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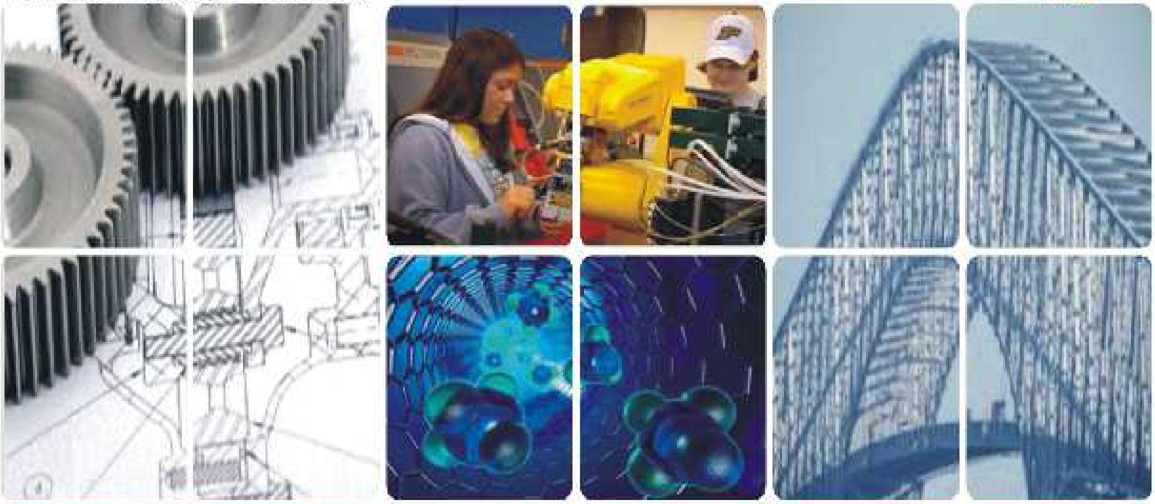

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AN EFFECT OF PLASMA PHYSICS IN HIGH POWER MICROWAVE MODULES AND TERAHERTZ DEVICES

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Declaration

The Declaration of the authors for publication of Research Paper in The Indian Journal of Research Anvikshiki ISSN 0973-9777 Bi-monthly International Journal of all Research: We, *Ram Gopal Sonker, Anand Gandhi Patel and Vikas Mishra* the authors of the research paper entitled AN EFFECT OF PLASMA PHYSICS IN HIGH POWER MICROWAVE MODULES AND TERAHERTZ DEVICES declare that , We take the responsibility of the content and material of our paper as We ourself have written it and also have read the manuscript of our paper carefully. Also, We hereby give our consent to publish our paper in Anvikshiki journal , This research paper is our original work and no part of it or it's similar version is published or has been sent for publication anywhere else.We authorise the Editorial Board of the Journal to modify and edit the manuscript. We also give our consent to the Editor of Anvikshiki Journal to own the copyright of our research paper.

Abstract

The authors have proposed introducing a micro pulse power technology in high power plasma experiments to boost up the return current, resulting in efficiently guiding of energetic electrons. The high current pulse power generators with a pulse trigger system generate high-density plasma that is well conductor. The plasma filling has been credited with increasing the electron beam current, bandwidth, efficiency and reducing or eliminating the need for guiding magnetic fields in microwave sources. The Neutralization of the e-beam space charge by plasma enhances the current capability and beam propagation, and the generation of hybrid waves in plasma-filled sources increases the electric field on axis and improves the coupling and efficiency. Control of the plasma density in these microwave sources is often required to avoid instabilities and variations in the output power level and pulse length. Nonlinear properties of the electron plasma in the transistor channel can be used for the detection and mixing of THz frequencies. At cryogenic temperatures resonant and gate voltage tunable detection related to plasma wave resonance is observed. At room temperature, when plasma oscillations are over damped, the FET can operate as an efficient broadband THz detector. We present the main theoretical and experimental results on THz detection by FETs in the context of their possible application for THz imaging.

Keywords: High power microwave devices; Terahertz Devices, Microwave generation; Plasmonics, microwave measurements; Electron beams; Noise measurements; microwave tubes.

1.Introduction

In 1885-1889 Heinrich Hertz, generation and study of radio waves and confirming Maxwell's Theory. On other hand Tesla proposed radio wave radar in 1917. During 1920-1940 US, UK, France, and Germany developed radar for ship & aircraft navigation and enemy plane detection. Microwave radar using UK-invented, US-improved (MIT Rad Lab)

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and US-manufactured high power magnetrons enabled efficient airborne radar to detect U-boat periscopes, anti-aircraft gun defenses, UK radar jammers, and provided air superiority to UK in WWII.

The new research has demonstrated that the presence of a controlled amount of plasma inside microwave sources can, in many cases, dramatically improve the tube performance compared to vacuum devices.

Here we will not attempt to describe a long history of the development of plasma filled microwave sources, which was recently overviewed during the 1990's. Plasma filling has been used in a variety of sources, including backward wave oscillators (BWO), traveling wave tube (TWT) amplifiers, gyrotrons, and other high power microwave tubes, to increase the overall efficiency, gain, frequency bandwidth, maximum electron beam current, and in some cases to reduce or eliminate the need for guiding magnetic fields. These advances are critically important for the development of frequency agile microwave systems where size and weight are important. Some of the fundamental aspects of plasma filling of TWTs and BWOs were reviewed in a recent paper. Plasma filling of high power microwave sources can provide distinct advantages, provided that the plasma density is controlled and properly implemented.

The design and fabrication challenges that must be overcome to improve the performance of these devices are assessed, and this informs the development of an ultra-violet (UV) lithography and physical vapour deposition (PVD) process for the fabrication of 4x4 mm2 inverted high electron mobility transistor (HEMT) devices with an 800 nm periodic (400 nm stripe + 400 nm gap) coupling grid on a GaAs/AlGaAs substrate. Dot arrays, diffraction gratings, and perforated thin films are fabricated to develop a best practices approach; theoretical considerations to their plasmonic properties are discussed. A 2D asymmetric finite element model is developed to calculate the electric field distribution and current in a gold Hall-bar in an applied electric and orthogonal magnetic field using Maxwell’s equations.

The development of future applications requires fast circuits and devices. The frequency range is of few hundred Gigahertz to Terahertz, for applications such as the radio astronomy, the earth observation (satellite), high bit rate communications, medical and security imaging’s …For these applications a new way is the ballistic transport of electrons. The ballistic nano-devices are studied since the 2002, at IEMN. Their mode of functioning is based on the fact that it is possible to decrease electron interactions by defining dimensions lower than the mean free path, which is for example for GaInAs material of the order of 100 nanometers at room temperature. In a ballistic or quasi-ballistic device, electron scattering is reduced. This allows to reach very high speed and so transit time very short (few 0.1ps), which augur of THz operation. The studied devices are "Three terminal Ballistic Junctions" (TBJ), which present pronounced non-linear effects. The non-linear behavior of these devices can turn out interesting for "rectifier", "frequency doubler ". Another mode of functioning can be obtained by placing deliberately an obstacle on the ballistic path of electrons. In that case, it is possible to modify the ballistic path of electrons. An example is given figure 1,2 &3, where a gate was added to a TBJ. According to the potential of the gate, it can be possible to deflect the flux of electrons of a branch towards another branch.

