An-Najah Univ. J. Res., Vol. 11, (1997) 39-57

Construction of MIM Diodes Suitable for Use in FIR Generation By Mixing Two Carbon Dioxide Laser Beams.

Mohammad Abu-Taha

Physics Department, College of Science and Technology, Al-Quds Univ., Jerusalem, Palestine.

Abstract

Metal Insulator Metal (MIM) diodes have been constructed with a tungsten whisker making contact with different post materials such as nickle, brass, carbon, stainless steel, aluminum and tungsten. The I-V characteristics of these diodes have been studied. It was found that 2 mm section cut from a shaving blade held against a polished carbon post showed similar I-V characteristics to the previous diodes. Resistances of these diodes were found to vary between 0.1-1k . The use of MIM diodes for CO_2 laser mixing is briefly discussed.

I. Introduction

Frequency mixing is a technique in which radiation is generated at frequency equal to the sum or difference of two interacting frequencies and possibly their harmonics. For different mixing of laser radiation in the infrared region two basic methods are used: nonlinear crystals (Aggarwal and Lax, 1977) and point contact technique (Hocker and Javan, 1968 a, Hocker et al, 1968b, Danue et al, 1969 and Drullinger et al 1983, I noue and Yasuoka, 1985). Materials such as GaAs, CdTe and ZnSe are commonly used in nonlinear bulk crystal mixing. When using crystals certain properties are required. These include transparency at the interacting and the produced frequencies, high birefringence to allow phase matching, high refractive index and in addition immunity to damage by the incident power (Zernike and Midwinter, 1973). For successful mixing large sized crystals are required

(Aggarwal and Lax, 1977) with a low absorption coefficient independent of temperature. These reasons, together with practical complexities forced a search for an alternative inexpensive and simple technique. This paper will discuss the fabrication of MIM diodes as an example of the point contact technique such as is used for the mixing of two laser beams. The point contact techique is achived by constructing a very thin tungsten (W) wire in the form of a Whisker sharped to a fine tip and contacted against a metal or semiconductor post material. Full practical details are given in section II. It is expected that gas molecules are going to be trapped on the post material through adsorption, thereby constituting the diode parts: metal (Cat's Whisker), insulator (gas molecules) and metal (post material). Only this type will be discussed in this paper.

The I-V characteristics have been studied and given in a record photographed from an oscilloscope screen. It is shown that the sharp edge of a simple shaving blade can substitute for the usual tungsten whisker and devices made in this way shown same MIM diodes characteristics. MIM diodes was first suggested by (Dees, 1966) as a suitable device for millimeter wave detection. Then Hocker et al (1968a) reported the use of MIM diodes for mixing 337 m from HCN laser radiation mixed with that from 190 m (D_2O + C_2N) laser and the 118 m H_2O laser. The mixing of two adjacent lines of the P-branch of the 10.6 m CO_2 laser was also reported (Hocker, et al 1968 b). The first successful harmonic mixing at infrared frequencies was then reported (Danue, et al 1969) which involved mixing 28 m from a water vapour laser with 9.3 m from a CO_2 laser and K- Band (24 GHz) microwave radiation. This was followed by more thorough studies and developments of theoretical models and experimental work aiming at optimization of the different parameters involved in the construction of MIM diodes, (see for example references: (Faris, et al 1973 Twu and schwarz, 1974, Twu and Schwarz 1975 and sanches,et al 1978). MIM diode studies using corner reflectors were reported (Krautle, etal 1977 and 1978). Recently MIM diodes have been used in heterodyne detection of visible laser radiation at a frequency difference of 2.5 THz (Drullinger, etal 1983). MIM diodes are formed by the use of a tungsten wire sharpened to a very fine tip by conventional electropolishing techniques and mechanically contacted to another metal (Post material) which is usually nickel (Ni). The tungsten wire- the so called the cat's whisker of the diode is usually made using tungsten because of its reliable mechanical properties. For different types of post materials metals such as nickle, tungsten steel, brass, gold, molebdenum and phospher bronze (Bradley and Edwards, 1973) as well as graphite have all been used. Although nickel does not give the best signal-to- noise ratio, it is preferred as it is the most stable of all post materials in forming the junction.

