SYMPOSIUM AA

Millimeter/Submillimeter-Wave Technology–Materials, Devices, and Diagnostics

April 24, 2000

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SESSION AA1: CHARACTERIZATION AND DIAGNOSTICS
Chairs: S. K. Sundaram and Paul P. Woskov
Monday Morning, April 24, 2000
Salon 15 (Marriott)

8:30 AM *AA1.1
MILLIMETER AND SUBMILLIMETER WAVE COMPONENTS FOR FUTURE DIAGNOSTIC INSTRUMENTATION. Chris Mann, The Rutherford Appleton Laboratory, Chilton, Oxfordshire, UNITED KINGDOM.

Until very recently, cost and availability of millimeter and submillimeter wave components has restricted their use to applications such as Remote Sensing, Radio Astronomy and Plasma Diagnostics. Exploratory research aimed at demonstrating new potential applications such as material diagnostics, process control and medical imaging have suffered as a result. Sources and detectors which form the basic building blocks for new instrumentation are now becoming much more readily available. Such devices are likely to incorporate active devices in an integrated "flip chip" configuration rather than the "whiskered" device that has been the mainstay for so many years. Novel fabrication approaches have resulted in the lithographic realisation of RF circuitry to 2.5THz and beyond. The arrival of the Heterostructure Barrier Varactor (HBV) for frequency multiplication promises solid state power in the 10's of milliwatt level for the submillimeter region. New accurate circuit simulators have allowed the development of very high performance, compact, subharmonic frontends, offering high instantaneous bandwidth and low noise, room temperature operation. These can be used in conjunction with digitally swept Backward Wave Oscillators, ultra broadband fixed tuned HBV multipliers to carry out fast, swept frequency measurements. Finally, new manufacturing approaches such as micromachining and casting offer both a dramatic reduction in cost and more complex circuit/system implementation. This talk aims to describe the latest developments in millimeter and submillimeter component technology.

9:00 AM AA1.2
ACTIVE MILLIMETER-WAVE PYROMETER TEMPERATURE AND EMISSIVITY MEASUREMENTS. David Y. Rhee, Integrated Enviromental Technologies, LLC, Richland, WA; John S. Machuzak and Paul P. Woskov, MIT, Plasma Science and Fusion Center, Cambridge, MA.

Millimeter-wave pyrometry can be used reliably for non-contact temperature measurements in harsh environments that are inaccessible by conventional infrared and thermocouple sensors. Millimeter-waves are long enough to see through dusty, smoky, and optically obscure propagation paths, but short enough for useful spatial resolution. Additional advantages include the ability to use refractory materials for waveguide and optics components, wide dynamic range for temperature measurement, and fractional degree relative accuracy to the highest temperatures. In addition, simultaneous surface emissivity measurement is possible when the viewing geometry can monitor a specular return reflection, which is more readily established at millimeter-wavelengths than at shorter wavelengths. The capability to monitor thermal emission and reflection not only improves temperature measurement accuracy, but also can provide additional information on the properties of the materials being monitored. Such properties include material conductivity and fluidity. A 134-139 GHz heterodyne radiometer has been used on a plasma arc furnace for temperature measurements from room temperature to as high as 2200°C and on an electric resistive heated furnace to study molten glass. Relative temperature measurement sensitivity of 0.3°C for one-second time resolution was achieved throughout the temperature measurement range. Graphite or Inconel waveguides were used to efficiently access the inside of the furnace. In the arc furnace a waveguide with a graphite miter mirror was rotated for scanning the internal furnace temperature profile with a 5-cm spatial resolution. The combined profile and emissivity information allowed the correction of furnace thermal gradients for non-ideal black-body conditions. Coherent reflection signals clearly showed molten glass displacements due to turbulence and fluid flow with less than 1-mm spatial resolution.

9:15 AM *AA1.3
110 TO 325 GHZ VECTOR NETWORK ANALYSIS CALIBRATION PROBLEMS CAUSED BY COMMON WAVEGUIDE COMPONENT IRREGULARITIES. Charles Oleson, Anthony Denning, Oleson Microwave Labs, Morgan Hill, CA.