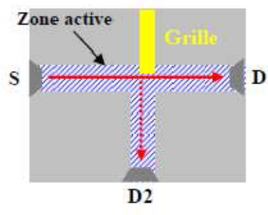

Figure 1 Top view of TBJ with gate

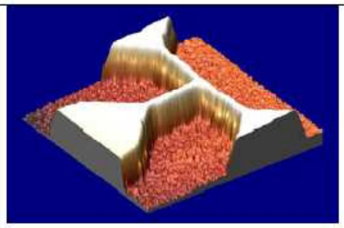

Figure 2 Atomic Force Microscopy of TBJ. Branch width defined by Mesa etching is 100nm.

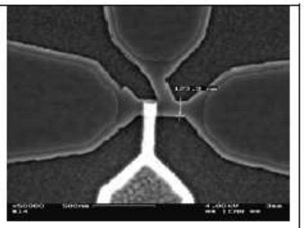

Figure 3 TBJ with gate. Branch width is 120nm.

2.About Plasma Physics

Plasma physics is a relatively new branch of physics that became a mature science over the last half of the 20th century. It builds on the fundamental areas of classical physics: mechanics, electrodynamics, statistical mechanics, kinetic theory of gases, and fluid mechanics. The distinguishing feature of the plasma medium is that its properties are determined by the nature of the interactions between the charged particles in it collective rather than binary and weak compared to their thermal motions.

Plasma is often called the fourth state of matter. The various states of matter occur as a substance is heated to temperatures above the binding energies for particular states of matter and thereby undergoes phase transitions. As an example, consider the states of H20 and its molecular, atomic and elementary particle constituents at various temperatures, as indicated in Fig. 4. Below 273 K (*0.0235* eV) it is in a crystalline form known as ice (a solid), the first state of matter, which is a strongly coupled medium (binding energy large compared to thermal energy). At temperatures between 273 K and 373 K the crystalline bonds are broken, but large scale molecular structures exist and H_2O is called water (a liquid), the second state of matter, which is also a strongly coupled medium. At temperatures above 373 K (0.032 eV) the long-scale molecular structure bonds are broken and the independent H_2O molecules form a gas, which is commonly known as steam. Upon further heating to a temperature of the order of the molecular binding energy (0.3 eV), the molecules dissociate into independent hydrogen and oxygen atoms. While this is no longer steam, it is still a gas in which the elemental constituents (H_2 and O_2) are electrically neutral. This third state of matter is a neutral gas, which is a weekly coupled medium (on average), interactions between particles are weak, compared to their thermal motions.

The science of plasma physics draws heavily on many areas of classical physics and applied mathematics. Typically, not all of these subjects are well known to the wide variety of students (from physics, engineering physics, electrical engineering, nuclear engineering and other undergraduate curriculam) who begin studies of plasma physics. Also, most of the needed background material is not readily available in concise, accessible forms. Two new promising concepts of plasma-filled microwave devices were suggested and successfully realized. The first concept is based on the use of hybrid modes, which can be formed in plasma-filled slow-wave structures (SWS) by superposition of the plasma waves and slow waves of the SWS. These two sorts of waves become coupled when their phase velocities are synchronized and also their transverse structures overlap. The use of this concept has led to substantial increase in the gain and bandwidth of coupled-cavity traveling-wave tubes.

The second concept was suggested and pursued at Hughes Research Lab, where the devices named PASOTRONs (this acronym stands for Plasma-Assisted Slow-wave Oscillators) were invented and successfully developed. Pasotrons are unique devices, in which the electron beam propagation through the interaction space is provided not by solenoids or magnets, as in conventional microwave tubes, but by ions, which compensate for the radial beam space charge force, and thus, cause the effect known as a Bennett pinch. The absence of the guiding magnetic field makes a number of interesting effects possible in PASOTRONs.

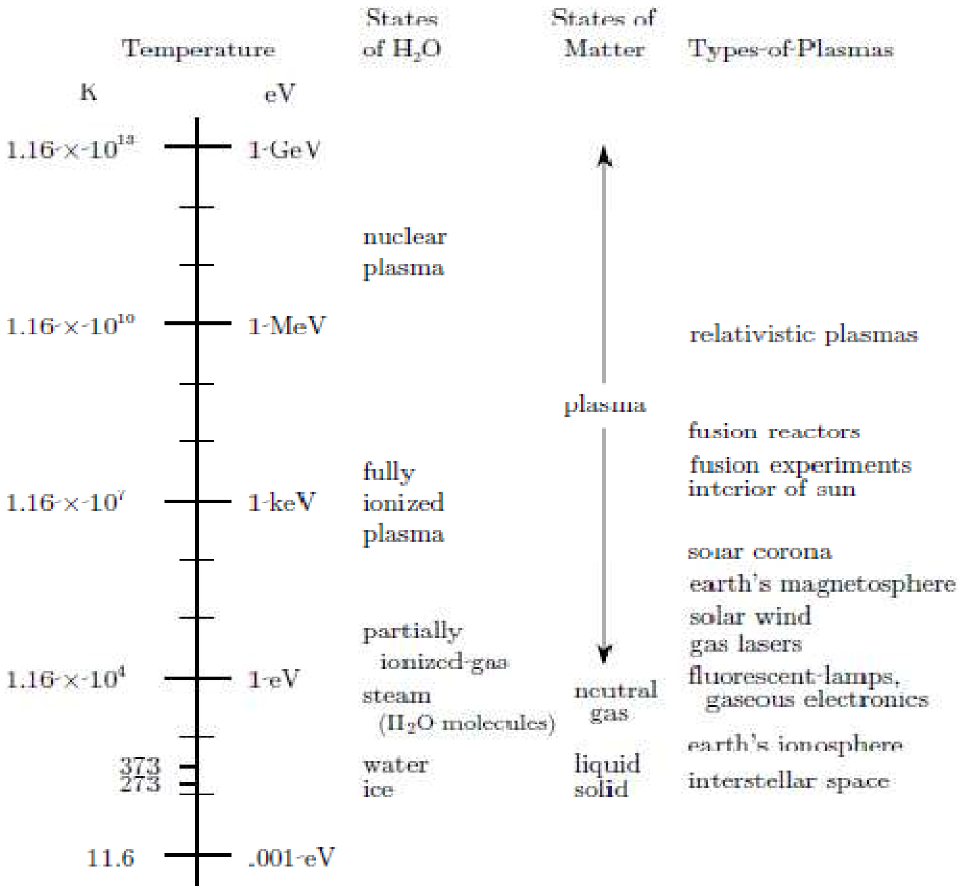

Fig.4-Schematic of states of H_2O as it is heated. Also shown are the corresponding states of matter and some of the types of plasmas that can occur in the various temperature ranges indicated.

