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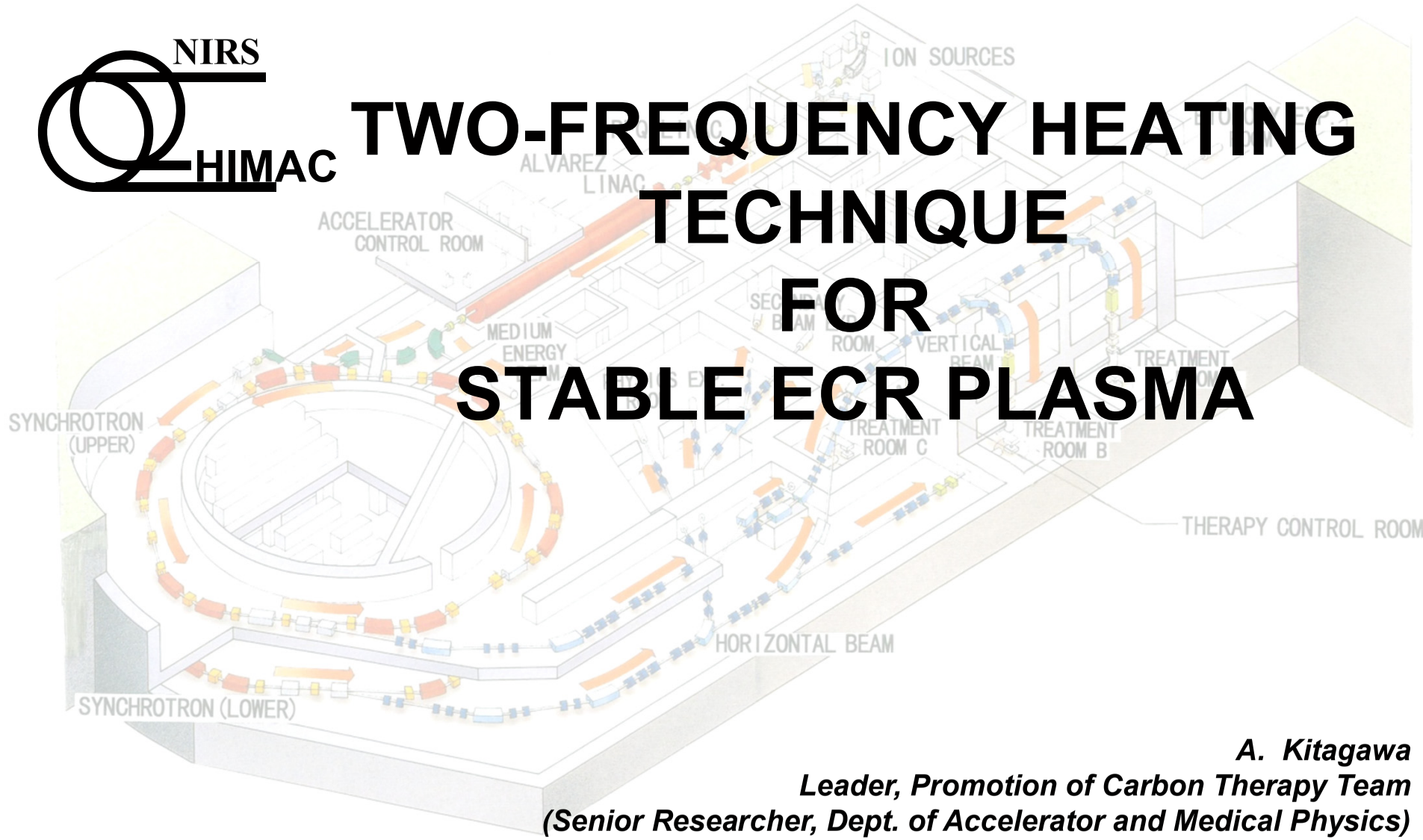
TWO-FREQUENCY HEATING TECHNIQUE FOR STABLE ECR PLASMA



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National Institute of Radiological Sciences

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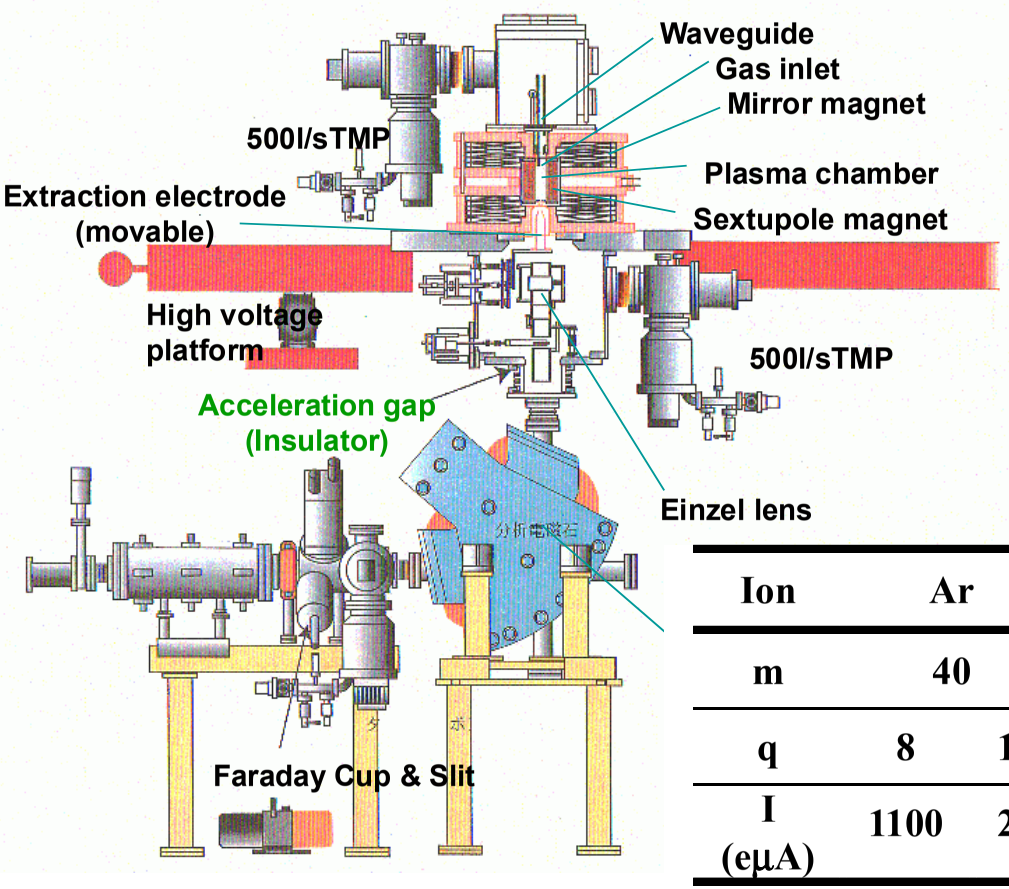
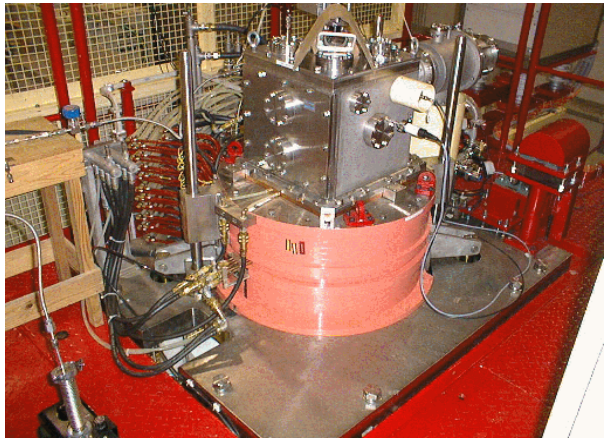
Requirements for heavier ions