Full waveguide band vector network analysis measurements are now being achieved in the 90 to 140 and 140 to 220 GHz waveguide bands. These measurements can now be accomplished in a single, full band setup and calibration. To achieve optimum results a working knowledge of the available calibration procedures is necessary. The characterization of the vector network analysis equipment requires the use of a precision waveguide based calibration kit. This same calibration kit is used for the characterization of waveguide components and systems. Semi-conductor characterization requires the use of substrate based calibration artifacts. The most productive semi-conductor test systems are characterized first at the equipment level, then to the device probe interface flange, and then through the device probe to the substrate calibration artifacts. During the development of these specific waveguide calibration kits many unexpected problems were encountered which are discussed. The required tolerances of the waveguide dimensions becomes more exact as the frequency increases. Physical deformities often found in waveguides above 110 GHz, such as improper corner radius, poor surface finish and the lack of waveguide rectangularity, serve to shift the waveguide cutoff frequency and it's effective phase length. At these frequencies the use of waveguide dimensional tolerances found in industry standards most often leads to improper physical constants being entered into the calibration routines of the automated vector network analyzer. The dimensional and angular accuracy and surface finish of the waveguide flange interfaces employed also impact the quality of the calibration achieved. Various waveguide irregularities, their impacts, and some often-overlooked nuances are examined. The need for physical measurement and vector network analysis of physical constants of each of the components in the test system is summarized.

10:15 AM AA1.4
WAVEGUIDE FOR HIGH TEMPERATURE MATERIALS CHARACTERIZATION USING MILLIMETER-WAVE TECHNOLOGY. S.K. Sundaram, Pacific Northwest National Laboratory, Richland, WA; Paul Woskov and J.S. Machuzak, Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA.

Millimeter-wave technology was applied to measure reflectivity or absorption of representative material surfaces at high temperatures (1000-1300°C) to develop advanced sensors for materials characterization and process diagnostics. The selected surfaces were simulated waste glass, alumina, Inconel, and silicon carbide. A heterodyne receiver operating at a frequency of 137 GHz was tested. A scalar horn was used to convert the receiver antenna mode to a fundamental HE11 mode so that quasi-optical waveguide techniques could be applied for optimum coupling of the receiver view to the material surface. As an internally corrugated metal waveguide is necessary to support the propagation of an HE11 mode, an inconel 690 corrugated waveguide was fabricated and tested for views into the hot interior of a furnace. The performance of inconel 690 as a millimeter-wave waveguide in a high temperature environment was evaluated. Approximately a 20-cm length of a 56 cm long Inconel waveguide was inserted into the furnace to view the material surface that would act as a return reflector of the millimeter-wave LO beam and incoherent black-body emission. The return signals were monitored. Changes in return reflection were compared with theoretical calculations. The performance of the waveguide in terms of reproducibility and signal deterioration due to cycling effect will be presented. The millimeter-wave reflectivity of the selected surfaces and their potential applications will also be presented.

10:30 AM AA1.5
MULTI-CHANNEL RADIOMETRY IN MMW IMAGING SYSTEMS. Vladimir Ablyazov, Vladimir Abramov, Vladimir Lyubchenko, Kadir Mourzabulatov, Sergey Turygin, Inst. Radioengr. and Electron., Russian Acad. Sci., Moscow, RUSSIA.

MMW imaging is becoming an attractive option for remote sensing because millimeter waves have the advantage of penetrating adverse weather or other atmospheric obscurants, and to some extent because of MMW beams ability to penetrate materials, while retaining reasonable spatial resolution. Civilian applications of this technology are emerging, however there has been no real-time imaging demonstration of a civilian application. Potential applications include detection of oil slicks, autonomous landing guidance for aircraft in fog, fire detection, automotive traffic monitoring, hidden object detection at security checkpoints, etc. Use of a single, high sensitive MMW receiver with a rapidly scanning antenna makes a MMW imaging system more readily achievable. However, imaging speed of such systems is rather low. On the other hand, focal plane arrays with large number of 94 GHz receivers were recently developed (TRW) and used to demonstrate the feasibility of real-time passive MMW imaging with enough sensitivity to provide real-time imagery at video rates. However, such focal plane arrays will remain very expensive for a long time. Use of focal plane arrays with moderate number of high sensitive MMW receivers with scanning antenna could be reasonable alternative for both - single scanning radiometer and multielement focal plane array. Such focal plane array 1x16 of 94 GHz receivers has been developed and tested with scanning offset parabolic antenna of 1120mm aperture. 16 superheterodyne receivers along with 16 square law detectors, 16 DC amplifiers, 16 zero-compensators form array of 16 identical total-power radiometers. Each radiometer operates with input brightness temperature range of 100K to 500K. Sensitivity of each radiometer is estimated as about 0,03K with integration time 1s. DC signals from outputs of DC amplifiers (+1V output DC voltage corresponds to input brightness temperature of 100K, +5V output DC voltage corresponds to input brightness temperature of 500K, minimum time constant 1ms) comes via interface to 16x1 multiplexer and A/D converter placed in personal computer. Control unit provides data exchange between receivers and computer. System calibration is realized as periodical amplitude scaling using mobile black body shutter (having two fixed temperatures) installed in the face of feeds. 4x16 and 8x8 focal plane arrays were also considered.