A simple explanation of the rectification phenomenon was given by Danue et al (1969) as follows: When the IR radiation of wavelength ( ) is coupled to the point contact element, a voltage pulse occurs across the junction acompanied by an alternating current at the IR frequency. The resulting current produced comprises a distorted waveform containing high order harmonics in addition to the average field component .The above mentioned explanation was also supported by (Sanchez et al 1972). The current components associated with the various harmonics and frequency mixing which is generated by the nonlinear resistance point contacts excite propagating current waves in the thin wire antenna to emit elecromagnetic waves at the corresponding frequency. The signal is therefore generated in two steps. First the current is induced in the antenna wire and second it is carried to the tip and rectified (Jasik, 1961). Faris, et al in (1973) remarked that the nonlinearity is in-consistent with electron trunnelling theory. Sanchez and co-workers (1978) in their explanation of the action of the diode used two models known as the antenna and " diode" models. They performed experiments in support of both models. In the antenna model the receiver is considered to be formed by a voltage source Vcos (wt) with an internal impedance (R_A) in series with nonlinear resistance R_D (diode resistance) which in turn connected in parrallel with the junction capacitance as shown in fig.1. Where R_A is the resistance component of antenna impedance and r in fig. 1 represents the spreading resistnace resulting from the current being spread in the post material. For MIM diodes this quantity can be neglected as it is small (~ 0.1) but for semiconductor point contact diodes it can be as large as 50 (Bradley and Edwards, 1973). This resistance is inversely proportional to whisker tip radius "a" (see the comprehensive review article by Knight and Woods, 1976).

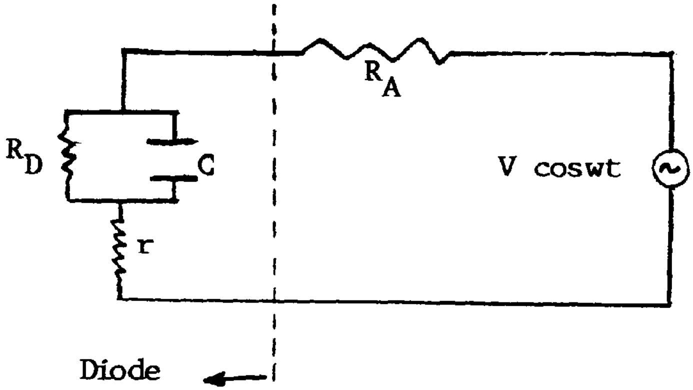

Figure 1: Equivalent Circuit of MIN Diode

It was reported (Matarrese and Evenson, 1970) that when more of the whiskeris etched away reducing by that its length (L); resulted in decreasing number of lobes. These lobes constitute the radiation patterns from the diode and wasfound to be concentric circular cones about the whisker's axis. The number of lobes are equal to (L/). Twu and Co-workers (1975) considered the effective length of the whisker to be its etched part. It seems that details of the whisker shape is important and radiation couples in the antenna until it reachesa chemical discontinuity between the etched and non etched parts of the whisker wire. Even omitting the kink which formed to give the whisker a springy property produce a subsidiary lobes in the major lobe (Matarrese,et al 1970). The appearance of this fine structure in the major lobe was explained asa partial transmission of electromagnatic waves across the boundary of theetched part so the rest of the whisker contributed to the overall radiation pattern. The second model involved in MIM diode theory (Sanchez, et al 1978) is called the diode model. The essence of this model is that electron tunnelthrough an oxide layer between the two metals of the order of 1 nm thick.

II. Preparation and Mechanical construction of the Mixer:

Tungsten was the most widely used material for the diode whisker because of its reliable mechnaical properties. Although nickel was widely used as a post material other materials will be used in this study. The whisker was etched from a 100 m diameter tungsten wire. A short piece of the wire threaded through a specially made jig to form the kink which provides the springy property of the whisker as shown in fig (2a) which shows the complete whisker.

