THE DESIGN CONCEPT OF A TERAHERTZ IMAGER USING A Ge:Ga PHOTOCONDUCTOR 2D ARRAY

Ken-ichi Watabe, Mikio Fujiwara, and Norihisa Hiromoto
Communications Research Laboratory, Ministry of Posts and Telecommunications
4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan.

ABSTRACT

A terahertz (3-THz band) camera using a gallium-doped germanium (Ge:Ga) photoconductor two-dimensional (2D) direct hybrid array is proposed. We describe the design concept of the camera, which has high spatial resolution, high responsivity, and photon-noise-limited noise equivalent power (NEP).

INTRODUCTION

Terahertz imaging has applications in the spectroscopy of molecules and solids, biology, astronomy, plasma diagnostics, etc. Conventional terahertz imaging mainly uses a single detector and a scanning mechanism [1], [2]. The use of such multiple detectors as a detector array, however, eliminates the need of mechanical scanning and makes video-rate (30-Hz frame rates) imaging possible. We are developing a terahertz passive camera using a 20×3 Ge:Ga terahertz photoconductor 2D direct hybrid array [3], [4]: the camera still uses mechanical scanning but the number of scans necessary for taking a 2D image is greatly reduced as a result of using the array detector.

Ge:Ga 2D ARRAY

The Ge:Ga photoconductor [5] detector array has a format of 20×3, with a unit sensitive area of 0.5×0.5 mm^2. The pixel pitch of the detector array is 0.55 mm and the detector has high responsivity and photon-noise-limited NEP. Crosstalk between neighboring detectors is less than 5 %. The Ge:Ga photoconductor array is directly hybridized to a cryogenic Si-pMOS FET readout circuit with 20×3 format each of which is a source-follower-per-detector type circuit.

DESIGN OF TERAHERTZ CAMERA SYSTEM

A configuration of the terahertz camera is shown in Fig. 1. The optical system was designed to have a spatial resolution of 0.5 mm, a dimension of 120×120 pixels, a magnification of 1.1, and an effective F-number of 4.5. The optics has been designed by using a ray tracing method. An example of the ray trace is illustrated in Fig. 2. The

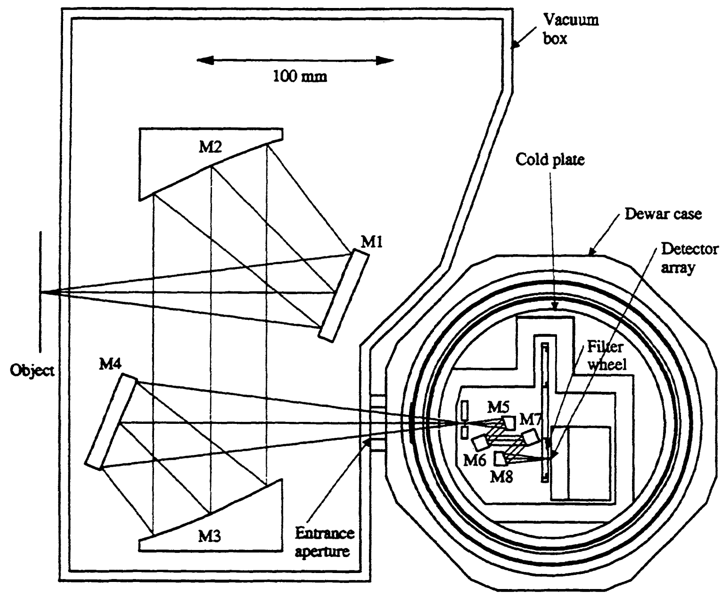

Fig. 1. Schematic layout of the terahertz camera.

optics consists of eight mirrors: mirrors M1, M2, M3 and M4 are in the vacuum box of ~ 10^{-3} Torr at room temperature, and mirrors M5, M6, M7 and M8 are cooled at 4.2 K in a 5-inch helium dewar. The distance between object and M1 is 150 mm. The beam is collimated by M2 and forwarded to the decollimator of M3 which focuses again at an entrance aperture of the dewar via the flat mirror of M4. An expanding beam inside the dewar is collimated by M5, and forwarded to the flat mirrors of M6 and M7, the latter of which is aperture stop. The decollimator of M8 reflects and focuses the beam on the 20 x 3 Ge:Ga detector array through the filter wheel. A long axis of the detector array is perpendicular to a plane on which the optical axis of the beam is arranged. The flat mirror of M1 is continuously scanned in the horizontal direction and it is shifted in the