10:45 AM *AA1.6

MILLIMETER-SUBMILLIMETER VECTOR MEASUREMENTS IN FREE SPACE, AND IN RESONANT STRUCTURES. APPLICATION TO DIELECTRICS CHARACTERIZATION. Philippe Goy, Michel Gross, Sylvain Caroopen, AB Millimetre, Paris, FRANCE; Juha Mallat, Jussi Tuovinen, Millimetre Wave Laboratory of Finland, Millilab, ESA external laboratory, Helsinki University of Technology, Radio Laboratory, Hut, FINLAND; Alain Maestrini, Submillimeter Waves Advanced Technology Group, J.P.L., Pasadena, CA; Guiseppe Annino, Maria Fittipaldi, Massimo Martinelli, Istituto di Fisica Atomica e Molecolare, CNR, Pisa, ITALY.

A vector network analyzer has been created since 1989, based on a very simple principle, patented: there is a PLL link between the source LO and the detector LO, and this link gives the necessary reference to the vector receiver. This analyzer offers the capability of making vector measurements in the full 8 to 1000 GHz frequency interval. The 8-200 coverage is obtained thanks to harmonic generation of the centimeter LO contained inside the analyzer. The 200-1000 GHz frequency interval can be covered by using a pair of extensions based on widely tunable Gunn oscillators feeding Schottky devices (harmonic generator, and harmonic mixer). It is well known that waveguide propagation becomes a serious problem at submillimeter frequencies. On the contrary, free space propagation is quite possible. The microwave devices can be associated to small horn antennas to emit and receive waves. It is possible to refocuse the diverging waves by means of lenses, mirrors, etc., according to the Quasi-Optical techniques. When introducing a dielectric sample in the wave path, the vector detection can give the material loss, from the wave amplitude attenuation, and also the material permittivity, from the wave phase rotation. This method is extremely simple to describe. The quality of the measurement will be limited by spurious standing waves effects. Besides, it is not possible to determine very low losses. In this last case, it is preferable to make use of the open cavity. A Fabry-Perot cavity, with an horizontal plane mirror below and a spherical mirror above, can be characterized in the unloaded state, then in the loaded state, after introduction of the sample slab, placed on the plane mirror. The comparison between the resonance positions and widths, with and without the sample, gives an accurate value of the permittivity, and of the loss. The observed vector signal describes a circle in the polar plane, at resonance, and permits unambiguous fitting. However this open cavity method cannot be precise enough, for loss determination, in the case of extremely low losses. The last technique which will be described is the characterization of whispering gallery modes of the cavity made from the dielectric itself. This technique seems to be the easiest and the best for measurements of extremely low loss materials. A very same sample (small disk) can be characterized from 100 GHz to 800 GHz in the same set-up.

11:15 AM AA1.7

OPEN RESONATOR TECHNIQUE FOR MEASURING OF THIN FILM DIELECTRICS ON OPTICALLY DENSE SUBSTRATES. Sergey Dudorov[1], Dmitri Lioubtchenko[1], Juha Mallat[1], Jussi Tuovinen[2], Antti V. Räisänen[1], [1]Millilab, HUT Radiolaboratory, Espoo, FINLAND, [2]Millilab, VTT Information Technology.