1.Plasma Filled Microwave Sources Technology

a.Plasma electron guns with Microwave Modules

In this case, plasma is generated in an enclosed volume, and electrons are extracted from one boundary of the plasma and accelerated to form the beam. The Hughes Plasma-Cathode Electron-gun (PCE-gun) was developed for the plasma-filled PASOTRON. This type of gun utilizes a low pressure noble-gas plasma discharge as the source of electrons, and a high perveance, multiaperture grid structure to extract and accelerate the electrons to form a beam. The PCE-gun controls the plasma density in the source to eliminate plasma closure of the accelerator gap. In addition, the multiaperture grids generate high perveance *e*-beams because the purveyance of each aperture is summed in forming the final beam. Two versions of the PCE-gun have been developed for different applications. The source of electrons in the gun is allowing pressure plasma discharge between a cathode structure and the first grid of the accelerator, which acts as the discharge anode. This grid is semitransparent, and electrons that are not collected by the grid structure enter the accelerator region. In this region, the plasma-discharge anode acts as the accelerator cathode-electrode by effectively ‘‘emitting’’ the electrons obtained from the plasma. The accelerator anode is a second grid with apertures precisely aligned with the apertures in the cathode grid. The potential difference between the grids is provided by a dc power supply.

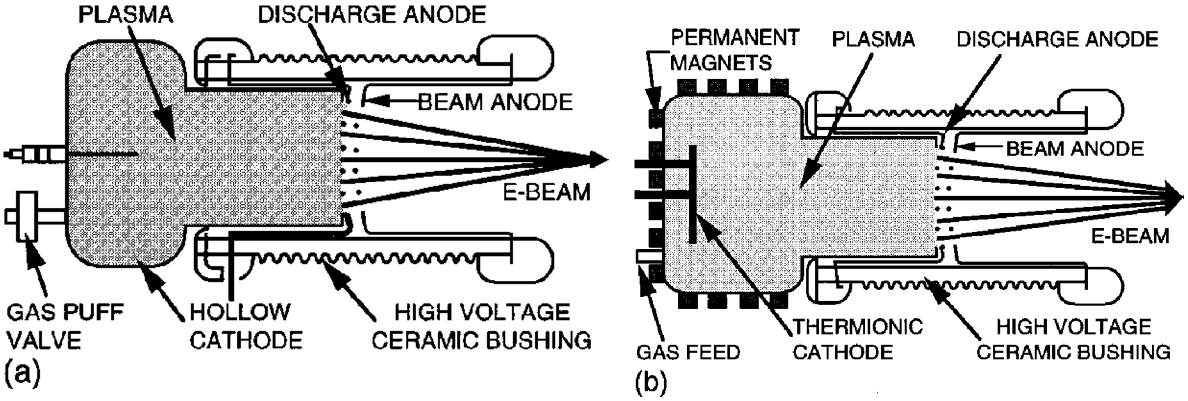

Fig.5- Plasma-cathode electron gun, gas-puff plasma generator (a) Low-pressure thermionic-discharge Plasma generation (b). Multiaperture high-perveance accelerator.

For low pulse-repetition frequencies (PRF) or single pulse operation, the gas-puff PCE-gun was developed. This gun, shown schematically in Fig.5 (a) utilizes a low-pressure (5–50 mTorr) glow discharge generated between a metallic hollow cathode and the discharge anode, and a transient gas puff to maintain a sufficiently low pressure in the tube for microwave generation. This gun has generated pulses of up to 1 kA at 200 kV for a duration in excess of 100 ms. For high PRF operation (>10 Hz), the thermionic-discharge PCE-gun shown schematically in Fig.5 (b) is used. The plasma-generation enclosure is surrounded by a permanent magnet array to provide confinement of the primary electrons emitted by the thermionic cathode in order to increase the ionization efficiency. The discharge cathode can be a Ba-oxide dispenser cathode, a lanthanum hex boride cathode, or a simple tungsten filament cathode.

Another technique to deal with plasma in the e-gun region is to utilize a very rugged cathode material and minimize the gas pressure and plasma generation near the gun region to reduce the ion bombardment to acceptable levels. Researchers have developed a differentially pumped lanthanum hex boride (LaB6) cathode electron gun for use in a plasma-filled TWT. In this case, a disc of LaB6 is heated from behind by an electron-bombardment heater. The gun utilizes standard focusing and anode electrode structures to form the beam. A pump arrangement is installed at the gun exit to reduce the pressure by up to two orders of magnitude between the SWS and the cathode to minimize ion generation in the gun. This gun has continuously produced 3A of beam current for 5000 h to date at a voltage of about 22kV without degradation due to the beam-produced plasma in the SWS. Researchers at the University of Maryland15have installed a unique arrangement of shields suitable for pulsed operation that block the plasma injected by a plasma-gun into their BWO SWS from reaching the cathode. This is illustrated in Fig.6. (a) in which a plasma-confinement shield in the collector and an on-axis plug near the gun shield the accelerating gap from plasma penetration during the pulse and protect the ring-cathode from ion bombardment. This configuration successfully eliminates changes in the gun current during the pulse caused by ions in the cathode gap. In addition, the cylinder in the collector keeps the microwave power generated in the SWS from reaching a local cyclotron-resonant absorption region in the collector region, which increases the output power and efficiency.

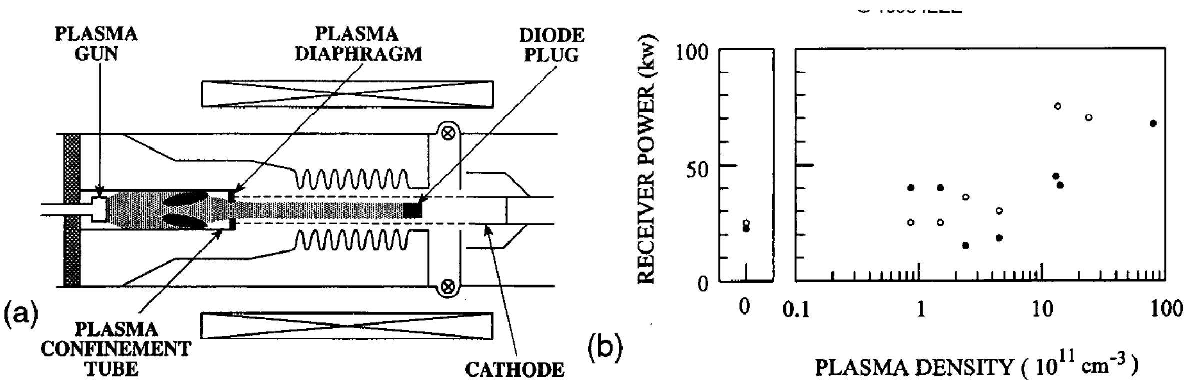

Fig. 6- The modified UMD BWO in (a) showing shields used to minimize plasma in the gun and eliminate a resonant absorption in the output. Increasing the plasma density in the SWS injected from the plasma-gun in (b) improves the efficiency by a factor of 3 without modifying the electron-gun parameters.

