- Aerospace Industry
- Steel Industry
- Agro Industry
- Paper and Packaging Industries

Kerone Research & Development Center (KRDC)

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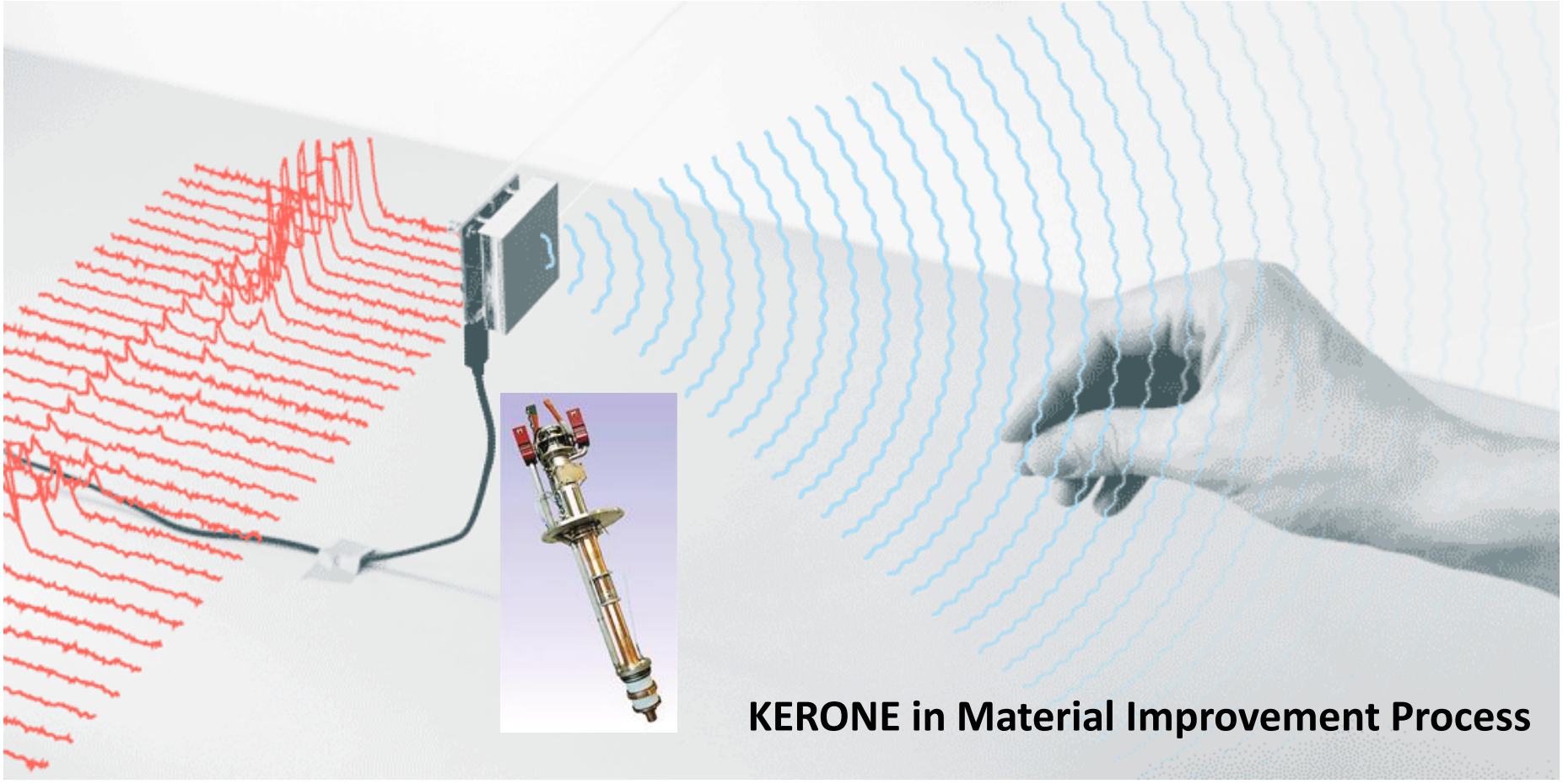
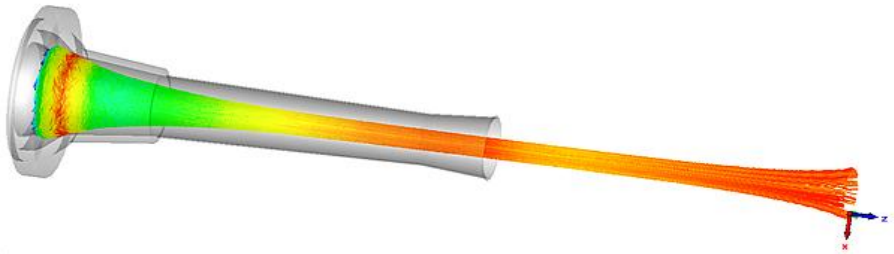
‘mm’ Wave Processing by Gyrotron