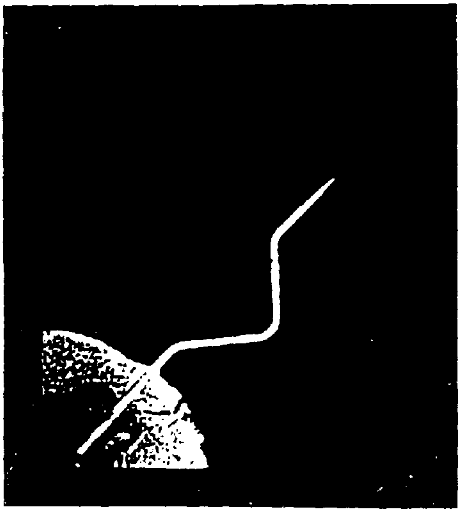

Figure 2. a: *Electron Microscope view of the whole tungsten whisker magnified ten times*

The formed whisker is then held in a vertical position and immersed in NaOH solution prepared by disolving 8 grams of NaOH granules in 250 ml of water. The tungsten was made the positive electrode and 50 volts D.C was applied. Electropolishing of the wire in this way was a self terminating process i.e the time was determined by the break of circuit current when the whisker is fully etched. After each process carefull measurements of whisker diameter near the tip and length of the etched part was carried out fig(2 b).

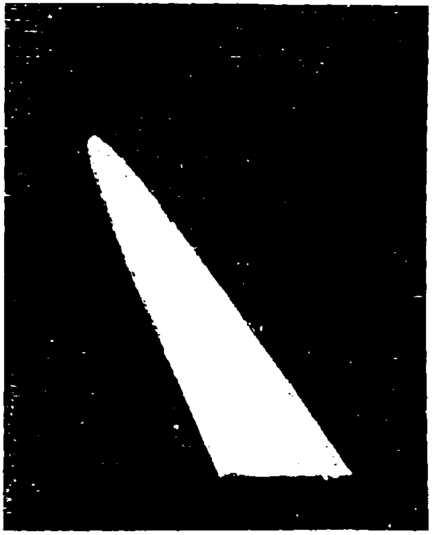

Figure 2. b: *Electron Microscope Scan (EMS) of the tungsten whisker tip magnified (5500) times*

If longer etched length is required then a longer length of tungsten wire is immersed for shorter times i.e before the current returns to zero. For short whiskers, higher NaOH concentrations and larger voltages are needed. In this work diameter tips ~ 0.2 m were acheived and etched lengths of were obtained. Then the whisker and post material was mounted on a specially designed mount which allows for vertical and up,down, rotational motions for angle adjustments and fine movement for side ways displacement of the whisker in the laser beam. The pressure of the point contact can be adjusted by means of micrometer which drives the spring loaded whisker holder (See complete system shown in fig 3).

The induced signal on the diode can be monitored through a coaxial cable. The whisker was connected to the inner wire and the base of the diode (post) was connected to the screen of the cable. The post material was cut from a

