-layer: Ir 100nm / Au 15nm
Tc: 138mK
Sn absorber: 0.5 × 0.5 × 0.3mm

Injected 14C ion is fully stopped inside the tin absorber.

We substitute the gamma-ray TES for heavy ion sensor.

TES is cooled by the cryogen-free dilution refrigerator, using the pulse tube cold head.

We have taken several steps against the mechanical vibration derived from the pulse tube cold head.
Gamma-ray detection

84 eV FWHM @59.5 keV (0.1 %)

$^{241}$Am (59.5 keV)

Sn Escape peak $K_\beta$ $K_\alpha$

$^{57}$Co (122 keV)
The carbon ions were injected from the tandem accelerator.
Signal pulses of the $^{14}$C incident events

The signal length is reflected the incident energy of the injected heavy ions.
Pulse shapes of $^{14}$C +5 ion incident events

Small pulse groups indicates the different energy loss processes,
Relationship between the pulse height and the current integral of the incident $^{14}$C ion events

![Graph showing relationship between pulse height and current integral for $^{14}$C +4 ion and $^{14}$C +5 ion events.](image-url)
Conclusion

We began to develop the precision heavy ion beam detector applying the superconducting transition edge sensor (TES).

- Our Ir/Au-TES coupled to a tin absorber, have detected the carbon ions which were injected from the tandem accelerator
- Although pulses are fully saturated, the signal length is reflected the incident energy of the injected heavy ions.

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