This presentation has been prepared as a proposal of KERONE millimeter wave Processing Concept for "NIKE Incorporation, USA"



Accreditations

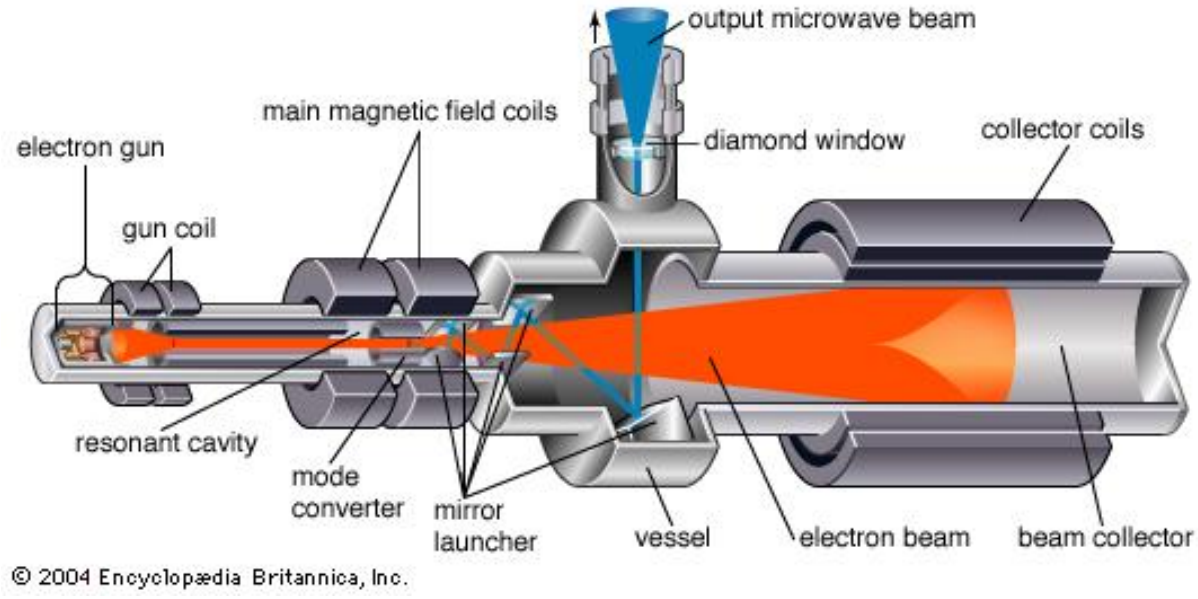
Member of AIMCAL	Member of IHEA	Strategic Partners of Emitech Italy	Member of ICT
Recognized and Rated by CRISIL	CRISIL Verified	Member of A.M.P.E.R.E. (Europe)	ASCB(E) Certification for Best practice

ISO 9001:2008 | ISO 9001:2015 | OHSAS 18001 | EMS 14001

Technical Requirements

Minimum Technical Requirements	
Frequency	28 Ghz
Power	20 kW
Oven opening height and width	36" x 16"
Tool weight oven needs to accommodate	250 lbs
Tool size oven needs to accommodate	26" x 30"
Centroid of mirror to top of tool	36"
Height from ground to top of tool when placed in oven	36.5"

Gyrotron – A signature Device for mmWave Generation



Low Frequency Gyrotron (24-28 GHz)

Courtesy : Gycom, Russia

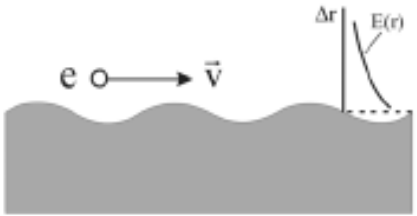
Why Gyrotron (- A Fast-wave Device)?

Slow-wave devices :

for a wave to propagate in vacuum in the direction of an electron beam with the same velocity as an electron speed the wave should have an imaginary transverse wave-number

$$v_{ph} = \omega / k_z \approx v_{el} < c$$

Slow waves are localized near the walls of a circuit



High Ohmic Losses!

Wavelength Shortening – Increase of Ohmic Losses!