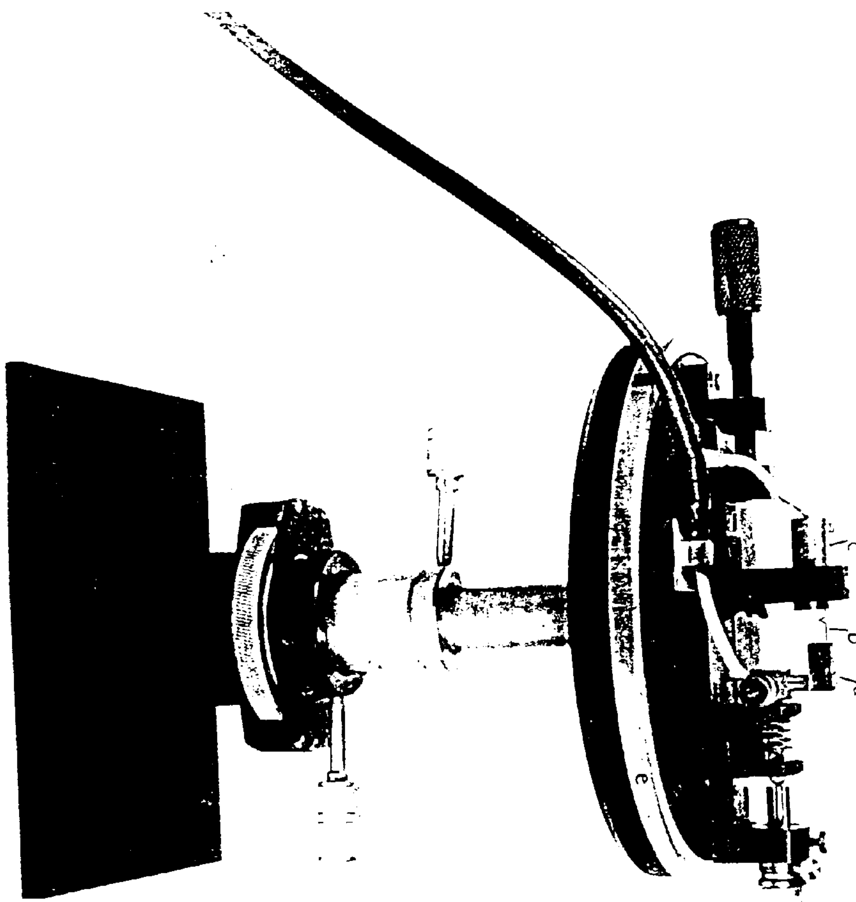

Fig.3 A photograph of the complete MIM System.
a: Whisker holder
b: Tungsten Whisker
c: Nickel post
d: Micrometer
e: Turntable

pure nickel bar to 1cm diameter and polished using fine silicon paper and rubbed with metal paste for a fine finish. Polishing of the post material proved to be important for the diode stability.

III. D.C Characteristics of MIM Diodes:

Studies of the current-voltage (I-V) characteristics when the whisker diode is positively (or negatively) biased have been carried out by point to point measurements of the current and voltage. The method was found to be difficult, time consuming and not accurate due to the unstable nature of the diode since the junction resistance varies rapidly. When the resistance change large jump in the current and voltage values is noticed and this will require re-adjustement of the contact pressure required to restore the junction resistance to its original value. A much better and accurate way is to use a transistor curve tracer which allows a quick trace of the I-V curve before the junction resistance varies. A curve tracer (model 577-177) from Tektronics has been used in this study. The doide was set at certain resistance and the curve is traced and stored in the curve tracer memory; then the point contact is adjusted for a different junction resistance and another curve is traced and so on for juction resistances between 10-700 ohms. The curves in the forward and backward are symmetric about the origins, but due to the small size of the tracer screen only the forward biasing curves are drawn (fig 4). Different post materials have been tried and showed similar results except for carbon rod post where nonlinearties are slightly clearer and generally speaking one can say that the curves are relatively nonlinear. The whisker was also replaced by an ordinary shaving blade edge of (2mm in width, few mm long) showed very similar results to the (W) cat whisker curves. Higher resistances was difficult to obtain in the blade diode when metal post is used. Both low and high junction resistances can be easily obtained for tungsten and Blade whiskers point contacted against a carbon post. In the following post materials are arranged according to stability of diode resistance with the most stable first: carbon (polished face) tungsten (W) electropolished, Ni (Nickle), Brass, stainless Steel and Aluminuim (Al), all polished with fine silicon paper as a coarse polish and then finely polished using a fine metal polishing paste. The best of all post materials used was carbon which was extremely stable compared with other materials. It was noticed that the junction resistance jumps to small values say from 100 to 10 ohms or lower when laboratory equipment was switched on or off, sepecially those containing inductive reactances.Finally it is worth mentioning at this stage that the characteristics obtained are similar to the theoritical curves obtained by Faris et al (1973) . In the curves shown some are thick. This was a concequence of variations in the junction resistance such that multiple traces did not accurately overlay each other. Usually instabilities occur at high junction resistances as can be seen from the curves of fig 4. (a-f) .