Additional investigations of optimal ways to generate and confine plasma in the desired regions of their sources resulted in further improvements in the performance. Figure 6 (b) shows the dependence of the output power from the shielded-BWO in Fig. 6 (a) vs the plasma density in the SWS. The presence of the plasma did not affect the beam parameters, indicating negligible plasma in the diode region, and injection of plasmas with densities of >**10^{12} cm^{-3}** increased the efficiency by a factor of 3 compared to the vacuum performance.

b. Microwave sources designed with plasma filled

A unique plasma filled source, called the Plasma Wave Tube was designed to utilize this effect to produce broadband radiation from compact package. As shown in Fig. 7(a), the electron beam from the PCE-gun described above is injected into smooth-bore cylindrical waveguide. The background gas pressure of this sealed tube is controlled by a Zr–Al getter that is filled with hydrogen, which regulates the pressure of hydrogen in the system by its temperature and pumps most other gases that evolve in the tube with time. The beam first ionizes the background gas to create plasma, and then interacts with the plasma to generate forward and backward scattered electron plasma waves. The radiated power from this device was reported to have a wide instantaneous spectrum (1–10 GHz typical) and a center frequency that changes with time as the plasma density increases in the cylindrical waveguide. Control of the beam current and voltage provides the desired microwave output characteristics. This is illustrated in Fig. 7(b), where the output power level in the *X*-band is plotted beam current for several beam voltages at a fixed gas pressure. Increasing the current and voltage provides higher power levels, but at higher beam currents the frequency shifts rapidly above the *X*-band and the indicated power level falls. Broadband power levels of up to 10 kW (across the *X*-band) at efficiency of about 1% have been achieved with this device.

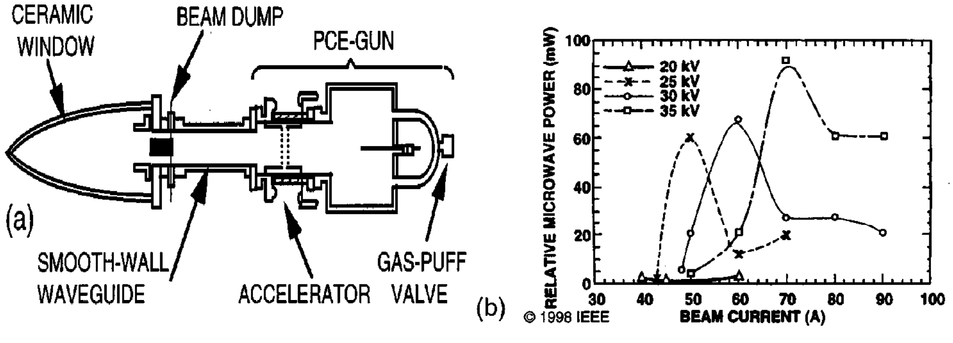

Fig.7- Schematic diagram of the Plasma-Wave Tube (a) that uses *e*-beam interaction with plasma waves in a smooth waveguide. The output power increases with beam power as seen in (b) but higher powers drive the frequency above the *X*-band range of the detector used in this figure.

The Pasotron High Power Microwave (HPM) source was designed to utilize plasma channel transport of the beam through a slow wave structure (SWS) to significantly reduce the size and weight in conventional linear High Power Microwave (HPM) sources by eliminating the need for the applied axial magnetic field. The Pasotron has an electron gun, slow wave structure (SWS) and output coupler/antenna similar to other linear-beam microwave tubes, but utilizes beam generated plasma filling the SWS to neutralize the space charge forces and transport the beam. The use of the PCEgunpreviously described eliminates the problem of back streaming ion bombardment from the beam generated plasma damaging the cathode.

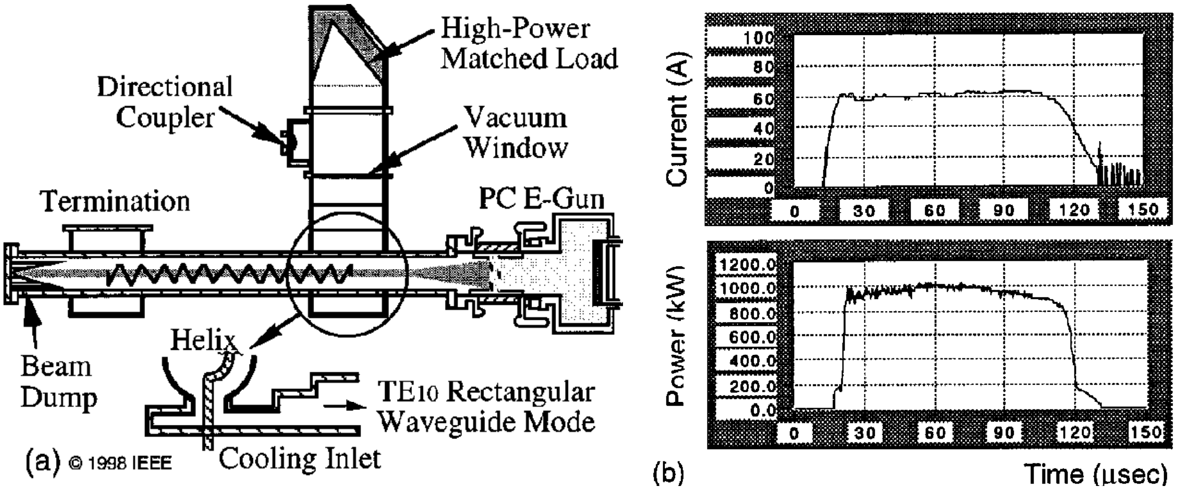

Fig. 8- Schematic diagram of the Pasotron HPM source (a) the helix SWS, output coupler, and waveguide load. This source produced the 1 MW, 100 ms pulse (b) at 54 kV, corresponding to an efficiency of 30%.