- **Any alternative to slow waves?**
- **Fast waves!**

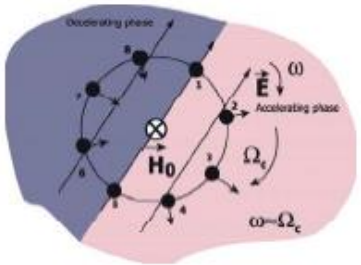
Theory and Principle (Interaction)

$$\omega - k_z v_z \approx s\Omega$$

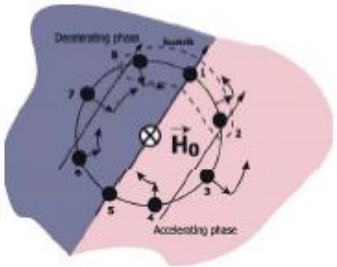
[Slow waves correspond to s=0]
In the case of non-zero s, electrons can interact with fast waves;
the condition of synchronism can be fulfilled when the phase velocity exceeds the speed of light!

$$v_{ph} \approx v_z + \frac{s\Omega}{k_z} > c$$

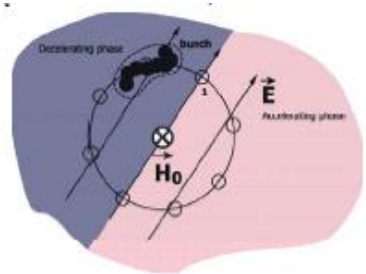
Beam-wave Interaction in gyrotrons



Electron energy modulation



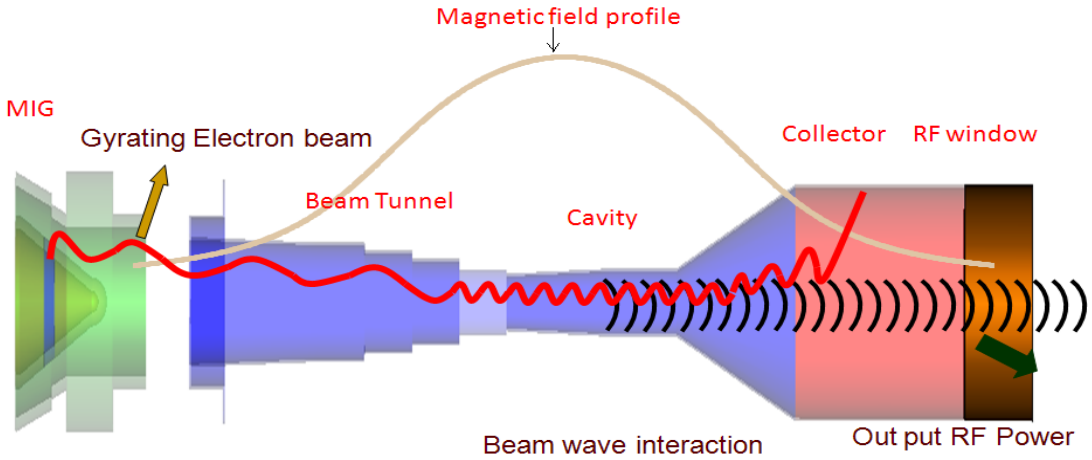
Electron orbital bunching caused by the energy modulation. When the wave frequency slightly exceeds the resonant cyclotron harmonic, the bunch is formed in a decelerating phase



Coherent radiation causes displacement of an electron bunch to the axis – electrons lose their orbital momentum

The interaction with TE-modes is stronger than interaction with TM-modes!

Major Components of Gyrotron



- The Electron Gun (Magnetron Injection Gun)
- RF Interaction Region (Resonant Cavity)
- Magnetic coils
- Collector
- Output Window

The Electron Gun

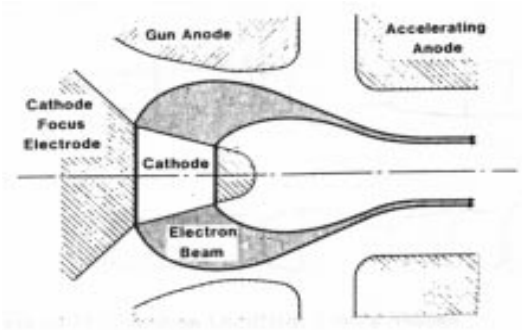
- To provide electron beam suitable for the beam wave interaction Electron Gun is the heart of any electron tube.
- the electron beam is emitted from the conical shaped cathode working on the principle of thermionic emission, which is based on the heating of an emitting surface to allow electrons to overcome the work function and escape up to the surface.
- The most common thermionic emitters are tungsten cathode, LaB_6 cathode, oxide cathode, dispenser cathode, scan-date cathode and thorium-based cathode