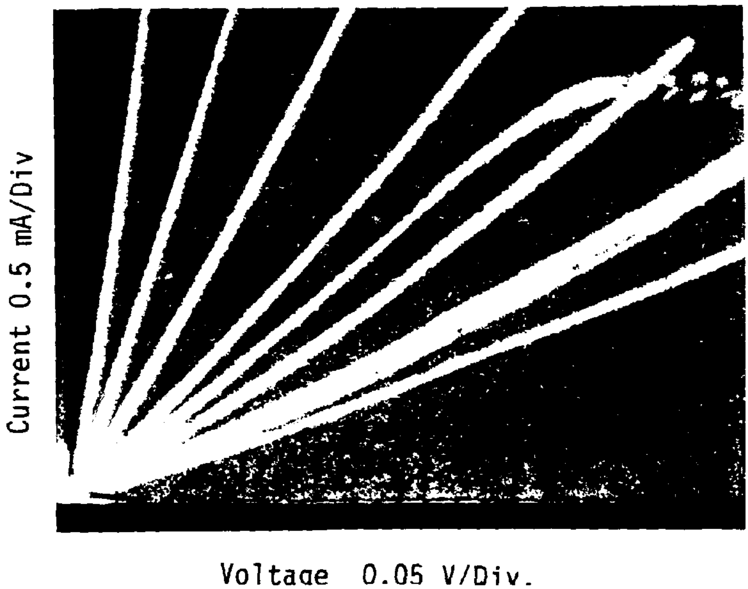

Figure 4. a: *I-V Characteristics of a W-W diode with resistances: 10,30,55,100,150,170,260,520 ohms respectively, starting with the curve nearest to the current-axis*

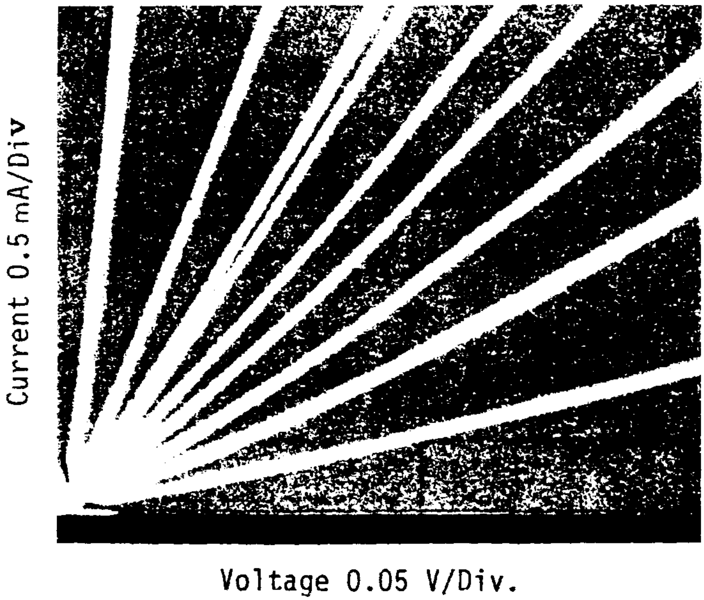

Figure 4. b: *I-V Characteristics of aW-Ni) diode at resistances: 10,40,60,65,95,150, 70, 170,260,520 ohms respectively, starting with the curve nearest to the current-axis.*

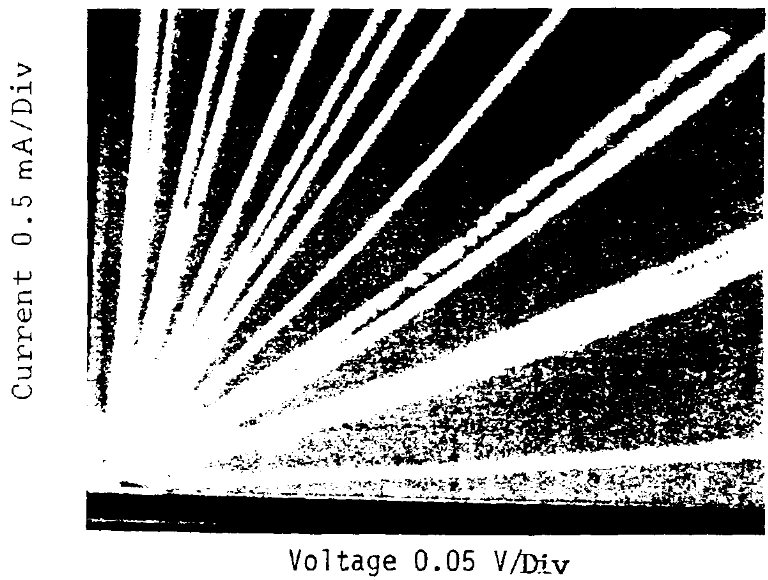

Figure 4. c: *I-V Characteristics of kW-brass diode having resistances: 5,10,20,30,45,55,65, 70, 100,165,260 ohms respectively, starting with the curve nearest to the current-axis. Trials to acheive high stable resistance was not successful*