Dielectric materials are nowadays widely employed in millimeter and submillimeter wave applications. Dielectric waveguides are attractive alternatives to be used instead of metallic single-mode waveguides and could be compatible with optoelectronics and microwave integrated circuits, if made using low loss GaAs or Si epitaxial layers on dielectric substrates. Recently, new promising materials are being developed. For example, GaN and AlN epitaxial layers on a semiinsulating GaAs or sapphire. The problem is that these layers are not only thin as compared with the wavelength, but also that their permittivity is close to the substrate permittivity. Therefore the problem of precise measurement of their properties is challenging. One of the most accurate methods of measurement of dielectric properties is an open resonator technique, which have been developed by several authors mostly for one layer sample measurements, and recently the multilayers were studied as well. In this work, we have developed this technique for applications with bilayer dielectrics in which one layer is thin in comparison with a wavelength. The general theory for the case of 2-layer dielectric was already developed by Wang & al. In the case when one of the two layers is very thin, i.e. $n_f k t_f << pi/2$, where t_f is the thickness of the thin film, we have simplified these equations. The principle of the determination of the properties of the thin film is obtained by comparing the resonant frequencies and quality factors of the resonator containing the substrate with and without thin film. Recently, we have obtain a good accuracy (error 1%) in refractive index between the tests and simplified approach described above for a thin GaAs layer on a sapphire substrate.

11:30 AM AA1.8

SUBSURFACE DAMAGE CHARACTERIZATION OF HYDROGEN ION IMPLANTED SILICON WAFER WITH UV/MILLIMETER-WAVE TECHNIQUE. Yoh-Ichiro Ogita, Ken-Ichi Kobayashi, Kanagawa Inst. Tech., Dept. Electrical & Electronic Engineering, Kanagawa, JAPAN; Hideyuki Kondo, Takeo Katoh, Mitsubishi Materials Corp., Silicon Research Center, Saitama, JAPAN.

As gate oxide thickness of MOS devices in ULSI is thinner, subsurface damage induced by mirror polishing in Si wafers degrades gate oxide integrity. However, it is hard to detect this damage because of very slight damage, its existence in a nearby surface, and influence of a surface property. A photoconductivity measurement with an ultra violet irradiation and a millimeter detection (UV/Millimeter-Wave Technique) has characterized subsurface property in chemical-mechanical polished Si wafers. However, whether the technique reflects the subsurface and very slight damage has not necessarily been confirmed. The purpose of in this study is to show that UV/Millimeter-Wave Technique reflects information of very slight damage induced by hydrogen ion implantation in the subsurface. A dinitrogrn laser with 20 nm penetration-depth and a millimeter-wave with 100 GHz were employed in UV/Millimeter-Wave Technique. Photoconductivity amplitude (PCA) and recombination carrier lifetimes were measured for two kinds of sample; 1) 10 ohm-cm p-type Si wafers with hydrogen-ion implantation dose of 0 to $1x10^{16}$ cm $^{-2}$, and 2) 10 ohm-cm p-type Si wafers with hydrogen-ion implantation energy of 0 to120 keV. The peak of implantation damage existed at 226 nm depth regarded as a nearby surface. The dose dependence of PCA measured showed drastic decrease with dose increase. Measured PCA decreased depending the implantation energy. However, time resolved carrier lifetimes measured in a initial time region were varied depending on the implantation energy. This means that PCA signal reflects shift of the damage layer accompany with ion implantation energy increase. As the conclusion, it has been confirmed that UV/Millimeter-Wave Technique well reflects subsurface property and very slight damage.

11:45 AM AA1.9

SUBSURFACE DAMAGE PROFILE CHARACTERIZATION OF Si WAFERS WITH UV/MILLIMETER-WAVE TECHNIQUE AND LIGHT SCATTERING TOPOGRAPHY. Takeo Katoh, Hideyuki Kondo, Mitsubishi Materials Corp., Silicon Research Center, Saitama, JAPAN; Yoh-Ichiro Ogita, Ken-Ichi Kobayashi, Masaki Kurokawa, Kanagawa Inst. Tech., Dept. Electrical & Electronic Engineering, Kanagawa, JAPAN.