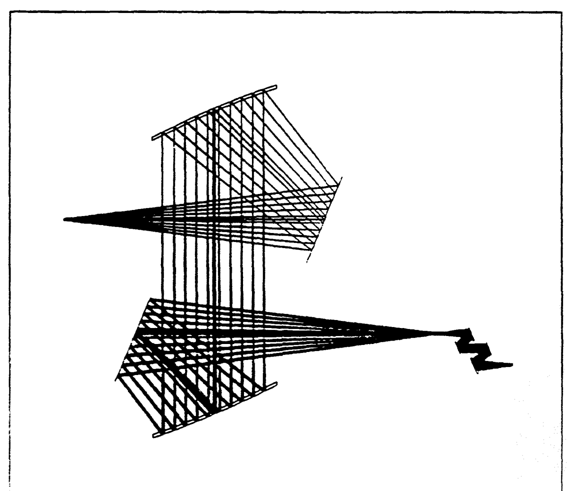

Fig. 2. Ray tracing for designing optics.

vertical direction by 6 times to take an image of 120 × 120 pixels, and the offset paraboloid mirror of M2 is straightly scanned on the optical axis to the M1 in order to adjust the focal depth. Ray tracing indicates that spot sizes (Fig. 3) are less than 0.25 mm even for the worst (off-axis edge) pixels, well below the pixel size of 0.5 mm square, and the image distortion is about 10 % of the pixel size even for the worst pixels. This implies that the performance of this optics is sufficient for the required resolution and the distortion. A field of view (60 × 60 mm^2) will be useful in observing biological and biomedical objects, such as a leaf or a skin of a human being.

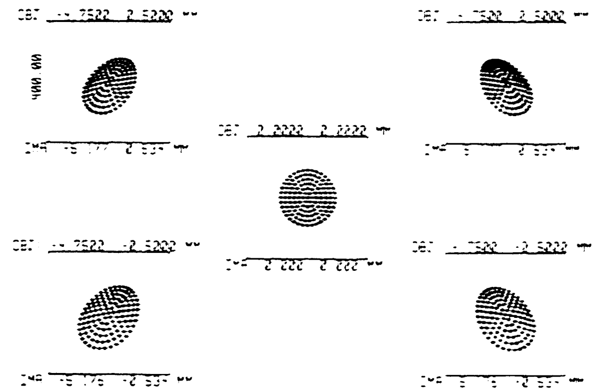

Fig. 3. Spot diagrams for the camera optics. OBJ is the position of object point, and IMA is the image point. The squares are 0.4 mm in size.

Better spatial resolution up to the wavelength of light can be obtained by decreasing a F-ratio of the input optics down to one-fifth of the present design.

ESTIMATED PERFORMANCE OF TERAHERTZ CAMERA

The camera will be used to map spatial variation in the terahertz properties of objects such as dielectric constants, emissivity, absorbance, and temperature, including the spectral properties of dielectrics and semiconductors, superconductors, biological objects, liquids, and gases. We estimate that noise equivalent temperature difference (NETD) at a background of 300 K is 0.09 K (Table I) for each area of 0.45 × 0.45 mm^2 with emissivity of 1.0, when it is measured with the object space of F-number of 4.1, spectral range of 300 GHz, and a integration time of 0.2 ms, which corresponds to a frame rate of 1.7 Hz. The optical quantum efficiency of the detector is supposed to be about 0.2. In the measurement of biological objects, we can, for example, detect the water content of a leaf because the emissivity of the water is different from that of leaf. We will obtain a signal-to-noise ratio of 49 dB for emissivity of 0.96 (water) and 0.90 (leaf). Better NETD can be obtained by increasing the integration time, decreasing the F-ratio of the input optics and increasing the spectral range. We can, for example, obtain NETD of 0.009 K by adopting an integration time of 6.1 ms and an input optics's F-ratio of 0.9. Using illumination of terahertz light, we will be able to have much higher contrast, because the water content inside the leaf causes strong absorption of far-infrared light. If far-infrared light of 1 mW is illuminated at behind the sample, a signal-to-noise ratio will increase to 79 dB.

TABLE I
Specifications and performance of the terahertz camera

Resolution of each detector	0.45×0.45 mm^2
F-number of object space	4.1
Field of view	60×60 mm^2
Format of array	20×3
Quantum efficiency	0.2
Spectral range	300 GHz
Minimum integration time	0.2 ms
Background	300 K
Emissivity of object	1.0
NETD (Noise equivalent temperature difference)	0.09 K

CONCLUSION

In this paper, we proposed a novel concept for the terahertz imaging system using Ge:Ga photoconductor array. The camera will have high performance for taking terahertz images with high resolution, high responsivity, and high S/N ratio. Construction of the camera system is progressing and applications to imaging of various materials including biological and biomedical objects will be carried out in the future work.

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