As above, the devices typically use an electron beam with energies of 50–250 kV, beam currents of 50–1000 A, and pulse widths of about 100 ms. RF power up to 20 MW has been obtained from the RWG BWOs, depending on the configuration and beam parameters. Recently, helical SWS have been used in the Pasotron to reduce the SWS size at low frequencies and increase the bandwidth and average power capabilities of the source. A unique output coupler eliminates breakdown at high power at the helix termination sand permits coolant to be passed through the hollow helix tubing for high average power operation. The configuration of the Helix-Pasotron7 is shown schematically in Fig.8 (a). Peak powers of over 2 MW have been achieved for 100ms at voltages of 50–100 kV and beam currents of 50–200A. A typical 1 MW peak output pulse from the Pasotron is shown in Fig.8 (b), where the gun was operated at 54 kV and the efficiency was 30%. Careful control of the beam generated plasma channel is required for reproducible, high-power operation of this device. In addition, the level of parasitic signals with plasma was found to be at least 50 dB below the carrier signal level, which was comparable to the vacuum performance of this device. It appears that any spurious ion noise or ion-driven side bands in this device were masked by the power supply or other pushing-factors in the tube, which often occurs in very high power devices. Ion noise can be an important issue in plasma-filled devices in some applications (radar and communications, for example), and must be examined further. For very low noise applications, additional techniques such as feed-forward correction circuits may provide additional reduction of ion noise and spurious signals.

c. Output power and stability in plasma-filled tubes

Depending on the characteristics of the device, excess plasma generation can also cause the coupling structures to approach cutoff or the beam to form instabilities which can degrade the output power level and pulse length. Plasma generation in microwave tubes has often been blamed for causing output power variations and pulse shortening. It is well known that plasma production in tubes causes ‘‘ion focusing,’’ which reduces the diameter of the electron beam compared to the hard-vacuum condition. It’s this effect that causes the reduction in beam space charge and permits plasma-channel transport of unmagnified electron beams discussed above to work. In TWTs, ion focusing effects from ‘‘gassy tubes’’ reduce the beam diameter and beam current intercepted on the helix and walls in both solenoid and Permanent Periodic Magnet (PPM) focused tubes. Small changes in the beam size due to plasma can have a dramatic effect on the coupling of the beam to the interaction structure and the rf output power of the tube. Forexample a 10% change in the beam diameter in a couple cavityTWT can cause a 3–6 dB reduction in the gain of the tube, which directly affects the output power of the amplifier.

4.Advantage of Plasma Filling of Microwave Sources

a. Increased beam current

The maximum electron beam current that can be propagated through a microwave device, assuming a sufficiently strong axial magnetic field is applied, is determined by the voltage depression in the beam from space charge effects. At sufficiently high currents, a virtual cathode forms in the beam due to electron space charge and electrons in excess of the maximum number are reflected back to the electron gun.

Plasma is effective in compensating for these space charge effects in high-current electron beams, which allows plasma filled devices to operate at beam currents much larger than the maximum current for vacuum tubes.1 The beam-plasma system achieves quasineutrality by establishing a potential relative to the wall that electrostatically ejects the slow plasma electrons, which leaves the ions to neutralize some or all of the beam-electron space charge. For example, the space charge limited current (in kilo amps) of a thin, hollow beam with a mean radius a propagating in a drift tube of radius *b* is

$$I=\frac{17[\gamma_0^{2/3}-1]^{3/2}}{[2\ln(b/a)][1-f]}, \qquad (1)$$

where γ_0 is the relativistic correction factor $[1-(v/c)^2]^{-1/2}$ and f is the neutralization fraction given by the ratio of the plasma ion density to the beam density.

b.Reduction in the applied magnetic field

The addition of plasma to the beam, either by injection from external sources or self-generation of a background gas by the electron beam, reduces the outward radial force in the beam by canceling some or all of the beam’s space charge. Plasma, therefore, can reduce the magnitude of the magnetic field needed to transport the beam.

It is simple to calculate3 to first order the reduction in the applied magnetic field due to the presence of plasma in a solid beam. For uniform electron beam propagation (i.e., stable equilibrium with laminar electron trajectorie), the amount of applied axial magnetic field must be

$$B_z \geqslant \frac{mc}{e}[2\omega_b^2\gamma_0(1-f-\beta^2)]^{1/2}. \qquad (2)$$

Where *Bz* is the applied axial magnetic field, *m* is the electron mass, *c* is the speed of light, *e* is the electron charge, β=vz /*c*, vz is the axial electron velocity, $\omega_b^2 = 4\pi e^2 n_b / m$, and n_b is the beam density. The percentage reduction in the required magnetic field is just the ratio

$$B_z(\text{plasma})/B(\text{no plasma}) = [(1-f-\beta^2)/(1-\beta^2)]^{1/2}. \tag{3}$$

A small amount of plasma results in a significant reduction in the required magnetic field. The requirement just mentioned of applying a sufficiently high magnetic field to counter the electron beam's radial space-charge force in order to achieve beam transport through the microwave generation region of the tube is also modified by the presence of plasma.

c.Increased power and efficiency

The first reported fast-wave device that benefited from plasma in the interaction region was a Russian gyrotron6 in 1978. A preionized plasma fill at an optimum density in this device resulted in an increase in the electron beam current by a factor of about 2, which was attributed to a ''compensation of the space-charge of the beam electrons,'' and an associated radiated output power increased by a factor of up to about 3.

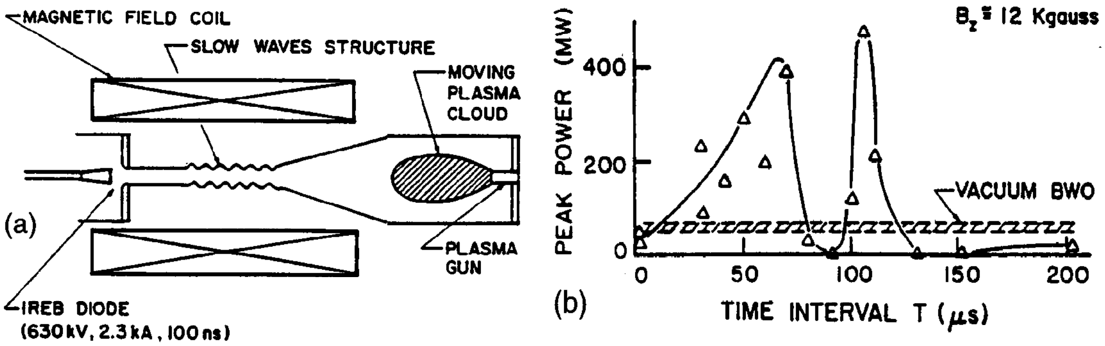

Fig.9- Schematic diagram of plasma-loaded BWO (a) output power vs time delay between plasma injector pulse and electron beam pulse (b) Efficiency increase is achieved at an optimum plasma density in the SWS corresponding to the time interval.

The most dramatic increase in efficiency and power due to plasma filling of a slow-wave device was published9 by Carmel in 1989. They reported a factor of 8 increases in the efficiency of the high power BWO shown schematically in Fig.9 (a) at an optimum plasma density, compared to the vacuum BWO under the same conditions. Fig .9 (b) shows the peak power output from their device as a function of the time interval between the plasma injection and the electron beam pulse, which determined the plasma density in the slow wave structure (SWS) during the beam pulse. At an optimum density, the fundamental TM01 mode radiation was increased significantly, while an excessive plasma density was observed to trigger mode competition.