We have characterized subsurface damage profiles of hydrogen ion implanted silicon wafers by means of non-contact UV/Millimeter-Wave Technique and Light Scattering Topography (LST). The subsurface damage profiles shallower than one micron were controlled by chemical mechanical polishing after hydrogen ion implantation. The Photoconductivity Amplitude (PCA) signals measured by UV/Millimeter-Wave Technique drastically weakened and the haze values measured by LST increased on the area with subsurface damage. A clear correlation has been found between the peak depth of subsurface damage and the haze value. The spectral analyses of the surface images obtained by Atomic Force Microscopy (AFM) were carried out to separate the influences of surface micro roughness and subsurface damage on the haze value. The contribution of subsurface damage on the haze value can be formulated as convolution of the damage profile and the transparency function of the incident laser in silicon crystal.

SESSION AA2: MATERIALS COMPONENTS AND DEVICES

Chairs: Jussi Tuovinen and Yoh-Ichiro "Joe" Ogita
Monday Afternoon, April 24, 2000
Salon 15 (Marriott)

1:30 PM *AA2.1

MILLIMETER-WAVE SOLID STATE DEVICES. Neville Luhmann, Dept of Applied Science and Dept of Electrical and Computer Engineering, University of California, Davis, CA; Cheng Liang, Steven Rosenau, Dept of Electrical and Computer Engineering, University of California, Davis, CA; Calvin Domier, Dept of Applied Science, University of California, Davis, CA.

Recent advances in the state-of-the-art in millimeter-wave solid state devices are driving the growth of many new applications in materials science. Examples of various solid state devices will be presented, together with descriptions of the applications in which these devices may be utilized. Device examples and applications include the following. GaAs mixers have application as millimeter-wave detectors and receivers, and mixer arrays for millimeter-wave imaging. GaAs varactor diodes arranged in large grid arrays can form millimeter-wave frequency multiplier based sources, or be used in phased antenna array beam steering and high speed switching. Micro-electromechanical systems (MEMS) switches are exciting new devices with numerous applications, including low loss millimeter-wave switches, phase shifters and mechanically tunable structures.

2:00 PM AA2.2
NANOFABRICATED SiO_2-Si-SiO_2 RESONANT TUNNELING DIODES. J.G. Fleming, E. Chow, Shawn-Yu Lin, Sandia National Laboratories, Albuquerque, NM.

One possible approach to the generation and detection of millimeter wavelength radiation is the use of Resonance Tunneling Diodes (RTDs). These structures consist of a thin (nm scale) layer of high quality semiconducting material, sandwiched between two thin (nm scale) barrier layers. These devices can exhibit negative differential resistance and extremely high-speed operation. RTDs have almost invariably been fabricated using epitaxial growth techniques. This restricts the possible combinations of materials that may be employed, typically to the III-V or Si/Ge systems. In particular, there are few good choices for barrier materials and this limits device performance. Due to the overwhelming dominance of silicon in most areas of microelectronics and the maturity of Si processing techniques, SiO_2/Si/SiO_2 structures would be highly desirable. However, such a structure is impossible to fabricate using standard epitaxial techniques, due to the amorphous nature of SiO_2. In this paper we will describe a fundamentally different RTD fabrication approach, which makes use of novel combinations of well-known and controllable Si processing techniques. Single crystalline, parallel and smooth, sheets of Si were nanomachined using a combination of reactive ion etching and KOH wet etching of Si 110 substrates. The tunnel oxides were grown using processes developed for non-volatile memory applications. These structures were integrated with modified IC fabrication processes to form trench isolation and electrodes. The finished devices are orientated perpendicular to the wafer surface and had active areas between one and two microns square. Using this approach we have been, to the best of our knowledge, the first to demonstrate negative differential resistance with SiO_2/Si/SiO_2 structures.
This work was supported by the United States Department of Energy under contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

2:15 PM AA2.3
INTEGRATED GAAS DIODE TECHNOLOGY FOR MILLIMETER AND SUBMILLIMETER-WAVE COMPONENTS AND SYSTEMS. Thomas W. Crowe, Jeffrey L. Hesler, William L. Bishop, Willie E. Bowen, Dept. of Electrical Engineering, University of Virginia; Richard F. Bradley, Saini Kamaljeet, National Radio Astronomy Observatory; Steven M. Marazita, David W. Porterfield, Virginia Millimeter Wave Inc., Charlottesville, VA.