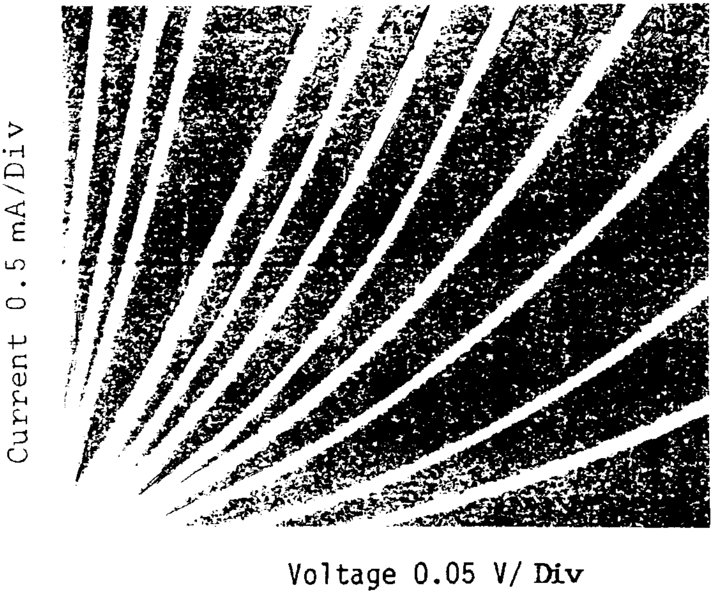

Figure 4. d: *I-V Characteristics of shaving blade whisker against a polished carbon post diode with resistances: 10,20,30,55,80,100, 140, 170,250,500,730 ohms respectively, starting with the curve nearest to the current-axis. The diode is very stable and high resistances value is easily attained*

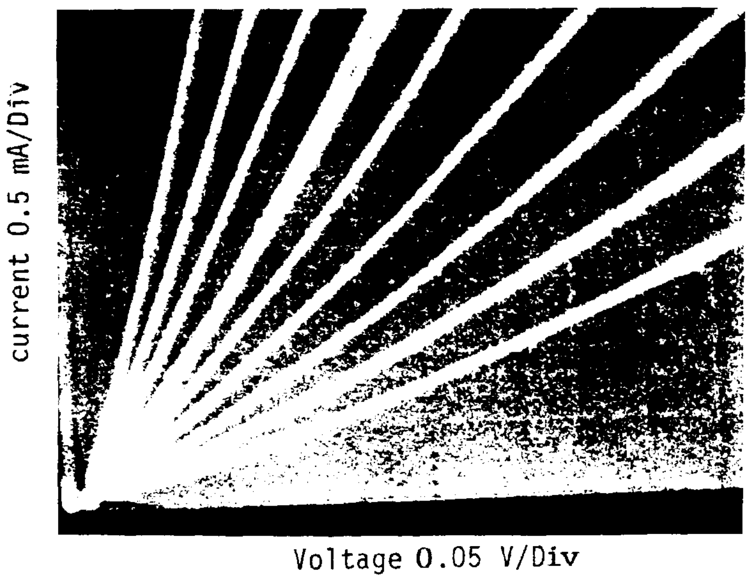

Figure 4.e: *I-V Characteristics of W-Carbon diode with resistances 25,40,50,65,75,95,195,250,390 ohms respectively starting with the curve nearest to the current-axis*