18GHz NIRS-HEC ECRIS





Output currents

Ion	Ar		Fe	Co	Ni	*Ge*	*Kr*	*In*	*Xe*
m	40		56	59	58	74	84	115	132
q	8	13	9	9	10	28	15	20	21
I (eμA)	1100	20	400	160	100	*50*	*200*	*140*	*200*

Important for downsizing

insufficient

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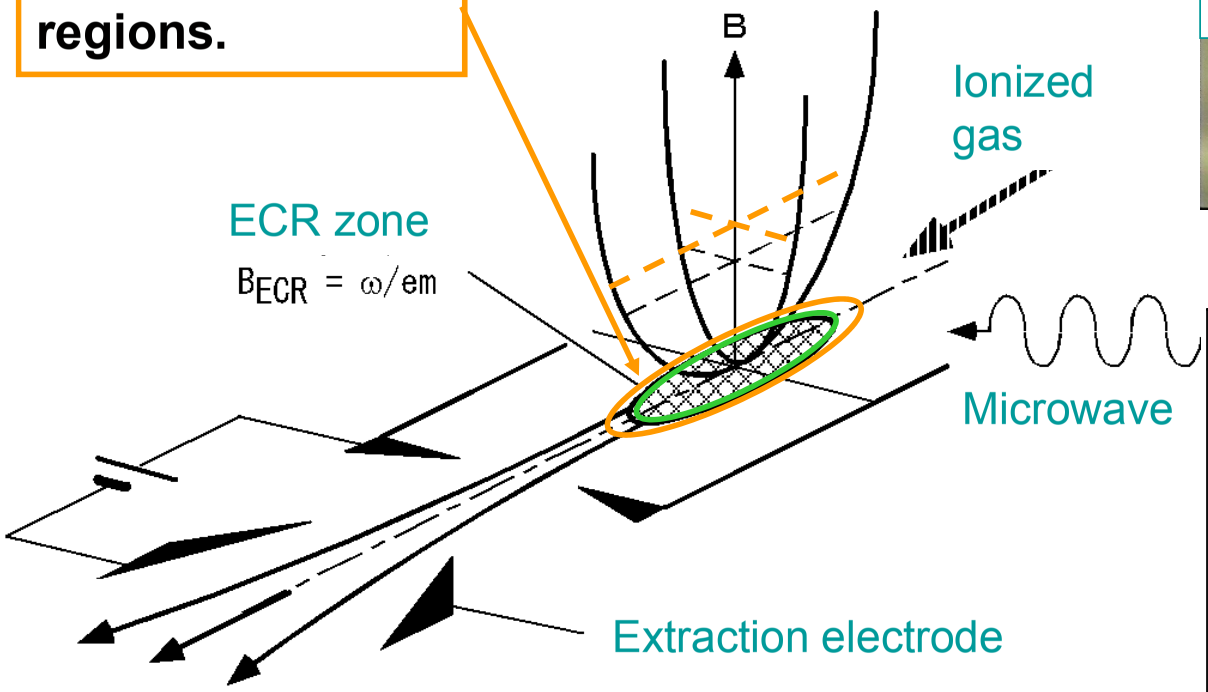
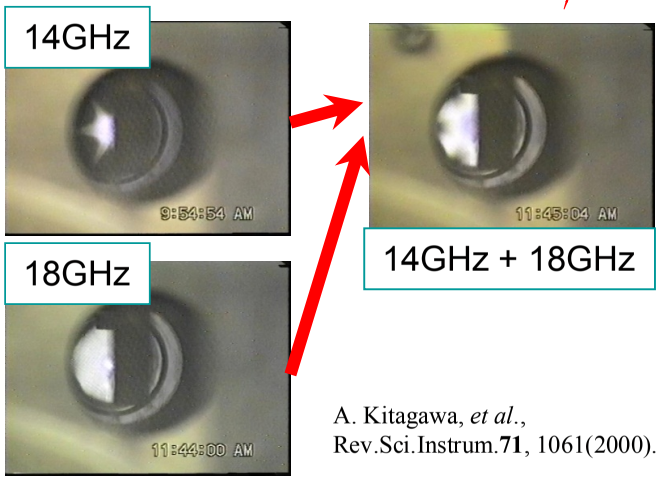
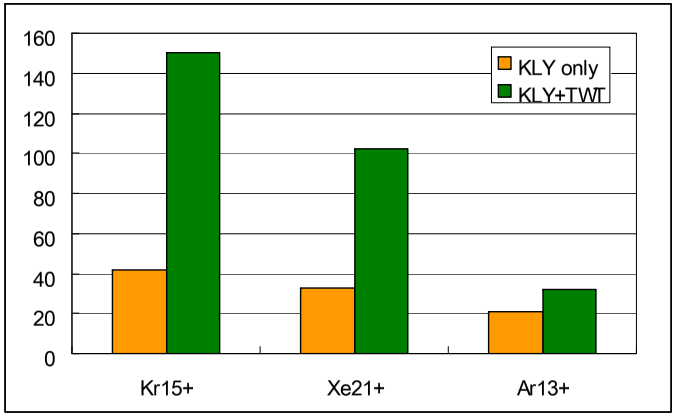
ECR condition and plasma distribution

It's expected Plasma is created at different spatial regions.





A. Kitagawa, *et al.*, Rev.Sci.Instrum.**71**, 1061(2000).



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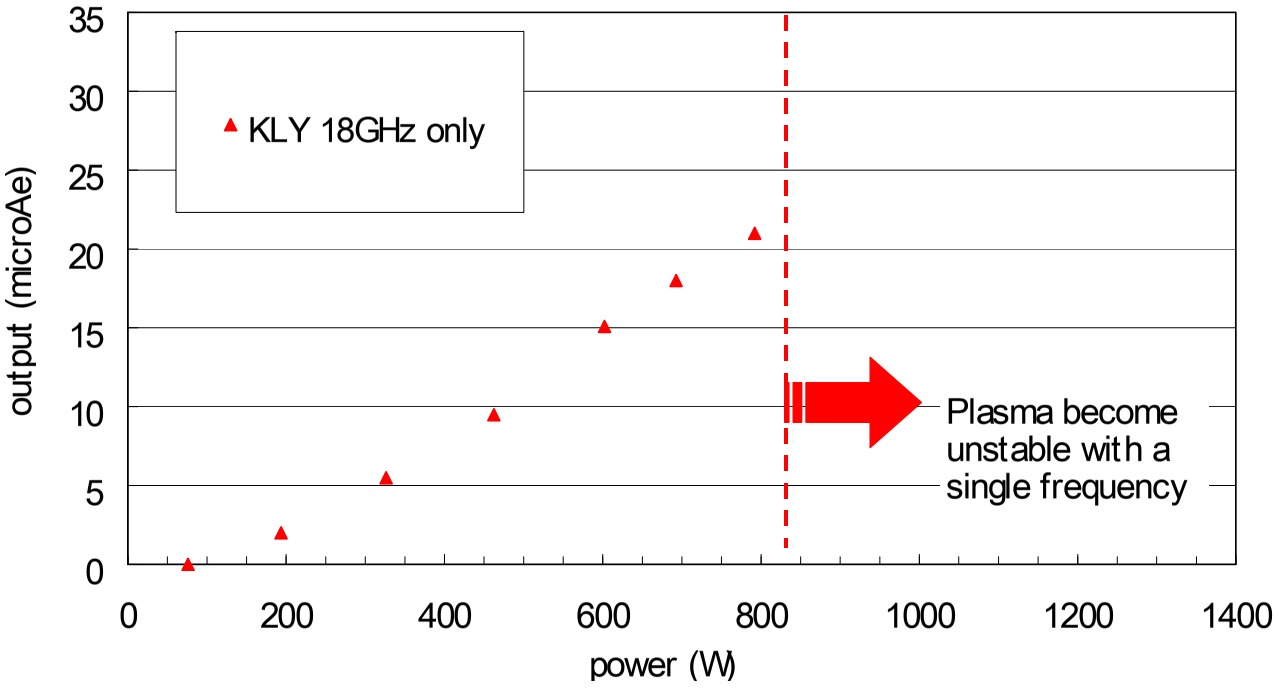
Dependence on microwave power

Experimental result of Ar^{13+}



1. Measurement by a single klystron amplifier (KLY) with 18.0 GHz (▲)

A beam intensity of highly charged ions is almost proportional to a microwave power. However, there is the limitation of maximum power to keep a stable plasma.