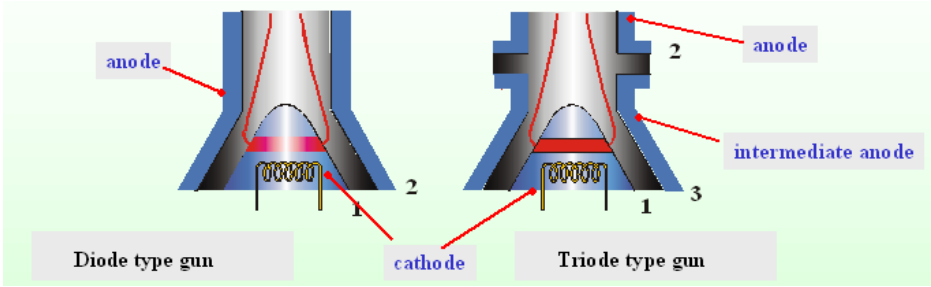
Types of Guns

Parallel Flow Electron Gun
Convergent Flow Electron Gun
Girded Electron Gun
Dual Mode Electron Gun
Convergent Hollow Beam Electron Gun (Magnetron Injection Gun)
Non-Convergent Gun

Magnetron Injection Gun (MIG) for a conventional Gyrotron

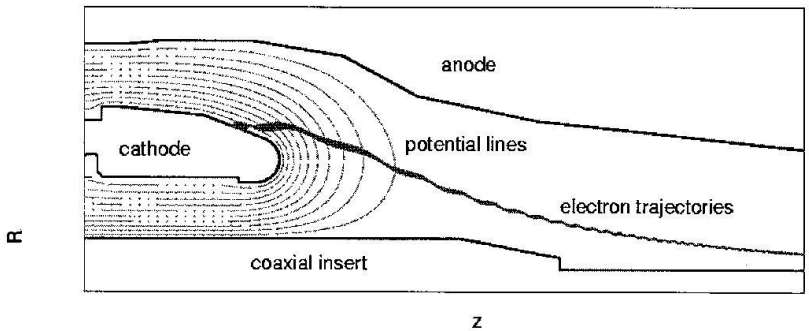
Electron beam source for co-axial gyrotron





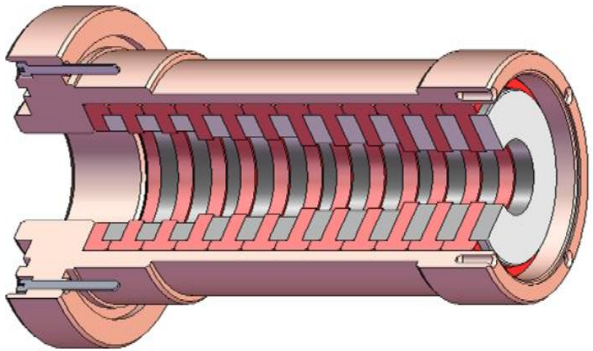
Dispenser type of cathode is usually preferred due to its better emission density, life and reliability

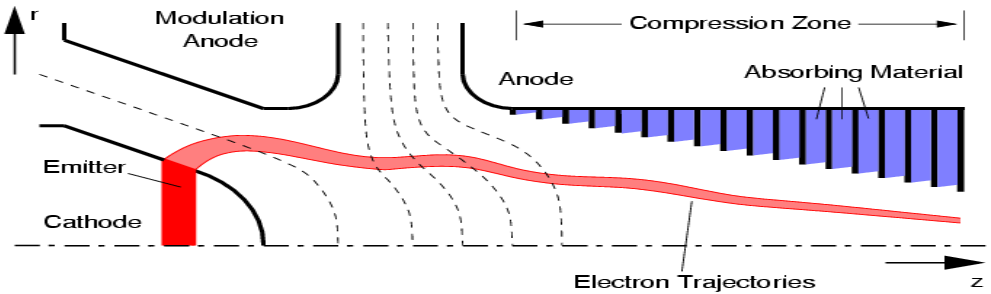
Geometrical configurations of MIGs



Beam Tunnel

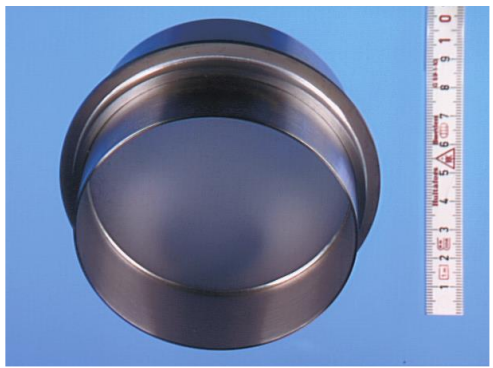
- It is highly required that all the generated power in the middle section of the interaction cavity should be reflected by the input tapper.
- Normally, it is found that about 3-5% of generated RF power returns into the MIG
- This amount of RF power is sufficient to degrade the electron beam quality in terms of increasing the velocity spread and the energy spread and even can damage the cathode used in MIG
- To protect the MIG from the backward propagated RF power, it is necessary to absorb this RF power as much as possible
- The beam tunnel is specially designed for this purpose as a circular waveguide type of lossy structure, installed between MIG and interaction cavity for the absorption of the backward propagated RF power coming from the interaction cavity





