SUBMILLIMETER WAVES - BRIDGING THE MICROWAVE/OPTICAL GAP

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Abstract

This paper surveys the current state of submillimeter wave techniques. Recent work on sources, detectors and other components is described, and areas of major difficulty are indicated.

Introduction

Because of the many difficulties peculiar to this part of the spectrum, submillimeter waves have been largely neglected for communications applications. This paper will describe the special features of the submillimeter region, then examine the current areas of research on sources and detectors, while indicating the major problems remaining to be solved.

Features of the Submillimeter Region

The submillimeter region consists of wavelengths shorter than 1 mm and longer than perhaps 0.03 mm (30 μm). The "microwave" region (including millimeter waves) lies at longer wavelengths, while the "optical" region (including the infrared) lies at shorter wavelengths. In the submillimeter region, a photon has an energy comparable to the thermal energy of a particle at room temperature ($h\nu \sim kT$), placing special requirements on sources and detectors.

The submillimeter region has a number of inherent advantages over the microwave or optical regions for radar and communications applications. For free space propagation, high resolution can be obtained using small antennas, with less of an aiming problem than with optical waves. There are no significant atmospheric windows in the submillimeter region. Although this might limit unguided propagation to space applications, atmospheric attenuation could be put to use for secure communications at short range. Wave guiding in the submillimeter region can be accomplished with small dielectric structures. Hollow metal or dielectric pipes may also be used. All devices and structures can be fabricated with moderate care to tolerances of a small fraction of a wavelength, a difficult feat in the optical range.

Submillimeter waves are a unique tool in a number of areas of research. They are ideal for high density plasma diagnostics (fusion work, etc.). Magnetic resonance spectroscopy can often be studied more advantageously than with microwaves. Radio astronomy, the general study of molecular and crystal structure, and pollution analysis are other spectroscopic uses of submillimeter waves.

Sources, detectors and other components for the submillimeter region have tended to be extensions or adaptations of their microwave or optical counterparts. There is a very fundamental materials problem, however, due to the nature of the wavelength region. The lattice absorptions of most materials are found here, and materials which are good dielectrics in the microwave or the optical region become very lossy or opaque at submillimeter wavelengths. Finding a variety of suitable materials is a major requirement for progress in this field.

Submillimeter Wave Sources

Extension of the Microwave Art

Although IMPATT and LSA devices are approaching the submillimeter region, it is not yet clear how far they can be extended. At present, fairly high power an be obtained at wavelengths down to about 0.5 mm using commercially available Carcinotrons. These are expensive and may be too short lived for all but specialized research applications. Harmonic generation from millimeter wavelengths has received some attention, but efficient devices are still lacking.

Extension of Coherent Optics

Discrete Frequency Sources. Many major advances toward useful submillimeter sources have been extensions of coherent optical techniques. Semiconductor injection laser technology now approaches the short wavelength end of the submillimeter region.[2] Gas discharge laser sources can produce pulsed or cw power at discrete wavelengths throughout the region.[2] The most important discharge lasers use water vapor (H_2O or D_2O) or hydrogen cyanide (HCN or DCN) as the active or amplifying medium. The latter is capable of several hundred milliwatts cw on its two strongest lines, 0.311 and 0.337 mm. Other submillimeter wave discharge lasers use H_2S, SO_2 or OCS as their active medium.

Optical pumping is a technique that recently has been applied with success to coherent submillimeter generation,[2,3] Here a high power infrared laser source is used to excite or pump molecules (for example, methyl fluoride or methyl alcohol) to higher energy levels from which they can emit coherent submillimeter radiation. Because of the enormous number of possible pump source and radiating molecule combinations, hundreds or thousands of discrete submillimeter wavelengths should be obtainable. The longest wavelength achieved with this technique is nearly 2 mm. Typical powers are at the microwatt or milliwatt level in present devices.

Parametric processes have been used to generate submillimeter difference frequencies by mixing the outputs of two lasers in a nonlinear single crystal. For example, lines from a CO_2 laser near 9.6 μm and 10.6 μm have been mixed to produce coherent output between 0.1 and 0.3 mm.

Tunable Sources. An extension of the work on difference mixing may lead to the realization of infrared-pumped, tunable submillimeter parametric oscillators. A more immediate approach that shows promise is the difference mixing of two infrared coherent sources, one fixed and the other tunable.[4] Tunable infrared lasers have been developed which make use of a magnetic field induced shift between the input pump and the output frequency (a spin-flip Raman scattering process). These devices may be an efficient source of pump power for difference mixing, but must be operated at cryogenic temperatures. Tunable infrared parametric oscillators can also be used. They require neither cryogenic temperatures nor magnetic fields, but may be more critical to adjust.

Much more work is needed to make available coherent tunable sources for the submillimeter range that are compact, efficient, high-powered, and capable of room temperature operation.

Detectors and Other Components

Detectors

Although most submillimeter wave detectors result from extensions of optical devices, diode detectors from the microwave art (Schottky barrier and metal-semiconductor junctions) also have found their way into use. Tungsten-silicon diodes have been employed as mixers and detectors at wavelengths shorter than 0.1 mm. Recently, the use of metal-oxide-metal diodes has been demonstrated down to wavelengths of 0.003 mm (3 μm). These devices are obviously useful throughout the submillimeter and infrared range, although their adjustment is too critical for any but laboratory studies at present.

Thermal detectors have also been specially adapted for use at submillimeter wavelengths. Carbon or germanium bolometers, requiring cooling to cryogenic temperatures, make slow but sensitive detectors. Faster are the pyroelectric detectors and electron bolometers (Putley type). The latter, which must also be cooled, are useful from the millimeter region down to about 0.3 mm. They rely on the heating of conduction electrons rather than a lattice, and so are faster than the other thermal detectors.

Quantum detectors generally must be operated at liquid helium temperatures, for the thermal energy of an electron at higher temperatures would be large compared with the energy absorbed from a quanta of submillimeter radiation. Germanium photoconductive detectors can be doped to work at wavelengths as long as about 0.13 mm, and doped gallium arsenide detectors have usable photoconductivity to about 0.4 mm.[5] Fast, sensitive room temperature detectors are still needed for advanced exploitation of the submillimeter region.

Other Components

It is in the area of special submillimeter components that the least work has been done. In part this is due to the difficulty of finding low loss materials. However, fairly transparent amorphous and crystalline materials can be found that will each be useful for some part of the region. These materials could be useful for dielectric waveguides and lenses. Birefringent crystalline phase shifters, grid or other polarizers, and waveguide horn or even wire antennas are also possible. Investigations of nonlinear processes in dielectrics at submillimeter wavelengths have been reported recently.[6] Related to optical and electrooptical nonlinearities, these may result in devices such as modulators and mixers, although they are inherently less efficient than their higher frequency counterparts.

Conclusion

Once economic and efficient sources, sensitive detectors and more suitable materials are available, much practical use should be made of the submillimeter wave region. Significant progress has been made toward these goals, but a good deal of research and development work remains to be done.

References

1. See, for example, Proceedings of the Symposium on Submillimeter Waves, Vol. 20 of Microwave Research Institute Symposia Series (Polytechnic Intitute of Brooklyn, New York, 1971).

2. See, for example, Handbook of Lasers with Selected Data on Optical Technology, Editor, R. J. Pressley, The Chemical Rubber Co., Cleveland, Ohio, 1971.

3. See Reference 1, page 93.

4. See Reference 1, page 135.

5. See Reference 1, page 591.

6. See Reference 1, page 157.