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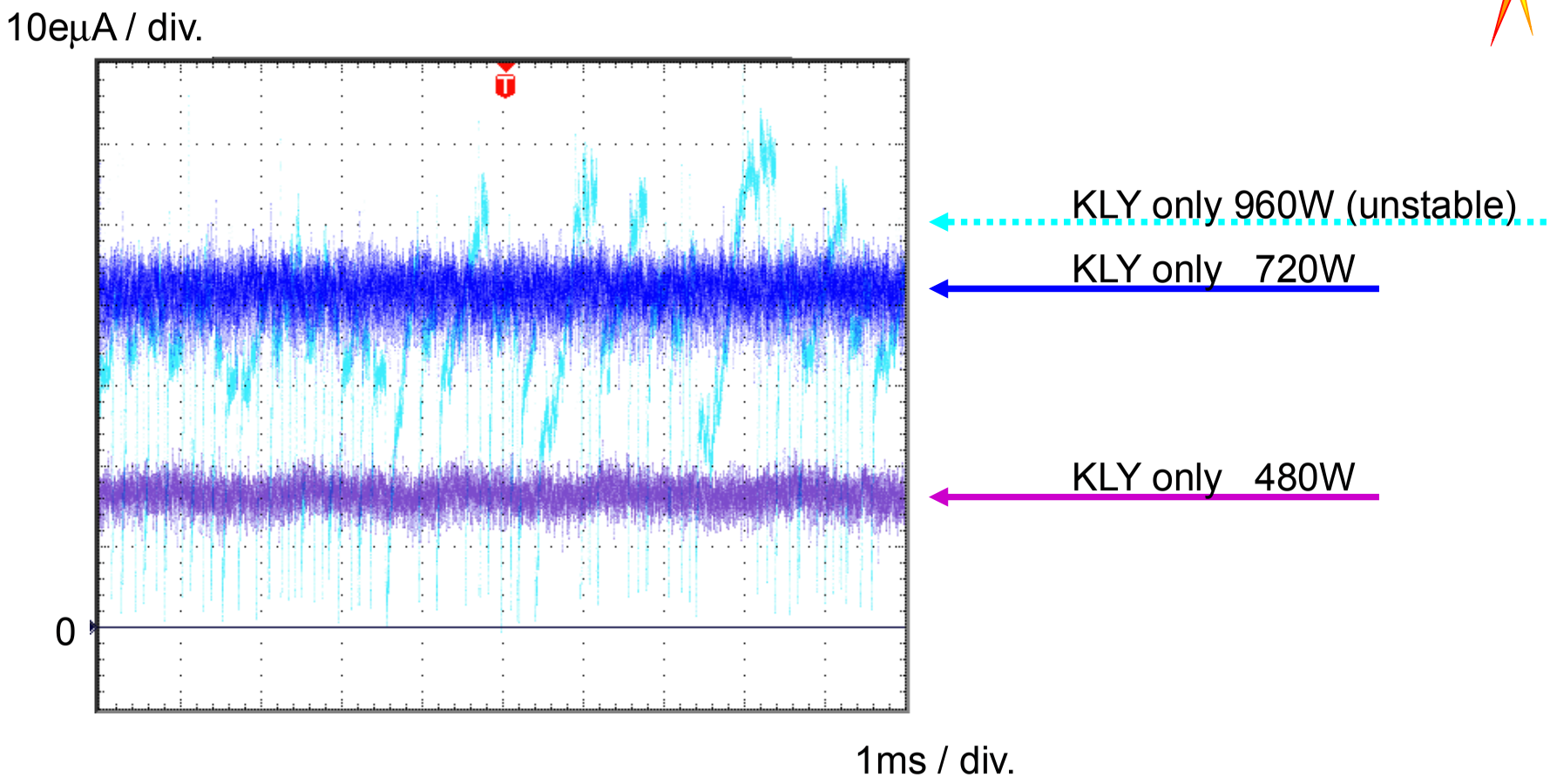
Plasma instability



Example of time structures (Xe^{21+})

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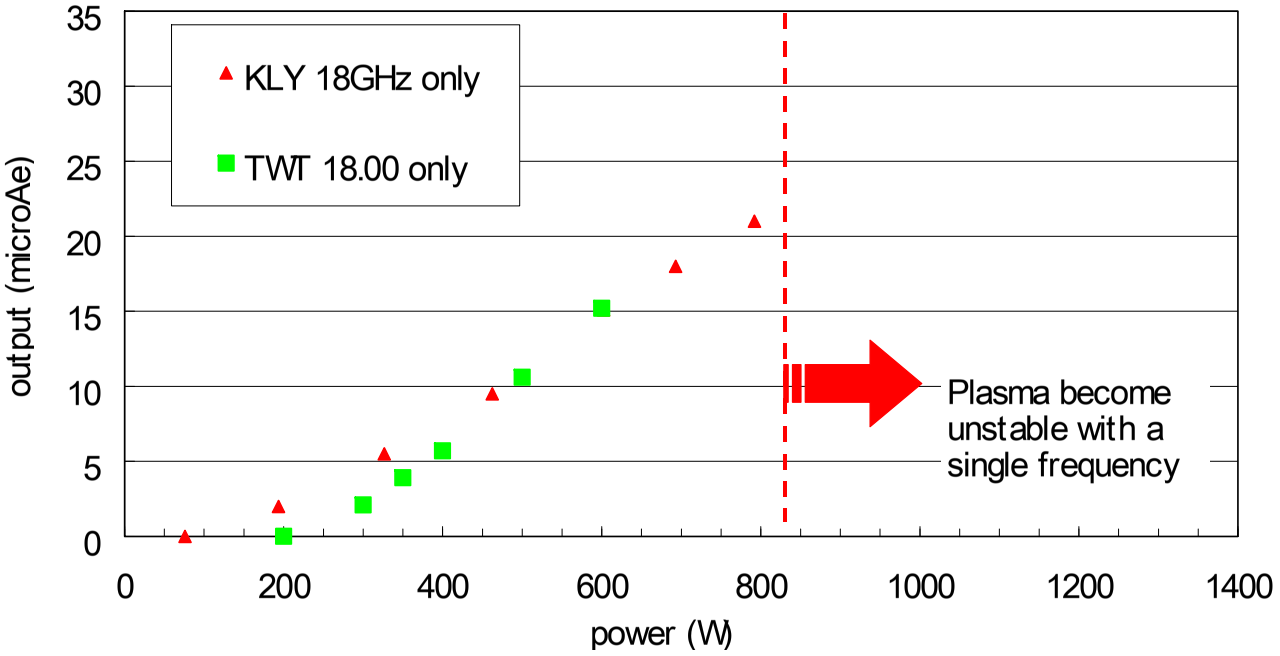
Dependence on microwave power by TWT



Experimental result of Ar^{13+}

1. Measurement by KLY with 18.0 GHz (▲)
2. by a single traveling wave tube amplifier (TWT) with 18.0 GHz (■)

An additional parallel traveling wave tube amplifier system showed the similar tendency as a klystron tube amplifier in the case of use the same frequency.