GaAs Schottky barrier diodes remain a workhorse technology for submillimeter-wave applications including radio astronomy, chemical spectroscopy, atmospheric studies, plasma diagnostics and compact range radar. This is because of the inherent speed of these devices and their ability to operate at room temperature. Although planar (flip-chip and beam-lead) diodes are slowly replacing whisker contacted diodes throughout this frequency range, the handling and placement of such small GaAs chips limits performance and greatly increases component costs. Through the use of a novel wafer bonding process we have fabricated and tested submillimeter-wave components where the GaAs diode is integrated on a quartz substrate along with other circuit elements such as filters, probes and bias lines. This not only eliminates the need to handle small chips, but also greatly increases circuit performance. This is because the parasitic capacitance is reduced by the elimination of the GaAs substrate and the position of the Schottky diode relative to the other circuit elements is defined lithographically rather than by a skilled technician. Our wafer bonding process has been demonstrated through the fabrication and testing of a fundamental mixer at 585 GHz (Tmix,dsb¡1200K) and a 380 GHz subharmonically pumped mixer (Tmix,dsb¡1000K). This paper will review the wafer bonding process and discuss how it is being extended to include additional circuit elements for submillimeter-wave mixers and frequency multipliers.

2:30 PM *AA2.4
PLANAR FERRITE MATERIALS FOR MILLIMETER-WAVE APPLICATIONS. S.W. McKnight, Northeastern Univ, Ctr for Electromagnetics Research, Dept of ECE, Boston, MA; S.A. Oliver, Northeastern Univ, Ctr for Electromagnetics Research, Boston, MA; H. How, EMA Corp, Boston, MA; C. Vittoria, Northeastern Univ, Dept of ECE, Boston, MA.

Magnetic oxide ferrites are the materials of choice for non-reciprocal functions in microwave and millimeter-wave circuits including isolators, circulators, and tunable phase-shifters. Techniques for the integration of planar ferrite devices into semiconductor integrated circuits have been sought for many years to supercede present hybrid technologies. Two paths have been investigated for fabricating thick ferrite films on semiconductor IC substrates: direct growth and film transfer techniques. Direct growth is hampered by the incompatibility of optimal ferrite fabrication temperatures (650-900°C) with semiconductor IC materials and processes. We have successfully transferred yttrium-iron-garnet epitaxial films from gadolinium-gallium-garnet to silicon substrates to create non-reciprocal circulator devices at X-band (8-12 GHz). To extend these techniques to millimeter-wave frequencies, ferrite materials with large intrinsic magnetic anisotropies are required to overcome the need for large DC magnetic bias. Hexagonal ferrites have been widely used as sintered ceramics, but their magnetic losses are a limiting factor for high-frequency devices. We have fabricated thick-film millimeter-wave circulators that integrate ceramic barium hexaferrite and strontium hexaferrite die with dielectrics on silicon substrates and have achieved good non-reciprocal performance and insertion loss of less than 2 dB near 30 GHz. Approximately 60% of the insertion loss can be predicted from calculated magnetic losses consistent with measured ferromagnetic resonance line-widths. The technology for fabrication of high-quality hexagonal ferrite films for future planar integrated millimeter-wave devices is under development. We have grown epitaxial films of barium hexaferrite ($BaFe_{12}O_{19}$) and scandium-substituted barrium hexaferrite ($BaFe_{12-x}Sc_xO_{19}$) on sapphire and MgO substrates by pulsed-laser deposition techniques. As-grown thin films on heated substrates display a high degree of orientation with the C-axis normal to the film plane at thicknesses less than $\sim 10\mu$m, but for thicker films nucleation and growth of non-preferentially-oriented facets is a problem, as are the large thermally-induced stresses that arise upon cooling after deposition.

3:30 PM AA2.5
SILICON WAFER SUBSURFACE CHARACTERIZATION WITH UV/MILLIMETER-WAVE TECHNIQUE. Yoh-Ichiro Ogita, Kanagawa Inst. Tech., Dept. Electrical & Electronic Engineering, Kanagawa, JAPAN.

