RADIATION SOURCES

Scanning with Ease Through the Far Infrared

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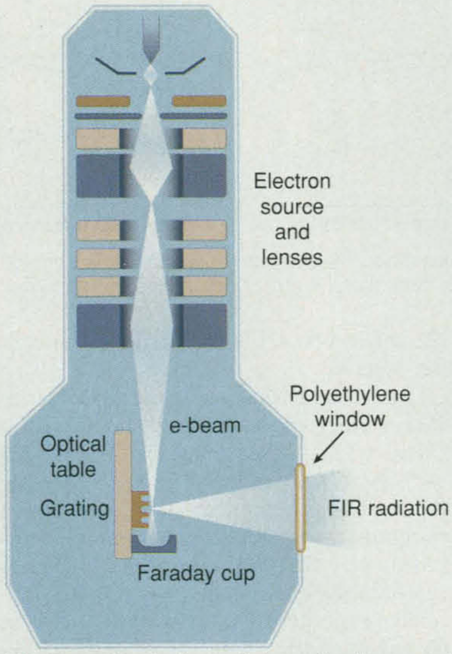
Scientists have long sought a convenient means of measuring the spectral features of solids, liquids, and gases in the far infrared (FIR) spectral region, which spans the wavelength range from about 10 μm out to 1 mm. A major advance in this quest has recently been made with a very surprising new approach: a Smith-Purcell radiation source that uses the electron beam of a standard scanning electron microscope. Results on this new source, with demonstrated wavelength tuning from 300 to 900 μm, have been obtained by Walsh and co-workers at Dartmouth College and recently reported in *Physical Review Letters* (1).

The FIR region of the electromagnetic spectrum is at once one of the richest areas for spectroscopic research and one of the most difficult areas for obtaining data. The FIR region contains the rotational spectra of atoms and molecules and the vibrational spectra of solids, liquids, and gases. FIR spectroscopy is used for a wide range of studies such as measuring the trace impurities in the atmosphere or the density of a plasma. Yet working in this wavelength range has historically been fraught with obstacles. For example, the atmosphere is highly absorbing over the entire wavelength range, making it difficult to conduct experiments. Yet by far, the greatest difficulty of working in the FIR is the absence of coherent sources of radiation that can operate continuously and tune over a wide range of the FIR wavelength spectrum.

The absence of coherent FIR sources is not for want of trying. For many decades, scientists have pursued a variety of approaches to achieve tunable coherent sources in the FIR. Many of these have been partially successful or only useful under limited conditions such as a restricted wavelength range or at very high peak powers. Most sources in the FIR are attempts either to extend low-frequency, electron beam–based microwave sources to a higher frequency or to extend high-frequency, infrared, or optical laser sources to a lower frequency. Many of these devices have been quite successful, but none has provided a simple convenient source that is useful for laboratory-scale spectroscopy over a wide region of the FIR.



Electrons to photons. Schematic diagram of the FIR source. Conventional scanning electron microscope optics produce the electron beam (e-beam). The e-beam passes a metal grating and the interaction generates FIR radiation. [Adapted from (*1*)]

The Dartmouth Smith-Purcell radiation source appears to be the answer to this long-awaited need for a coherent FIR source. The source, which is based on the radiation emitted as an electron beam passes over a diffraction grating, can be made from readily available parts, assuming that one has an old scanning electron microscope available in the laboratory (see figure). The electron beam is produced by the cathode shown at the top of the figure with beam energies of about 20,000 to 40,000 V at a current of less than 1 mA. The electron beam is transported to the region of the grating by a system of magnetic lenses that produce a tightly focused spot size of about 20 μm at the grating. This beam size is critical because it must be less than the wavelength of the emitted radiation. Fortunately, almost all electron microscopes can easily form such small beams. The radiation emitted is based on the Smith-Purcell effect, which arises from the passage of an electron over a metal grating. The electrons and their positive image charges effectively form an oscillating dipole array that can radiate coherently. The emitted wavelength (at the selected minus one grating order) is given by the grating period multiplied by the quantity $(c/v - \sin a)$, where v is the electron velocity, c is the speed of light, and a is the angle of the emitted radiation. Gratings with periods of about 100 to 300 μm are used and are much easier to fabricate than their optical wavelength counterparts. Wavelength tuning is accomplished by varying the electron beam voltage and thus its velocity, by changing the grating angle, or by changing the grating period. The scanning electron microscope has one added benefit. By regularly sweeping the beam in space, at a frequency of, say, 200 Hz, it is easy to modulate the FIR signal intensity. This makes it convenient to use the source in phase-sensitive detection schemes.

The first results of this novel radiation source have produced modest power levels, on the nanowatt to microwatt scale, which are already adequate for spectroscopic applications with available sensitive detectors such as bolometers. However, with planned improvements, the Dartmouth research team hopes to boost power levels up to at least the milliwatt scale, where almost all ordinary spectroscopic measurements could be handled. The Dartmouth group must also improve the coherence of the source by operating at levels well beyond the threshold for coherence.

Ideally, one could proceed to develop a dedicated scanning electron microscope for generating FIR radiation. However, this may not be the most cost-effective route. Almost every laboratory has one or more old scanning electron microscopes languishing in some corner of the basement, too good to throw out but not good enough to compete with more modern microscopes. With the Dartmouth group's new idea for FIR radiation generation, we could save many of these old models from the scrap heap and put them to a new use. This would provide two benefits. First, we would obtain a powerful new spectroscopic tool that would be useful for investigating trace impurities in the atmosphere, rotational structure of molecules, and countless other applications. Second, it would clear a large piece of equipment out of basement storage. I cannot say which of these is more valuable, but I should point out that at my laboratory, we have many outstanding scientists who are conducting important research but nobody has ever volunteered to clear anything out from the basement storage bin.

References

1. J. Urata *et al.*, *Phys. Rev. Lett.* **80**, 516 (1998).

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