Another effect that increases the efficiency of microwave sources that utilize slow wave structures is the generation of hybrid modes. These modes result from the coupling of slow plasma waves generated in the beam-plasma system with the slow electromagnetic structure waves. Therefore, the hybrid modes have a different radial profile of the RF electric field, which increases the axial component of the RF electric field and extends it to the device axis. This field geometry couples better to the interior electrons of a solid electron beam, resulting in increased power and efficiency. This is illustrated in Fig.10 (a), where the calculated radial profile of the axial RF field in a plasma filled dielectric waveguide model is plotted for vacuum and for plasma with a plasma-frequency equaling the operating frequency. In the absence of plasma, the field on axis is near zero. The finite plasma case shows a significant increase in the on-axis electric field due to the hybrid waves, which improves coupling to the beam. Likewise, Fig.10 (b) shows the increase in the calculated coupling impedance of a coupled-cavity TWT vs frequency with and without plasma. Since the gain of the TWT is proportional to the coupling impedance, the plasma filled TWT can be made significantly shorter and more compact for the same overall gain as the vacuum device.

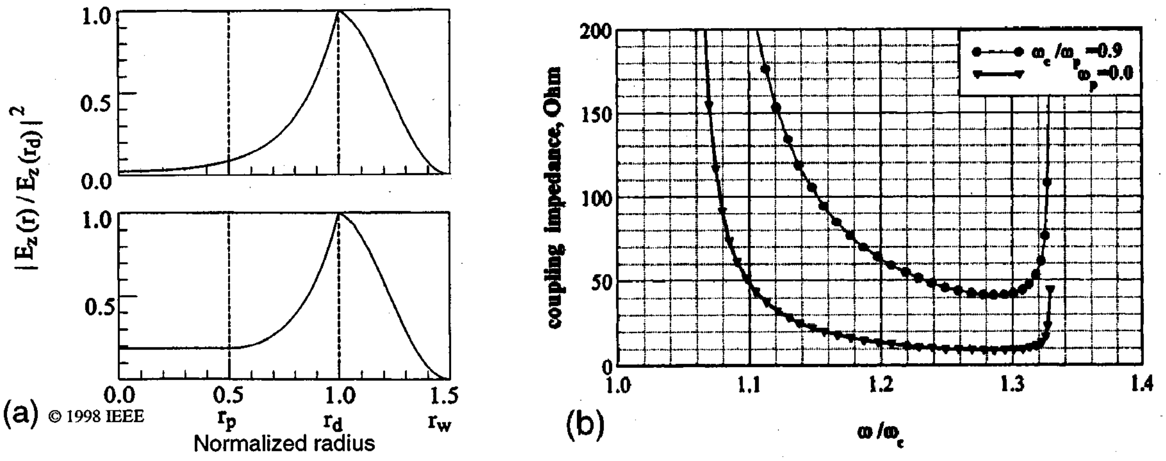

Fig.10- Radial profile of the RF electric field in a dielectric loaded waveguide (a) for vacuum and plasma filled conditions showing increased on-axis field with plasma due to the formation of hybrid modes. (b) also causes an increase in the coupling impedance, which improves the gain.

5. High-power Microwave

A Single-shot nanosecond duration high power microwave (HPM) pulses have been generated and characterized for various applications. HPM sources are being developed for applications in plasma heating, particle acceleration, high-power radar, and many other industrial and military fields. One of the crucial parts of the HPM system development is diagnosing intense single microwave pulses with powers greater than 100 MW and pulse widths between 5 and 100 ns. Gigawatt power HPM pulses have been generated by various devices. One among several types of pulsed high-power microwave generators is the virtual cathode oscillator (VIRCATOR). The VIRCATOR is considered to be very attractive due to its high-power capability, frequency tunability and device simplicity. In a VIRCATOR, an electron beam is emitted from a cathode and accelerated through a semitransparent anode. If the current exceeds the space charge limited current, a space charge (virtual cathode) forms behind the anode. The virtual cathode is unstable, and its oscillations can generate microwaves. Different experimenters have tried various techniques to measure ns pulse duration HPM power and frequency. Typically, the HPM power measurement is accurate within 20% (±1 dB), the pulse energy to within 20%, and the frequency to within 1% . These diagnostic techniques are not limited to use on any one type of HPM sources, but can be applied to a variety of HPM sources. For HPM power measurement the most widely used apparatus is the transmitting–receiving system. Transmitting–receiving systems are useful at high-power levels because all the HPM energy is broadcast into an anechoic chamber where a receiver picks up a known small fraction of the transmitted power. In this case, the amount of external attenuation required can be minimized. These measurements rely on the Friis transmission equation.

$$P_{\mathrm{T}} = P_{\mathrm{R}}(4\pi r/\lambda)^2/G_{\mathrm{R}}G_{\mathrm{T}},$$

Where the subscript T refers to the transmitter, the subscript R refers to the receiver, P is the power, G is the antenna gain, r is the transmitter to receiver separation distance and λ is the free space wavelength. The $(r/\lambda)^2$ characteristics allow large attenuations.

Figure 11 presents a block diagram of a narrow band HPM source. Pulsed power is the technology that converts some prime power source (whether the line voltage in the laboratory, jet turbine on an aircraft, or a battery pack on an unmanned drone) into a short, properly tailored, high voltage pulse. High voltage capacitors, together with fast switching techniques, are typically used to accomplish this. Once the pulsed power portion of the system has produced the desirable high voltage waveform, it is applied to an electron gun, also known as an electron beam diode. The electron beam diode produces a high perveance electron beam where space-charge effects dominate the interaction. It is because of the presence of space-charge effects that plasma physicists tend to dominate research activities in HPM.