Miniaturization of ULSI devices requires that MOS devices have thinner oxide. This thinner oxide is causing breakdown in a gate oxide which is fabricated in the subsurface of a silicon wafer. Therefore, a strict characterization of the subsurface is needed. Phtoconductivity measurement in silicon wafers using ultra violet irradiation and millimeter detection (UV/millimeter technique) has been proposed for characterizing a nearby surface of a silicon wafer and an epilayer on a silicon substrate. In this paper, we discuss millimeter skin effect relating to interaction between the millimeter wave and excess carriers transporting in a silicon wafer. We show both principles of epilayer characterization based on millimeter skin effect and of subsurface characterization based on extremely shallow photoexcitation and extremely short carrier transportation time. 10 micrometer thick epilayers having Mo and Fe contamination in silicon p/p^+ and n/n^+ wafers are characterized with carrier lifetimes obtained from photoconductivity decays measured using UV/millimeter wave technique. A slight damage induced in a nearby surface by hydrogen implantation is characterized based on implantation dose (dose range: 0 to 1x10 ^{16}cm^{-2}) and energy (energy range: 0 to 120keV) dependencies of photoconductivity amplitudes and initial carrier lifetimes measured by the technique. Very slight damage as slight scratches induced in a silicon wafer subsurface by chemical mechanical polishing as in a commercial level is characterized by photoconductivity amplitude signal measured by UV/millimeter-wave technique correlating to gate oxide integrity of MOS diodes and surface microroughness. The UV/millimeter technique is applicable as a monitor for characterizing an imperfection as epilayer contamination and also as subsurface damage like as contamination, and defects. Further, the technique makes it possible to detect a very slight damage induced by chemical mechanical polishing.

3:45 PM *AA2.6
MILLIMETER WAVE AQUAMETR. Viacheslav V. Meriakri, Institute of Radioengineering and Electronics Russian Academy of Sciences, Fryazino Moscow Reg., RUSSIA

The aim of this paper is to examine the peculiarities of the application of millimeter (MM) band (including long-wave submillimeter region) to water content measurement and moisture monitoring. The use of this frequency region (frequencies f = 30÷500 GHz) for aquametry has some specific advantages:
1. MM waves ensure better spatial resolution and better sensitivity to

water than microwaves (attenuation of MM waves in water is more than 15 dB/mm and increases more rapidly with decreasing wavelength than in majority of host media).
2. MM waves are less sensitive than microwaves to conducting impurities.
3. MM waves can be used for water test (including nondestructive monitoring) in media that are opaque to optical and infrared radiation.
The report presents dielectric properties (complex permittivity and attenuation) of many materials and media as an object for aquametry:
a) Liquid media. There are water solutions and emulsions. The permittivity and attenuation depending on water concentration, frequency, temperature for water solutions of alcohol, sugar, and salts and emulsions water in crude oil were investigated.
b) Solid media. We have investigated dielectric properties of many solid materials. There are porous dielectrics and powders, building materials, natural materials, materials for common use, for clothes, furniture, food etc.
There are many methods for water content determination in above mentioned media: measurements of transmission and reflection coefficients in quasioptical situation or in a waveguide filled with the monitored medium; measurement of wave propagation in guiding structure connected with the medium under test (slotted metal waveguide, waveguide supporting slow wave) when some part of power of this wave penetrates into material and as result the transmission coefficient depends on surrounding medium. In the paper we consider examples of devices for water control in crude oil, alcohol, sugar, humidity of materials for common use, building and nature materials, materials used in metallurgy (charge, bentonite). Usually it is possible to measure moisture content in real time (including in flow) with uncertainty better than 0.1%.

4:15 PM AA2.7
DEVELOPMENTS IN MICROWAVE DIELECTRIC CERAMICS FOR COMMUNICATIONS APPLICATIONS. Robert Freer, Feridoon Azough, Colin Leach, Materials Science Centre, University of Manchester/UMIST, Manchester, UNITED KINGDOM.

Five main families of microwave dielectric ceramics are currently available for communications applications. Most are titanates and relative permittivities are in the range 20-90. The properties depend upon processing, microstructure and composition. As a case study, specific attention will be paid to high permittivity ceramics of Ba-Nd-Ti-O. Specimens have been prepared with the additions of MgO by the mixed oxide route, with both random polycrystalline and textures. The use of small amounts of MgO led to an enhancement of the dielectric Q values. Impedance spectroscopy has been used to investigate the behaviour of grains and grain boundaries. Static simulation studies of Ba-Nd-Ti-O ceramics successfully reproduced the structure and lattice parameters within 1-2%. Predicted relative permittivities are in satisfactory agreement with experimental data. Methods to predict dielect losses are being explored.