Output Window

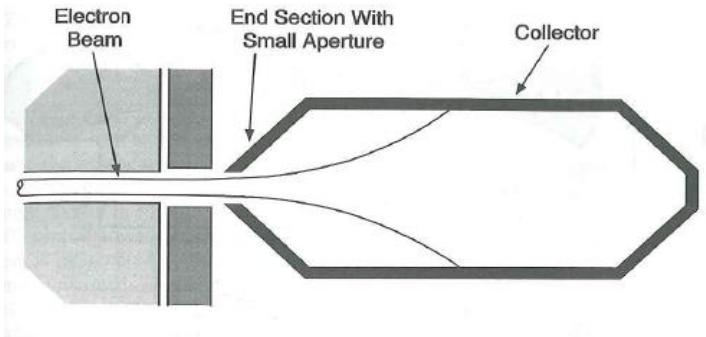
- The Gyrotron window acts as an outlet for the RF output power it is also used as a vacuum seal for the tube
- It must be fabricated from a low-loss material, which is also suitable for ultra high vacuum application
- For high power Gyrotron a temperature of 77˚K or lower is necessary to minimize the reflection.



Collector

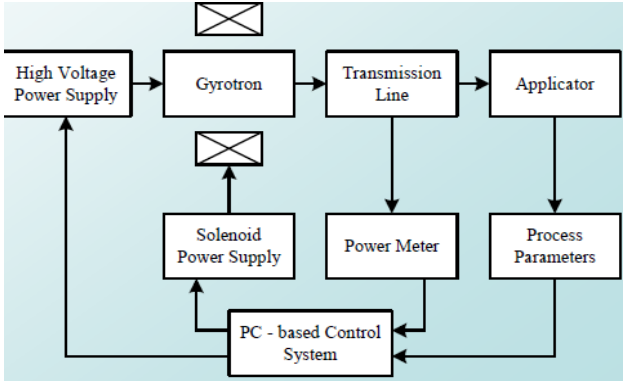
- Collector is one of the major components of Gyrotron to collect the spent electron beam and dissipate heat efficiently
- In collector, the kinetic energy remaining in the spent beam after participating in the interaction process is converted into electrical energy
- The energy of the beam is distributed up to certain region instead of collecting at one portion in order to avoid melting of the collector surface.
- The wall loading for collector surface should not be more than 0.5kW/cm^2

2.2 MW, CW collector

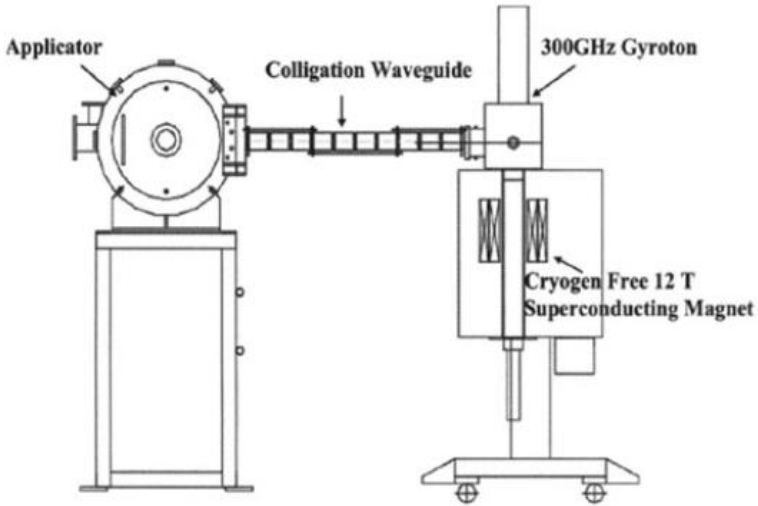


Material Processing System with Gyrotron Tube

- 24 GHz or 28 GHz, MW Power, the source of the mm-wave power
- A transmission line for transport of mm-wave power to an applicator
- An applicator of volume of X litres for operation in the 10-15 x 10^5 Pa pressure range, equipped with changeable mirrors
- A temperature diagnostics and Pc-based control subsystems for automatic/modes of processing
- A set of power supplies
- A microprocessor–based unit maintaining failure free performance of the system