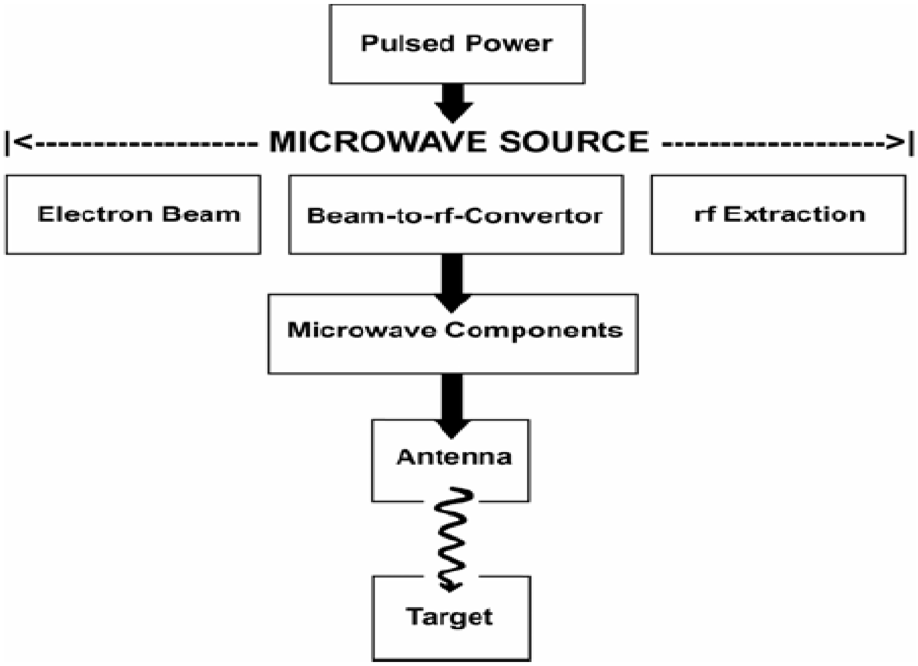

Fig. 11. Block diagram of an HPM system

An experiments were performed using the pulsed power generator KALI-1000 (kilo ampere linear injector: maximum output voltage 300 kV, output impedance 15Ω, and pulse duration 100 ns) to generate and measure HPM signal from a VIRCA-TOR device. KALI-1000 consists of a radial tesla transformer, a water transmission line and electron beam diode with voltage and current diagnostics.

Measurement of high-power microwave pulse

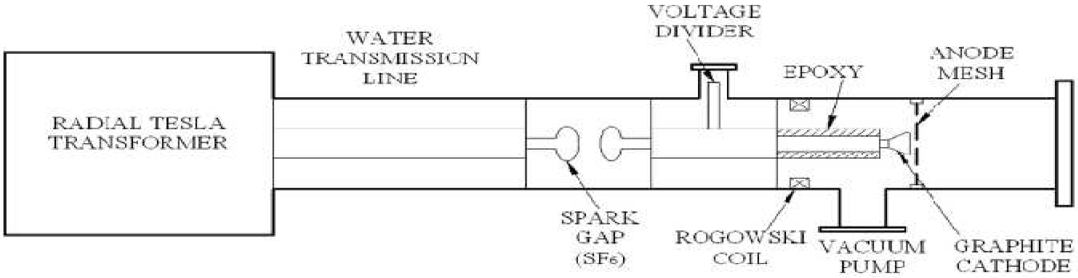

Fig12. Schematic of the experimental set-up

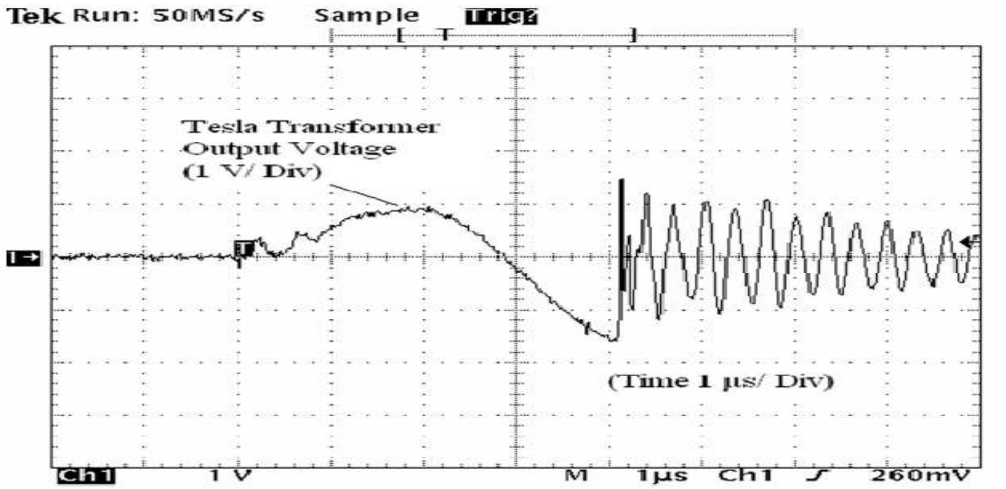

Fig13. Tesla transformer output signal

During the experiment it was observed that along with HPM the KALI-1000 system radiates intense electromagnetic noise (of a few MHz frequencies). This article describes HPM power measurements by transmitting {receiving systems and various experimental techniques used to override the noise signal to improve the microwave signal amplitude from the diode detector.

6.Terahertz Devices

The growing interest to terahertz (THz) region of electromagnetic spectrum is pulled by a variety of its possible applications for free-space communications, sensing and imaging in radio astronomy, biomedicine, and in security screening for hidden explosives and concealed weapons. Terahertz imaging may also be useful for industrial processes, such as package inspection and quality control. Despite strong demand in compact solid-state devices capable to operate as emitters, receivers, photo mixers of the THz radiation their development is still a challenging problem. The Millimeter-wave and THz frequencies (f = 0.1-10 THz) remain one of the most underdeveloped frequency ranges, even though the potential applications in remote sensing, spectroscopy, and communications are great. This is because the millimeter-wave and THz frequency range falls between two other frequency ranges in which conventional semiconductor devices are usually operated. One is the microwave frequency range, and the other is the near-infrared and optical frequency range. Semiconductor devices which utilize the classical diffusive transport of electrons, such as diodes and transistors, have a high frequency limit. This limit is set by the transient time and parasitic RC time constants. Currently, electron mobility and the smallest feature size which can be fabricated by lithography limit the frequency range to below several hundred GHz. Semiconductor devices based on quantum mechanical interband transitions, however, are limited to frequencies higher than those corresponding to the semiconductor energy gap, which is higher than 10 THz for most bulk semiconductors. Therefore, a large gap exists from 100 GHz to 10 THz in which very few devices are available.

In order to measure the intersubband THz emission and resolve its spectra, we constructed a set-up that included a Fourier transform infrared spectrometer (FTIR) with a composite Si bolometer as its detector. The system's schematic is shown in Fig. 2. We have improved this system and perfected our measurement techniques so that THz emission measurements can be routinely performed on our emitters with output power levels of 1-10 pW.