4:30 PM AA2.8
STRUCTURE AND CHEMICAL ANALYSIS OF As_2S_3 GLASSES USED FOR WAVEGUIDE APPLICATIONS. D.K. Verma, Advanced Materials Processing and Analysis Center & Mechanical, Materials and Aerospace Engineering and CREOL; S. Seal, Advanced Materials Processing and Analysis Center & Mechanical, Materials and Aerospace Engineering; C. Lopez, K.A. Richardson, School of Optics, CREOL; K. Zollinger, A. Graham, A. Schulte Department of Physics, University of Central Florida, Orlando, FL; K. Turcotte, J.M. Laniel, T. Galstian and A. Villeneuve, Universite Laval, Centre d'Optique, Photonique et Laser, Cite Universitaire, Pavillon A.-Vachon, Quebec, CANADA.

Chalcogenide glasses based on As_2S_3 have been studied extensively due to their optical and electronic properties and have been examined recently for use in various waveguide components. This paper reports are results of ongoing research on their structural, chemical and optical properties. Structural and chemical variations imposed by processing conditions (film deposition) can lead to changes in linear and nonlinear optical properties. X-ray Photoelectron Spectroscopy (XPS) has been employed to study the exact chemical composition at the film surface as well as in bulk, and to investigate variations in the nature of chemical bonds, electronic structure etc. These data have been compared to results from Raman spectroscopy aimed at characterizing such changes in bonding between bulk glass specimens and glasses in planar form. Effect of X-ray exposure, O2 contamination, and sample purity, is discussed, as well as changes introduced to the films during device processing. These results have been correlated with component linear and nonlinear optical properties. This work is funded by National Science Foundation.

4:45 PM AA2.9
BWO-CHARACTERIZATION OF MATERIALS AND DEVICES AT FREQUENCIES 100-1000 GHz. Alexander Volkov, Inst. of General Physics, Russian Academy of Sciences, Department of Submillimeter Spectroscopy, Moscow, RUSSIA.

On the basis of Backward-Wave Oscillators (BWOs) we have developed a highly efficient measurement technology for characterization of materials and devices in the millimeter-submillimeter wavelength spectral domain (l∼3-0.3 mm, n∼100-1000 GHz) [1,2]. Submillimeter BWO-spectrometers are designed utilizing comprehensively unique features of BWO-radiation: wide range electronic tuneability of frequency, high radiation intensity, monochromaticity and polarizability. The methods developed are of a hybrid type, combining features of both microwave technology and infrared spectroscopy: "high quality" radiation is treated by optical means in an open space. As a result, the information of the highest quality is obtainable rapidly in a real time scale, yelding spectra of both parts (real and imaginary) of the complex either transmissivity/reflectivity of devices or dielectric function (permittivity, absorptivity, conductivity, etc.) of material under study. Using the decribed method we have performed a great body of researches on a) electrodynamic properties of various quasioptical MM-SBMM devices and b) dielectric properties of wide range of substances. Polarizers, attenuators, cut-off and band pass filters, phase shifters, etc., have been studied in the a) case. In the b) case we have studied single crystals and ceramics, glasses and polymers, powders, composites, liquids, films, fibers, etc. We have investigated fundamental regularities of the frequency-temperature behavior of the dielectric response function in simple dielectrics, ferroelectrics, ionic conductors, dipole glasses, incommensurate crystals, semiconductors, superconductors, low-dimensional conductors and antiferrromagnets. Many results of the performed measurements cannot be obtained at present by any other technique.
1. A.A. Volkov, G.V. Kozlov, et. al. Infrared Physics, Vol. 25, N 1,2, p. 369, 1985; Vol. 29, N 2-4, p. 747, 1989.
2. A.A. Volkov, G.V. Kozlov, in Topics in Applied Physics, Vol. 74, pp. 51-109. ed. by G. Gruner, Springer-Verlag, 1998.