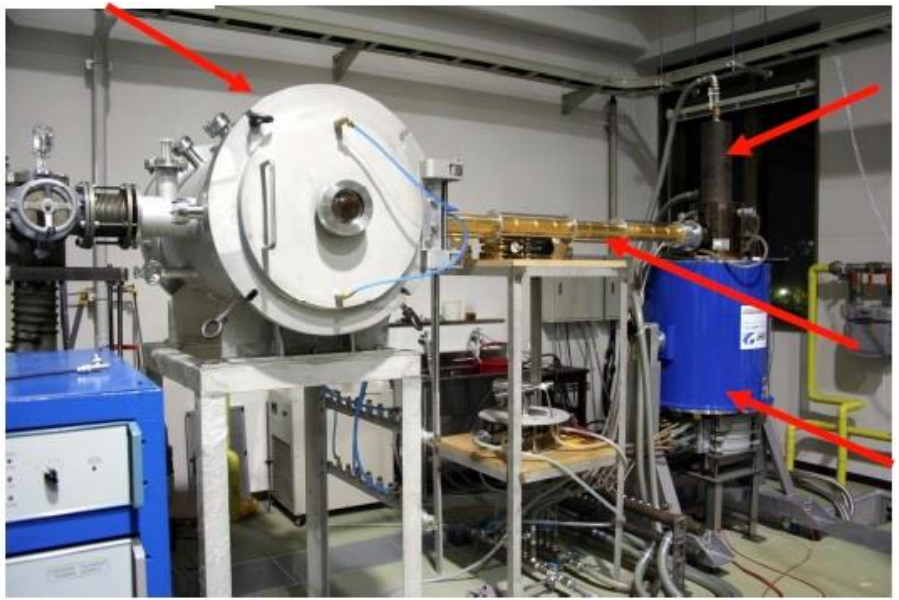


Gyrotron – A signature Device for mmWave Generation



Gyrotron and applicator system

Applicator

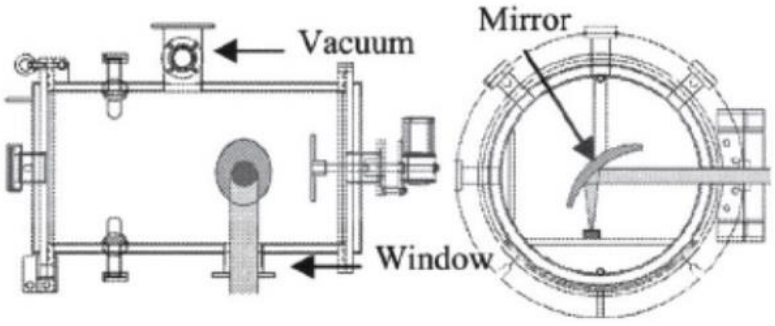


300 GHz (CW) Gyrotron

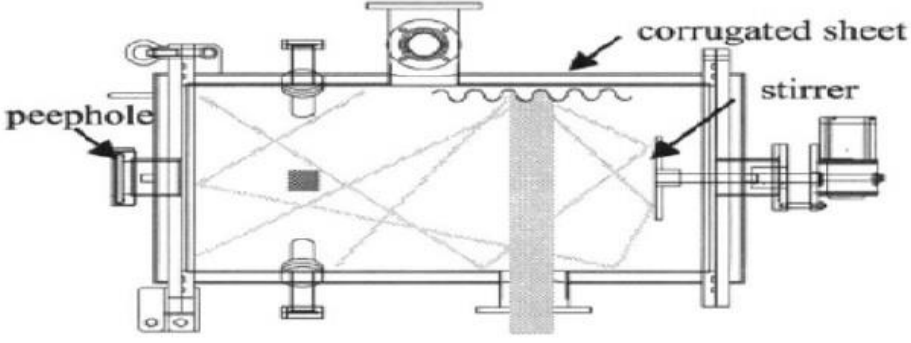
Corrugated Waveguide

12T Cryo-free SC magnet

Courtesy : Fukui Univ, Japan



Applicator with focusing mirror for surface heating

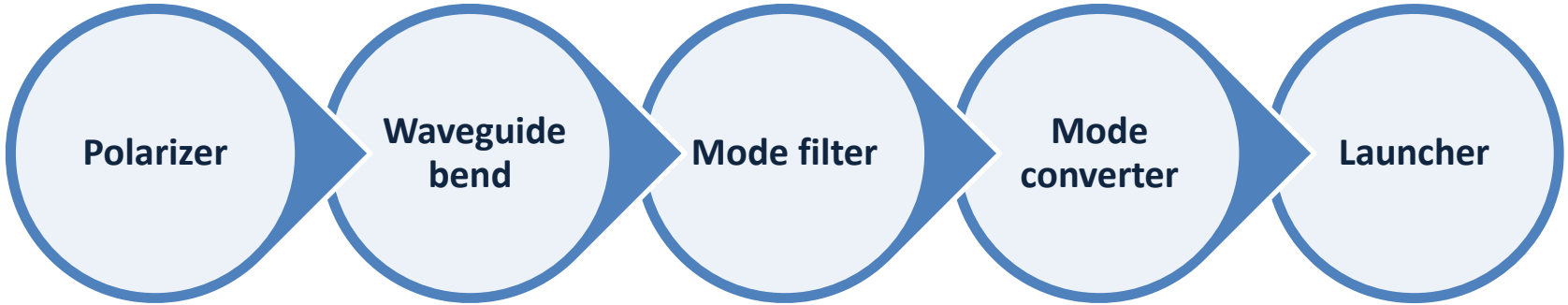


Applicator with focusing mirror for volumetric heating

Transmission Line and Microwave Applicator

The out put mm-wave power is transmitted from gyrotron to the applicator through a transmission line built up of the oversized circular waveguide components .

Transmission line components:



The mode filter :
Protects the gyrotron against the microwave power that can be scattered back from the applicator.

The mode filter is cooled with flowing water and furnished with a set of temperature sensitive elements and calibrator, which allows measuring the back-scattered microwave power.

Transmission Line /Wave guide Components

- Oversized transmission line (a >>λ) made as a set of quasi-optical mirrors, **multimode waveguides** and often their combination (**DC breaks 20-60 kV**)