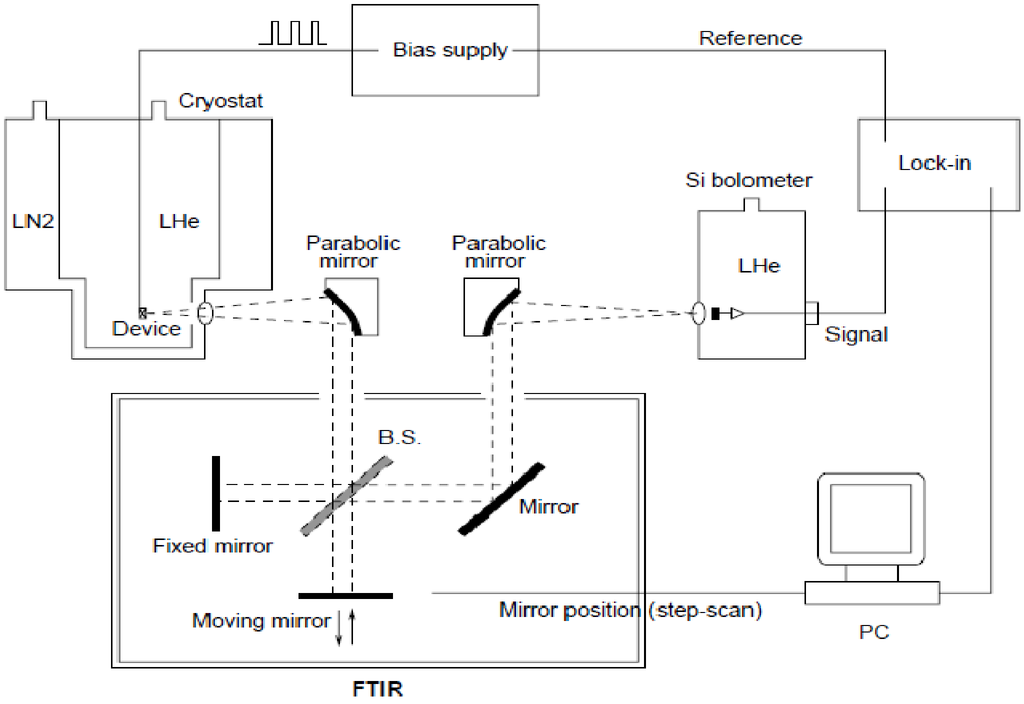

Fig14. Far-infrared measurement set-up that uses a Fourier transform spectrometer to spectrally resolve the emitted THz signals.

The MQW structures were grown using molecular-beam epitaxial (MBE). The emission spectra reveal a clear peak due to the E3 →E2 intersubband emission. A representative spectrum taken at 5 K is shown in Fig. 15(a), which was taken at a bias of 1.6 V (close to the designed value of 1.53 V). The measured peak frequency of 2.57 THz (corresponding to 10.6 meV) is close to the designed value of 11 meV. The full width half maximum (FWHM) of the emission peak is as narrow as 0.47 THz (1.93 meV). Spectra were also taken with the cold stage cooled with liquid nitrogen to 80 K. A measured spectrum is shown in Fig. 15(b). The main peak is essentially the same as the one measured at 5 K, with only a slightly broader line width of 0.52~THz (2.14 meV). The secondary broad feature is blackbody radiation due to device heating. The line width measured at 80~K is expected to be similar to that at 5~K, since nonparabolicity is negligible for THz intersubband emitters. Nevertheless, our experimental verification is encouraging for the development of intersubband THz sources at elevated temperatures.

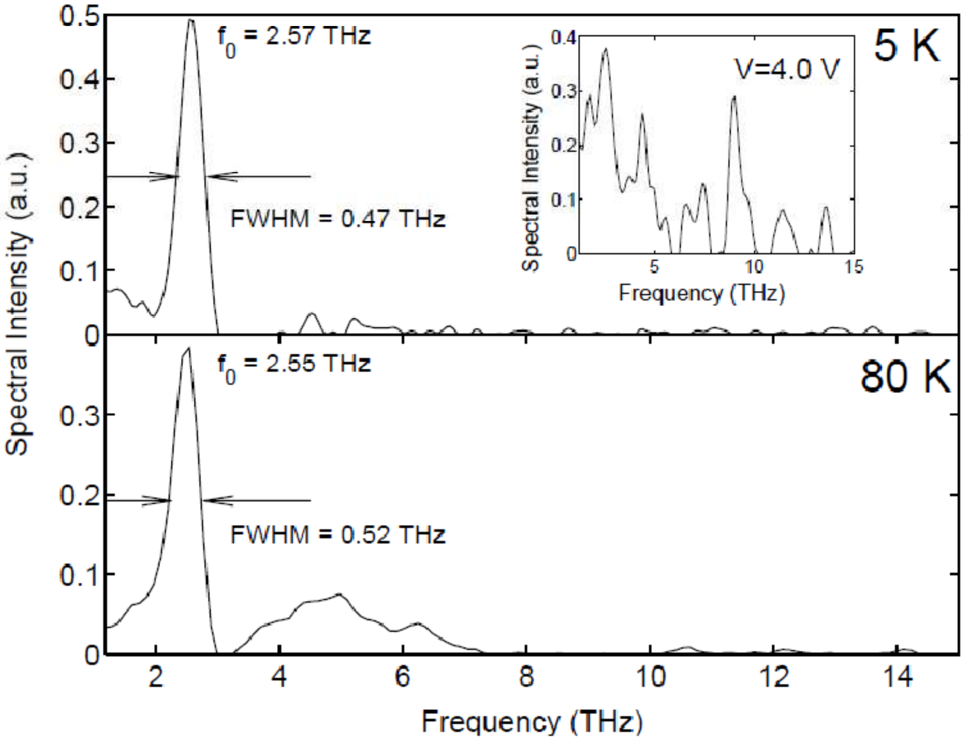

Fig15. Spectrally resolved THz intersubband emission taken at (a) 5~K and (b) 80~K under a bias of 1.6~V. The inset shows the spectrum under a 4.0~V bias.

7.Conclusion

The performance of these sources was often enhanced when filled with stable plasma at an optimum density, which depends on the specific source and its operating conditions. The enhancement occurred due to a variety of effects, including improved beam transport and bunching, the formation of hybrid waves that improved coupling, mode suppression and coupler pass-band increases. The most problematic issue in plasma filled microwave sources is the time dependent generation of excess amounts of plasma in devices that are not designed to handle the effects of plasma. Excessive amounts of plasma can, in these cases, adversely affect the performance of the microwave source. In addition, the presence of ion noise, which perhaps may not be as severe as one might have expected, still remains an area in need of further work and improvement, especially for certain applications. High-power microwave has been generated from the KALI-1000 pulse power system using a virtual cathode oscillator device. The typical electron beam parameters were 200 kV, 12 kA, 100 ns, with a few hundreds of A/cm2 current density. Finally, HPM pulse has been successfully detected using wide band antenna, RF cable and diode detector set-up. Signal-to-noise ratio improved due to inherent shielding present in the RF cable. Also diode detectors are very sensitive to electromagnetic noise and X-rays. Placing them in close proximity to pulsed power and e-beam diode that emits X-rays will produce much noise. Research into plasmonic THz devices has increased considerably in the last decade. Further progress is necessary to enable these devices to compete with commercially available THz detectors in terms of sensitivity, although their capacity to be tuned by a gate bias is a unique trait that most THz devices lack.

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