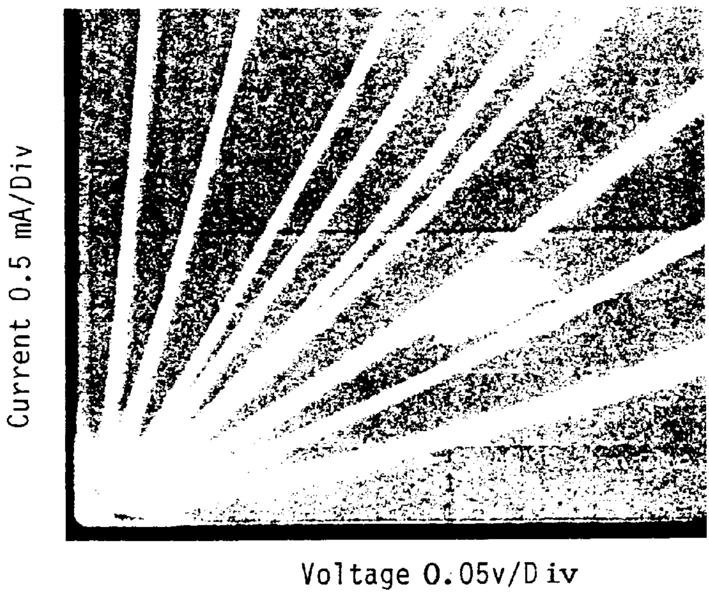

Figure 4.f: *I-V Characteristics of W-stainless ste l diode having resistances 10,30,55,70,100,120,170,260,520 ohms respectively starting with the curve nearest to the current-axis*

IV. Conclusion:

In this study the characteristics of different MIM diodes have been studied. It was found that the tungsten nickle combination formed a fairly stable diode. This type of diode has proved successful for CO_2 laser mixing by other investigators. It is also concluded that carbon and metal with a high adsorptance to air molecules such as nickel make good post materials that guarantee some degree of diode stability. Although CO_2 mixing has not been carried out in the present study, it is considered to be worth trying the newly discovered diode formed from a shaving balde carbon rod arrangement. The stability of this diode indicates high probability of success as a mixer but has yet to be verified. In view of the earlier overview of the MIM diode techniques it may be useful to point out their advantages. Their importance lies in their effectiveness for generating radiation thorughout the IR and FIR regions. The emitted radiation is intense enough to be useful for spectroscopic applications (Sanchez ,et al,1972). MIM diodes have a high cut off frequency compared with other techniques. This can be calculated using the formula (Knight and Woods, 1976):

$$f_{cut\ off} = (2\ C(v)\ r)^{-1}$$

Where C(v) is the junction capacitance and r is the spreading resistance. An increase of the cut-off frequency value can be acheived by making the contact area as small as possible since:

$$C \qquad a^2,\ r \qquad a^{-1},\ so\ Cr \qquad a$$

Where (2a) is the whisker diameter. The spreading resistance for MIM diodes is small, but using low resistivity materials will keep its value down. The value can be reduced by modifying the post material surface Frequencies up to 148 THz could be measured using MIM diodes (Jennings, et al, 1975). MIM diodes have response times of 0.7×10^{-14} (see Evenson, et al 1984). The advantage of MIM diodes over other techniques such as bulk mixing for example, is that they can be used freely up to their cut off frequency while non-linear crystals cannot be used if they are opaque at certain frequencies. Bulk mixing needs high power moreover some crystals have a high absorption coefficient at certain wavelengths. On the contrary, MIM diodes can operate at powers as small as 5 mW and no power is absorbed. Semiconductor point contact diodes need to be doped up to a certain charge carrier density. In addition they have a high spreading resistance in range 10-50 ohms which limits the cut off frequency of the diode. In MIM diodes this is neglegable, and typically 0.1 ohm. Finally MIM diodes are easy to manufacture compared with semiconductor diodes, or bulk crystals which need special cutting methods as well as specific crystal parameters.

A Knowledgment:-

The auther would like to thank prof. D. C. Laine of Keele University for his encouragement, support, helpful thoughts and allowing the use of his laser lab.

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بناء الصمامات الثنائية من نوع معدن-عازل-معدن للحصول على أشعه تحت حمراء طويلة الموجه وذلك من خلال مزج شعاعين من ليزر ثاني أكسيد الكربون

محمد ابراهيم ابوطه

ملخص

لقد تم بناء الصمامات الثنائية من نوع معدن - عازل - وذلك باستخدام شارب التنجستن وقاعدة من عدة مواد مثل النيكل، النحاس، الكربون، الصلب، الألمنيوم والتنجستين. وقد درست الخصائص الأساسية بقياس التيار وفرق الجهد لهذه الترتيبات المختلفة حيث وجد أن مقطعاً بعرض 2 ملم من شفرة الحلاقة العادمه كشارب مقابل قاعدة مصقولة من الكربون له نفس الخصائص السابقة.

واتضح من هذه الدراسة أن مقاومة الصمامات المختلفة تنحصر بين (100-1000)اوم. وتناقش هذه الورقة بشكل مختصر استخدام الصمامات في مزج أشعة ليزر ثاني أكسيد الكربون.