- Efficiency of the millimeter-wave power transport through lines is normally 0.95-0.98.
- Design of a transmission line depends on the trajectory, functions and field structure a customer wants to have in the applicator.

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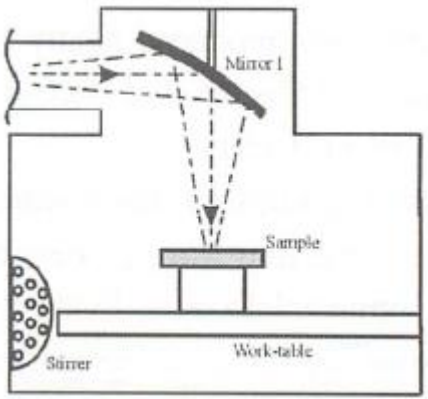
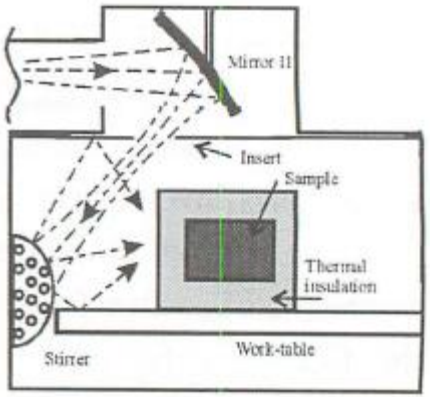
The mode converter :

Transforms the operating mode of gyrotron, TE11 into a quasi-gaussian wave beam , the wave beam illuminates the surface of a mirror that is installed in the upper part of the applicator

Gaussian beam: modes are solutions to the paraxial wave equation such that the form of the mode(intensity distribution) does not change with propagation. They constitute a very convenient basis set of fields with which to simulate the behavior of propagating beams in quasi-optical systems.

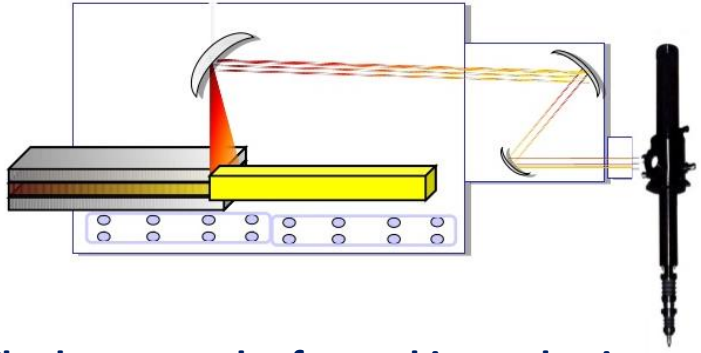


Surface Heating

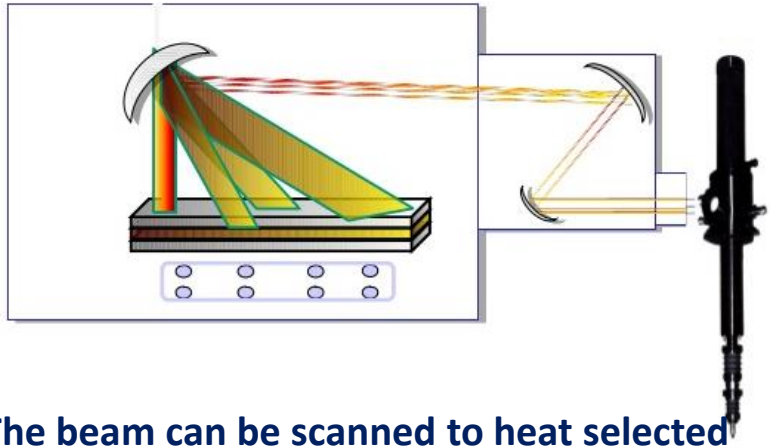


Volumetric Heating

Heating Option- Ribbon & Scanning



The beam can be formed into a horizontal or vertical ribbon shape and product can be moved relative to the stationary beam