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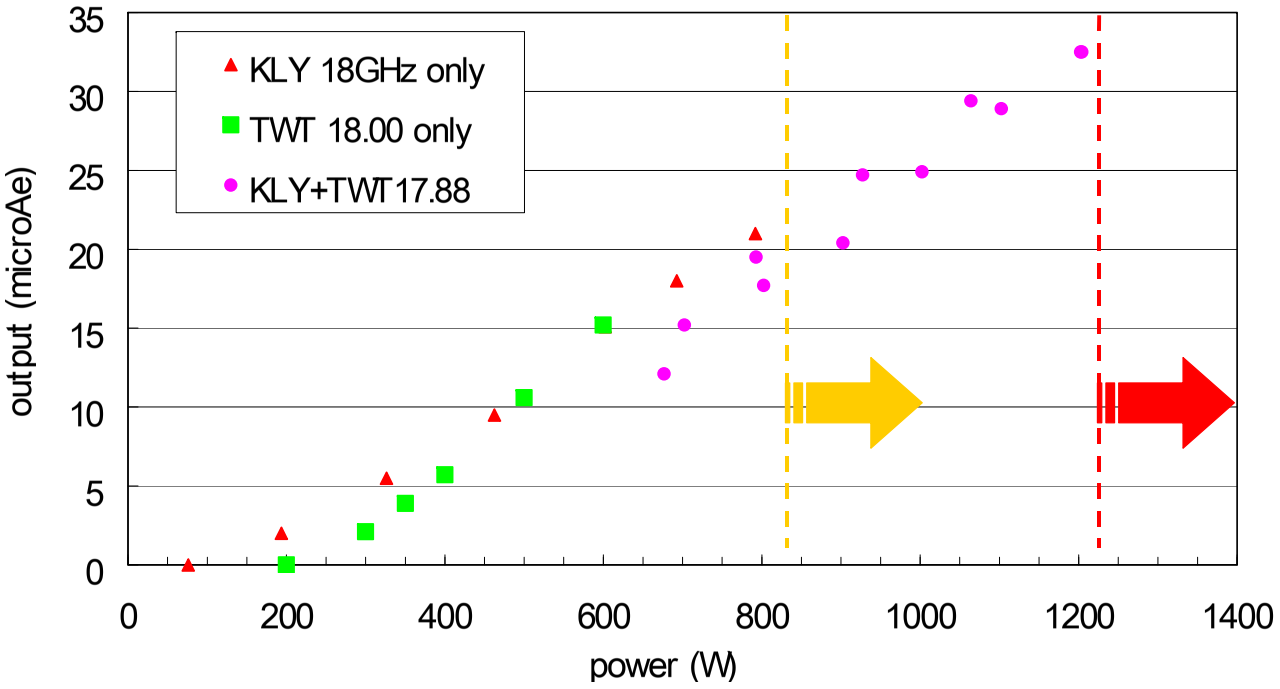
Dependence on microwave power by two frequency heating



Experimental result of Ar^{13+}

1. Measurement by KLY with 18.0 GHz (▲)
2. by TWT with 18.0 GHz (■)
3. Mixture of 18 GHz KLY and 17.88 GHz TWT (●)

The stable plasma was maintained by two microwaves even in the unstable power region with a single frequency. As a result, the intensity was probably improved with increasing the total power of two frequency microwaves.

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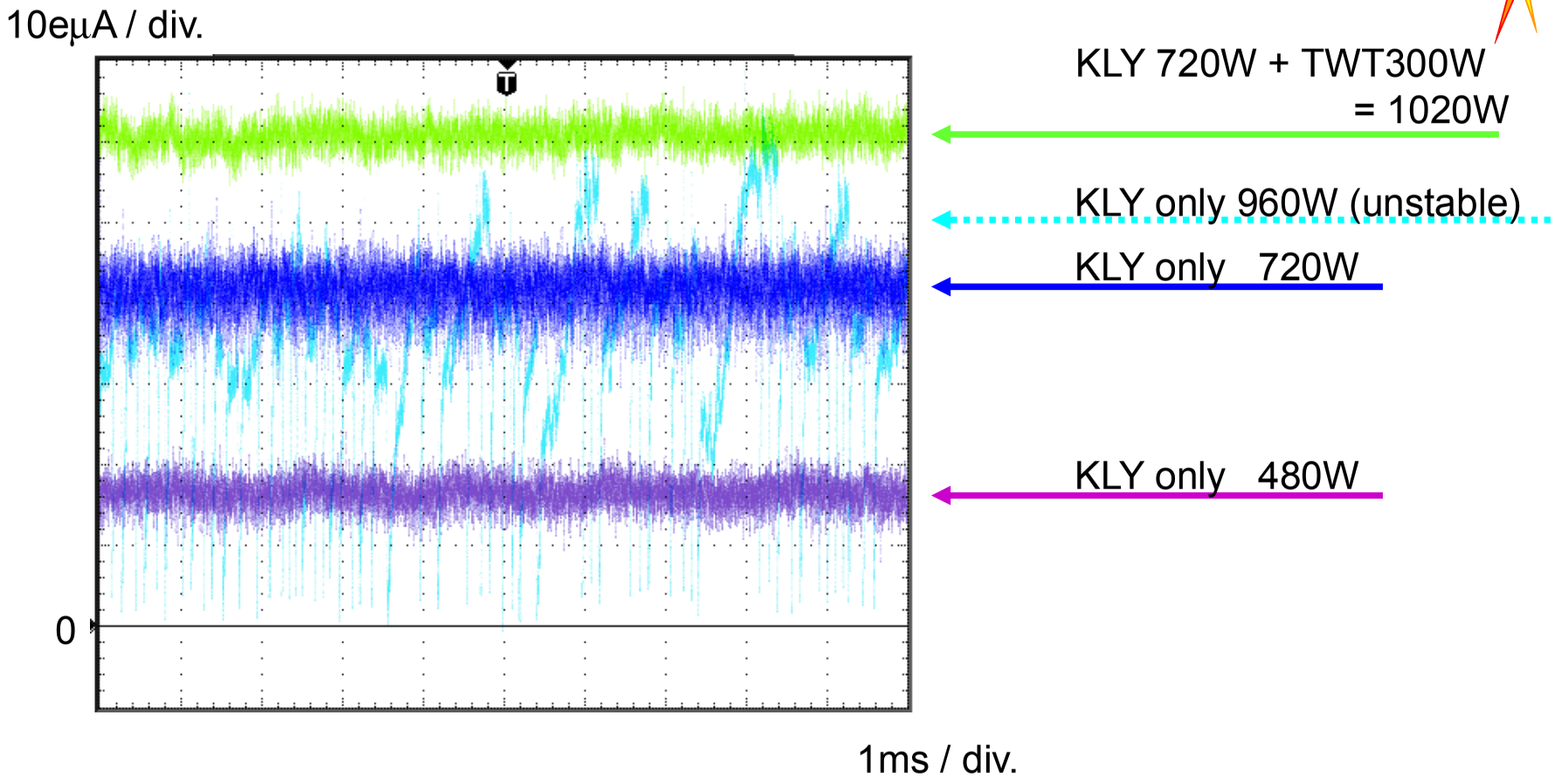
Improvement of plasma instability by two frequency heating