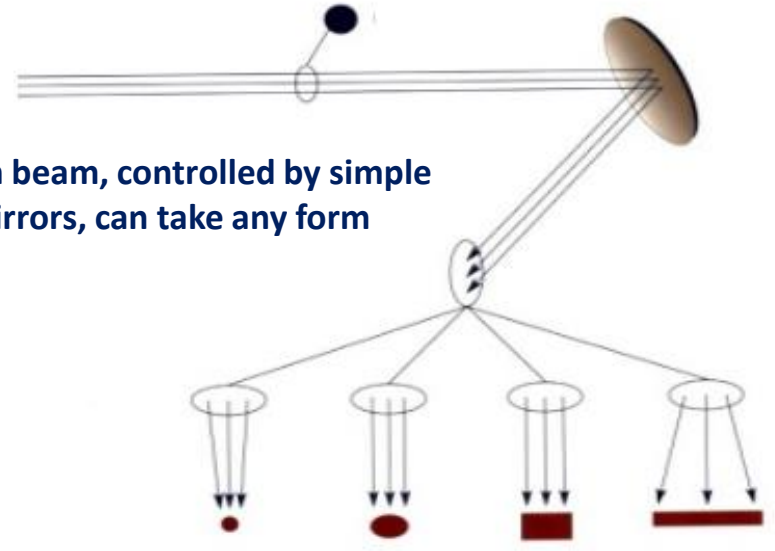


The beam can be scanned to heat selected areas to selected temperature using a configuration of moving mirrors

Gyrotron Beam

The beam can be shaped into any form- circular, strip, square etc by using simple metal mirrors, greatly increasing processing possibilities

0.3''- 0.5'' in diameter



The gyrotron beam, controlled by simple metal mirrors, can take any form

By using simple metal mirror

By using special focusing system

Gyrotron designed specially for industrial applications

Manufacturer	IAP	Varian (CPI)	Mitsubishi
diameter- to - the wavelength ratio			

Questionnaire & input parameters for Applicator

Electron Beam Parameters	From Customer	Remarks and other information , if any
Frequency (GHz)	28	
Power (kW)	20	
Efficiency (%)		
Voltage (kV)		
Beam Current(A)		
Cavity mode		
Magnet Power (kW)		
Efficiency with magnet(%)		

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Paints and Chemicals

Refineries

Foundries

Glass and Plastic

Automobile

Electronics

Industries we are serving cont…

Below are the few of industries/ Industrial applications we are serving :

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Ceramic Curing	Printing Ink Drying	Curing of Coating on Moulds, Adhesive Drying.	Pre-drying of Dyed Fabrics	Textile Coating & Processing
Thermoforming	PVC Preheating	PVC Embossing	Vacuum Heating Equipments	Heating of PET Perform
Oil & Gas Industries	Food Processing	Pharma Industries	Oil and Gas	Plastic Annealing and Welding

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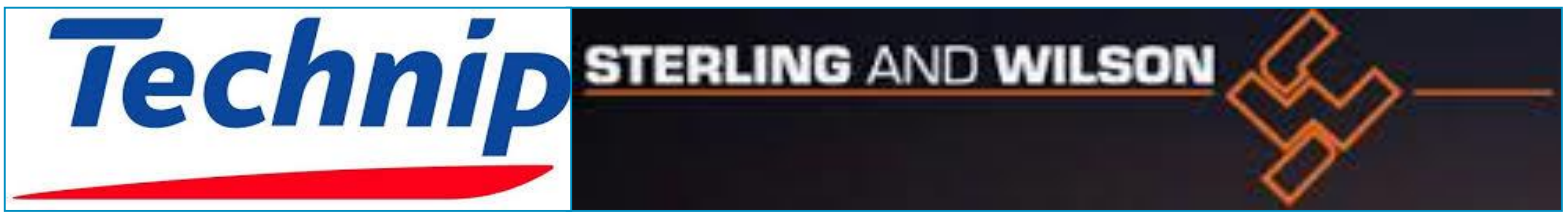

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