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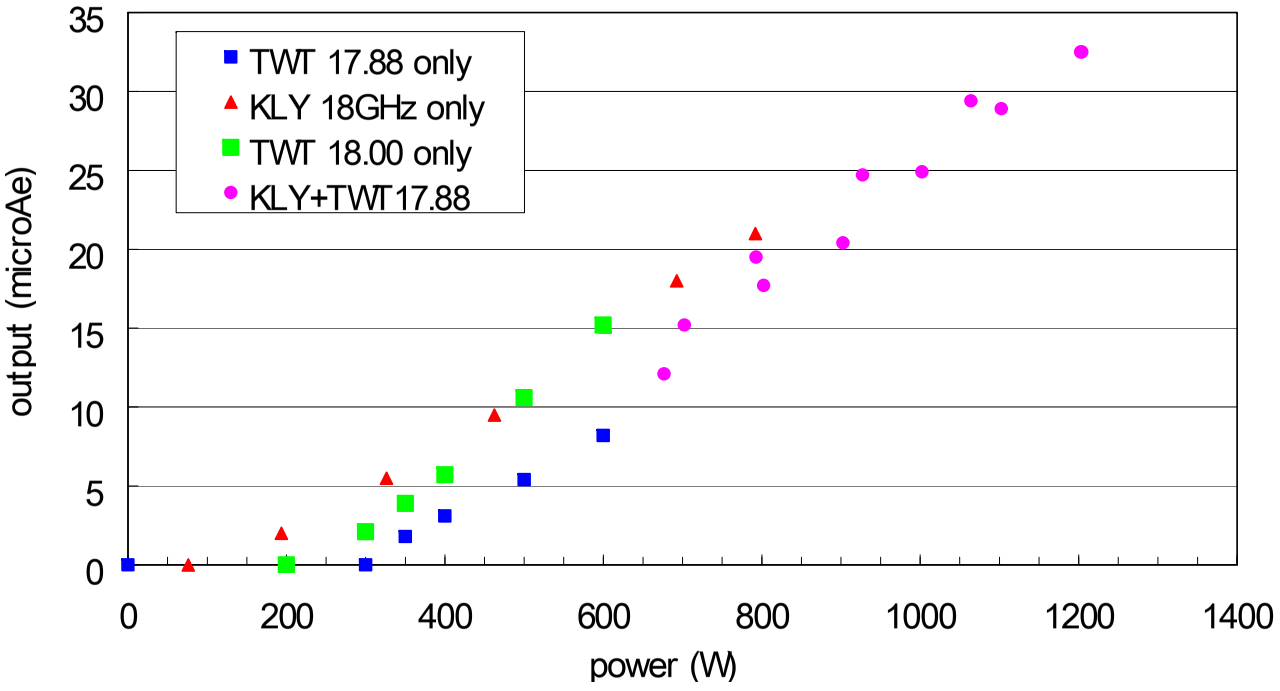
Summary of power dependence



Experimental result of Ar^{13+}

1. Measurement by KLY with 18.0 GHz (▲)
2. by TWT with 18.0 GHz (■)
3. Mixture of 18 GHz KLY and 17.88 GHz TWT (●)
4. by a single TWT with 17.88 GHz (■)

A beam intensity of highly charged ions is almost proportional to a microwave power. A balance between two microwaves slightly affected the intensity (maybe depends on the frequency tuning), but it's not

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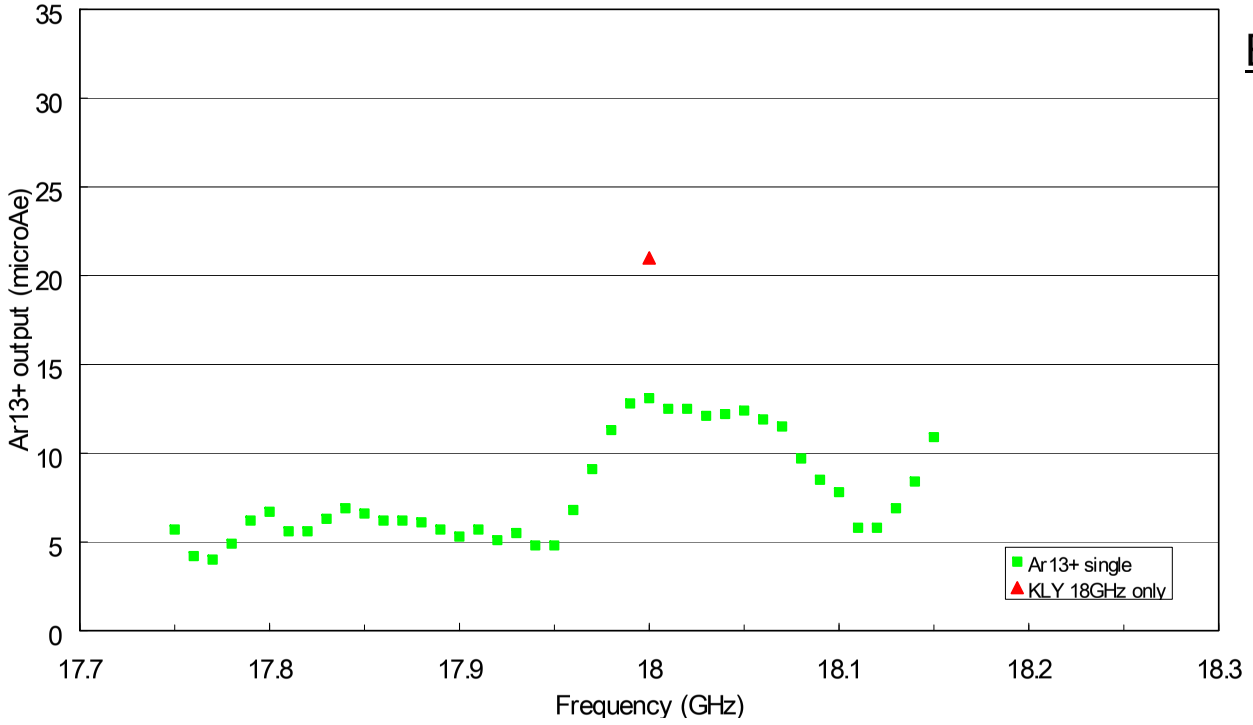
Dependence on microwave frequency (a single microwave)



Experimental result of Ar^{13+}

1. Measurement by KLY with 18.0 GHz (▲) under the optimized mirror magnetic fields, gas flows, beam extraction condition, etc.

2. by TWT with 18.0 GHz (■) under the same conditions.

Under the conditions optimized by KLY at 18.00 GHz, the fine tuning of a single TWT showed that the same 18.00 GHz was the best frequency.

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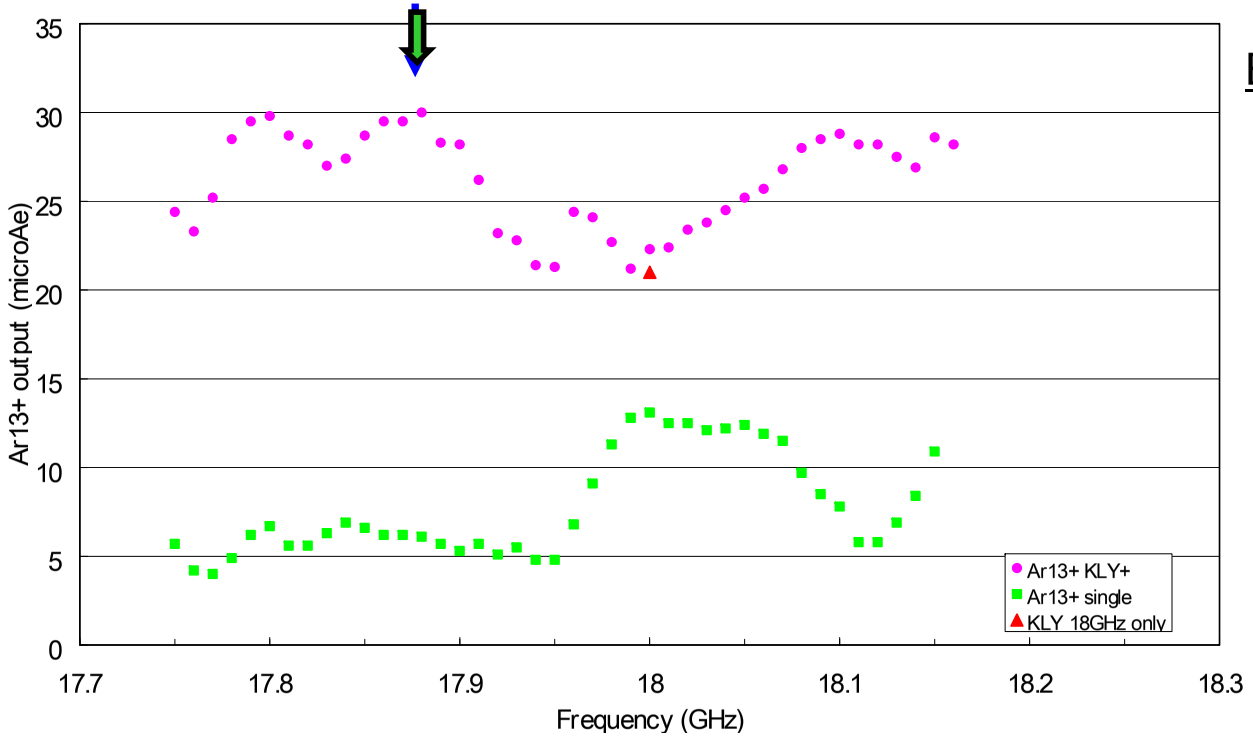
Dependence on microwave frequency (two frequency heating)



Experimental result of Ar^{13+}

1. Measurement by KLY with 18.0 GHz (▲)
2. by TWT with sweeping frequency (■)
3. by KLY and TWT with sweeping frequency under the same conditions (●)

The fine tuned frequency of the additional microwave was shifted from 18.0 GHz. The mixture of 18.0 GHz KLY and 18.0 GHz TWT showed the plasma instability.

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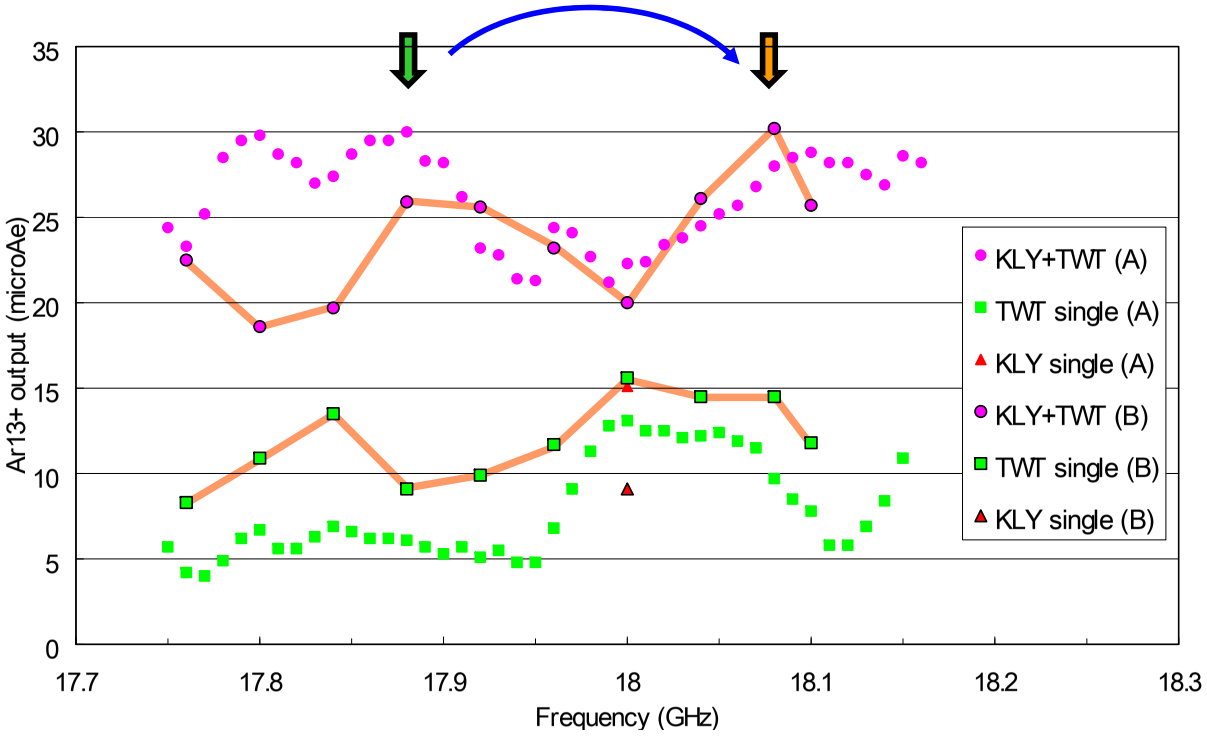
Correlation between operation conditions and frequency dependence



Experimental result of Ar^{13+}

1. Measurement by KLY with 18.0 GHz (▲)
2. by TWT with sweeping frequency (■)
3. by KLY and TWT (●)
4. By KLY and TWT under the other conditions*

(■ , ●)

* **The downstream mirror field decreased by 2.5% and other parameters were optimized.**

A fine tuned frequency of the additional microwave depends on operation conditions, especially magnetic fields.

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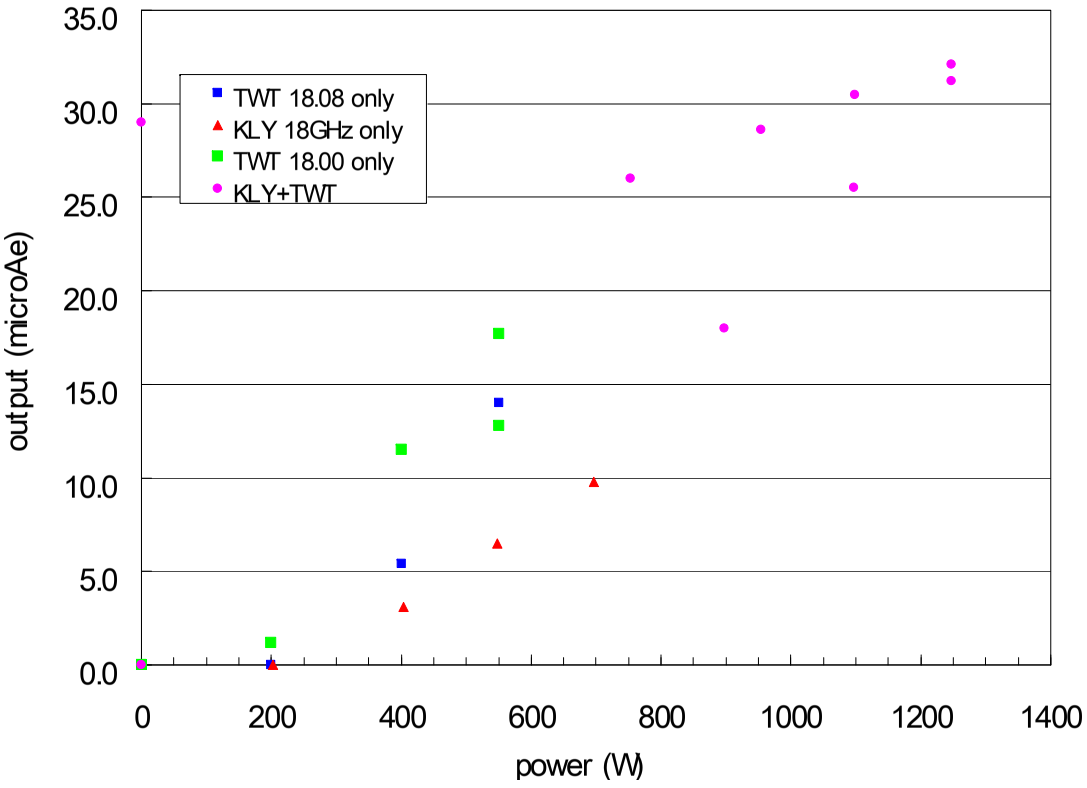
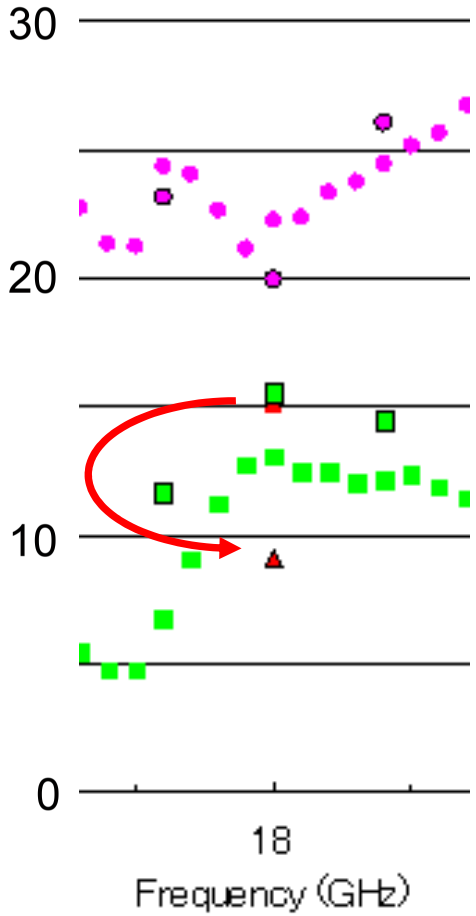
Dependence on microwave power by two frequency heating





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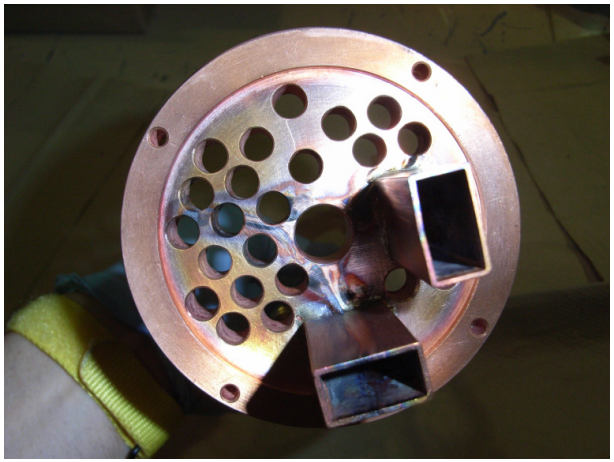
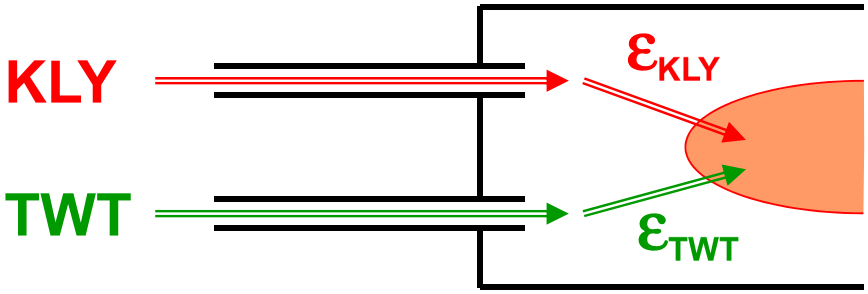
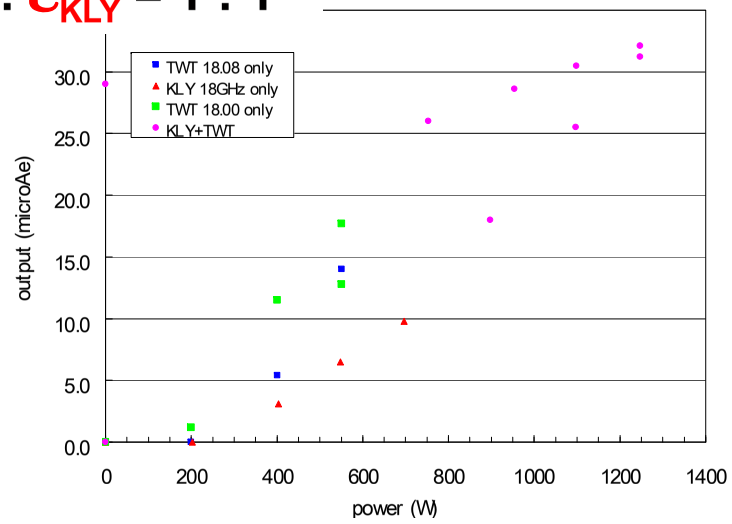
Microwave coupling efficiency

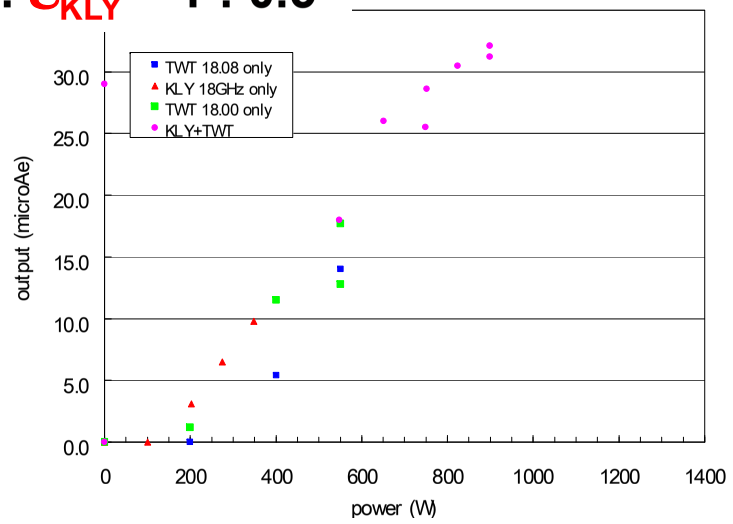




$\varepsilon_{TWT} : \varepsilon_{KLY} = 1 : 1$



$\varepsilon_{TWT} : \varepsilon_{KLY} = 1 : 0.5$



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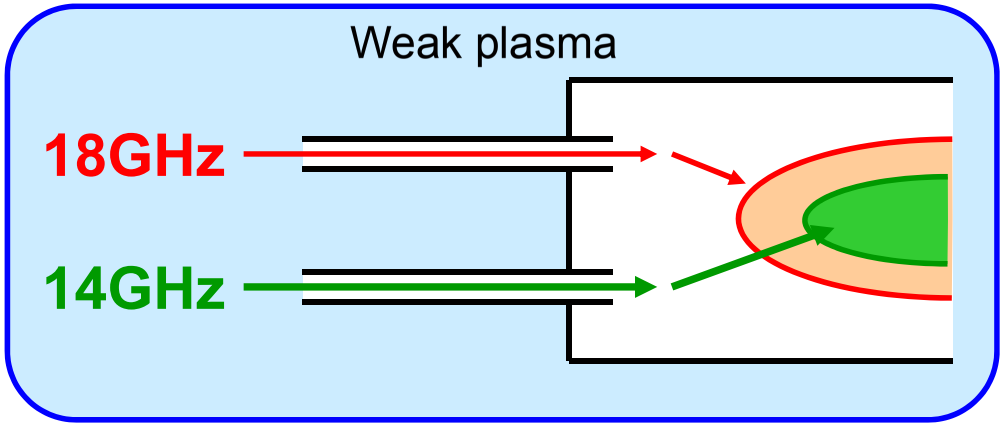
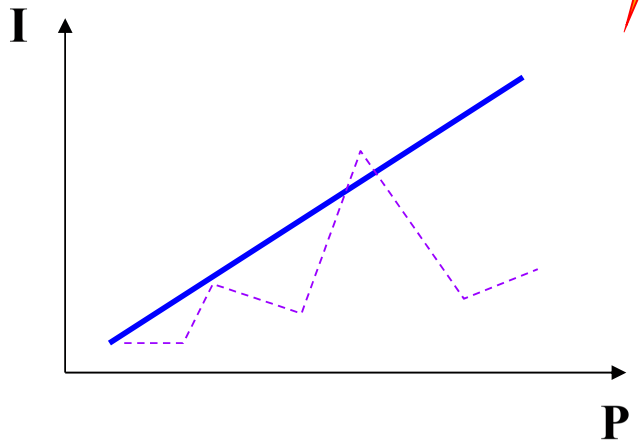
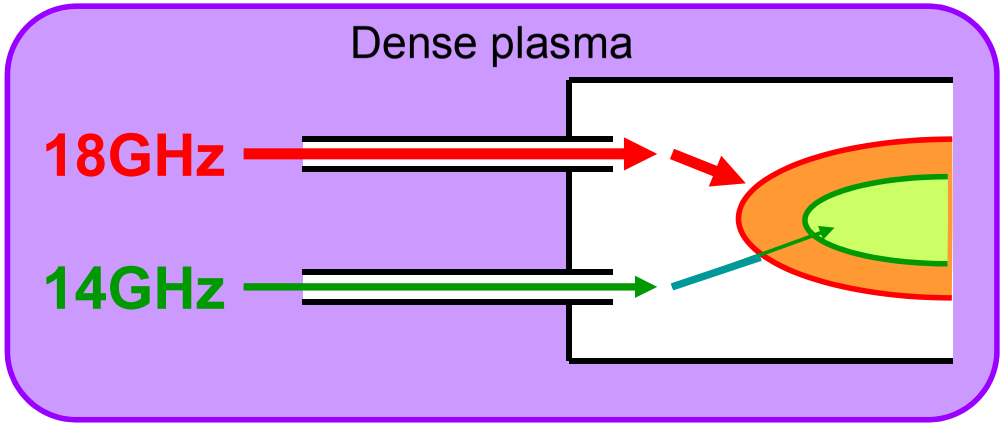
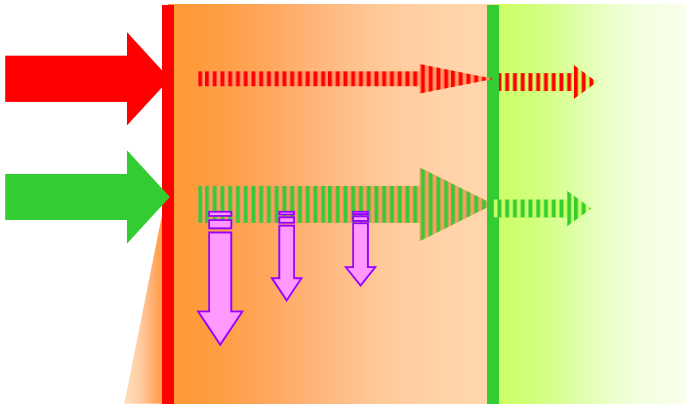
Interference between two microwaves









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Development of high power TWT amplifier

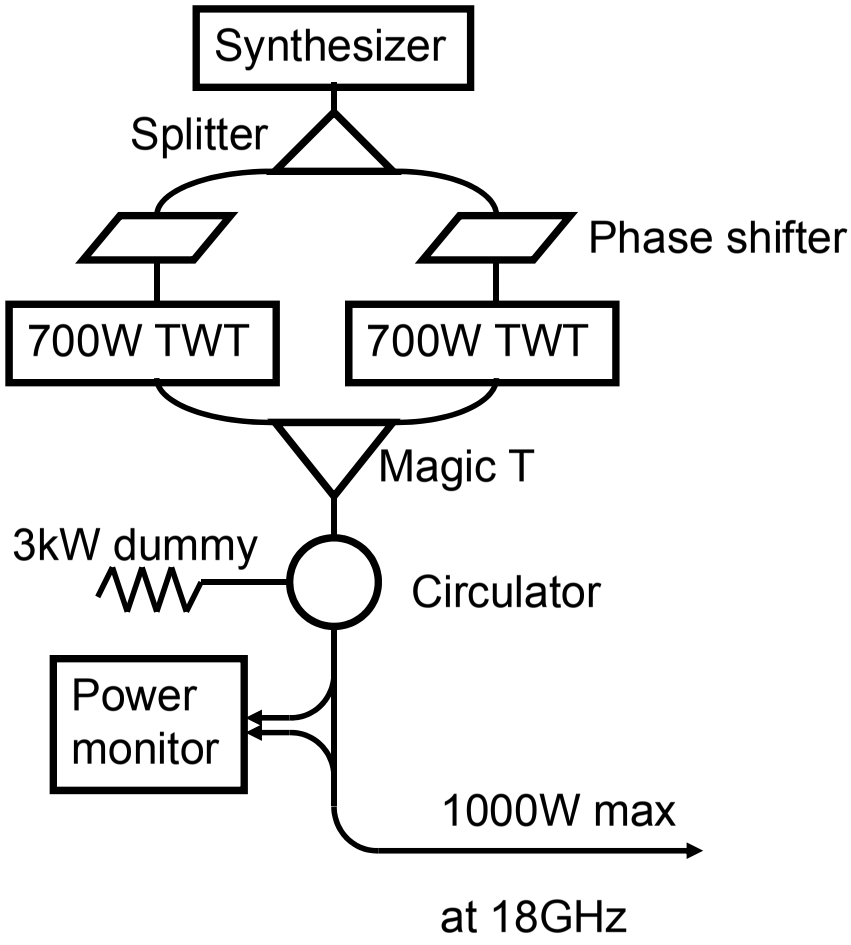
Target specification

Band width: 17.2 ~ 18.4 GHz

Power: 1 kW at 18.0 GHz

Block diagram

Combined two TWT



Schedule

Installed in May 2013