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Coherent THz Noise Sources

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Noise Source

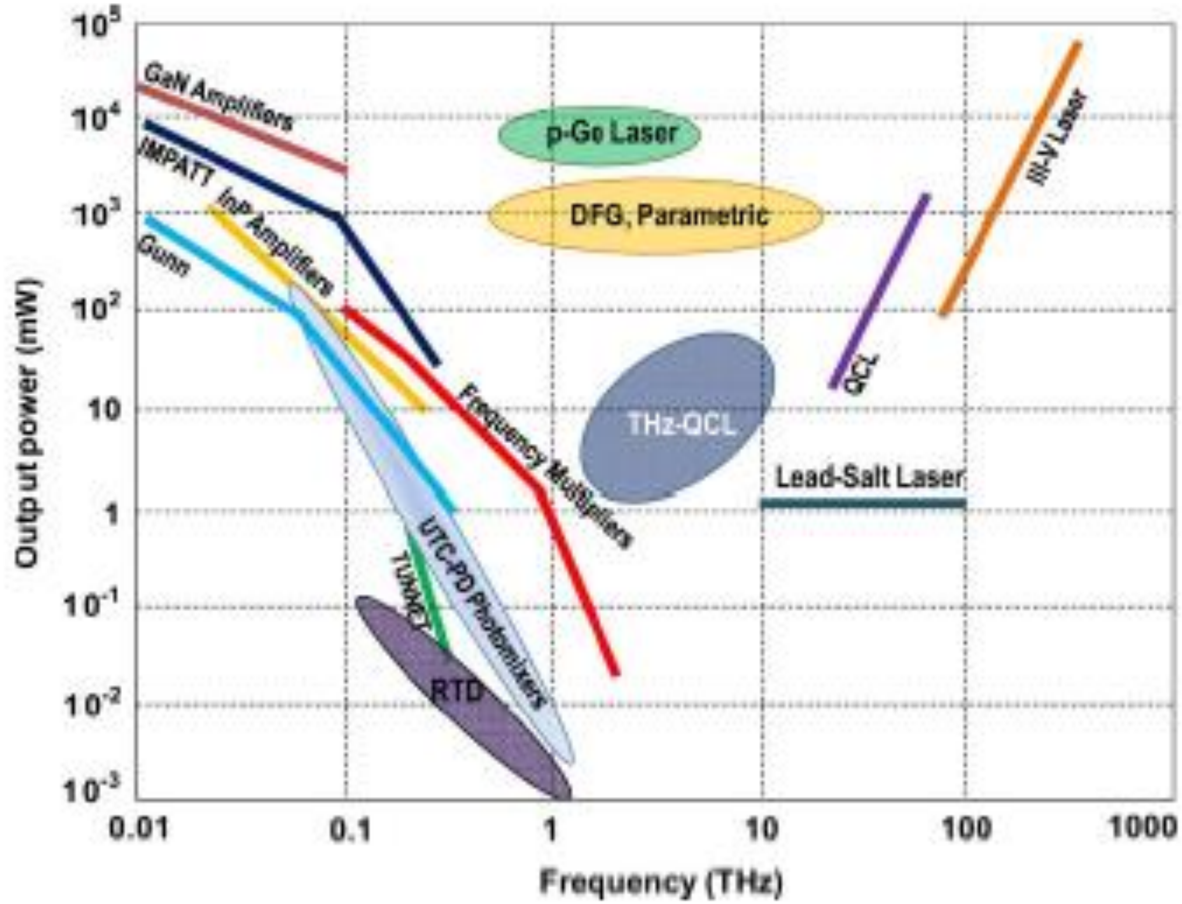
- An unusual source
  - Broadband
  - Incoherent
  - Lambertian emission
- Why consider it?

Power from various devices in the THz frequency range

- Electronic devices
  - Device current is modulated at frequency of emitted wave
  - Stuck on low frequency side of frequency range
  - Output power dropping with increasing frequency

- Photonic devices
  - Relaxation of a system from a higher energy state to a lower energy state emitting a photon in the process
  - Stuck on high frequency side of frequency range
  - Output power dropping with decreasing frequency

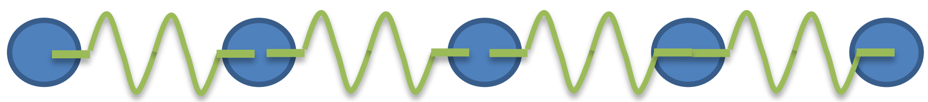
- The two methods do not overlap leaving a gap in frequency where there are no small, powerful portable sources of radiation



Chattopadhyay G.; "Technology, Capabilities, and Performance of Low Power Terahertz sources", IEEE Trans on THz Science and Tech.; Vol 1; No 1; Sept 2011

Material considerations

- Consider a simple model of a monatomic chain of atoms:-
  - Balls of mass m
  - Springs of the spring constant k
- Analysing the vibration modes of the chain produces a dispersion relation
  - Dispersion relation has one branch

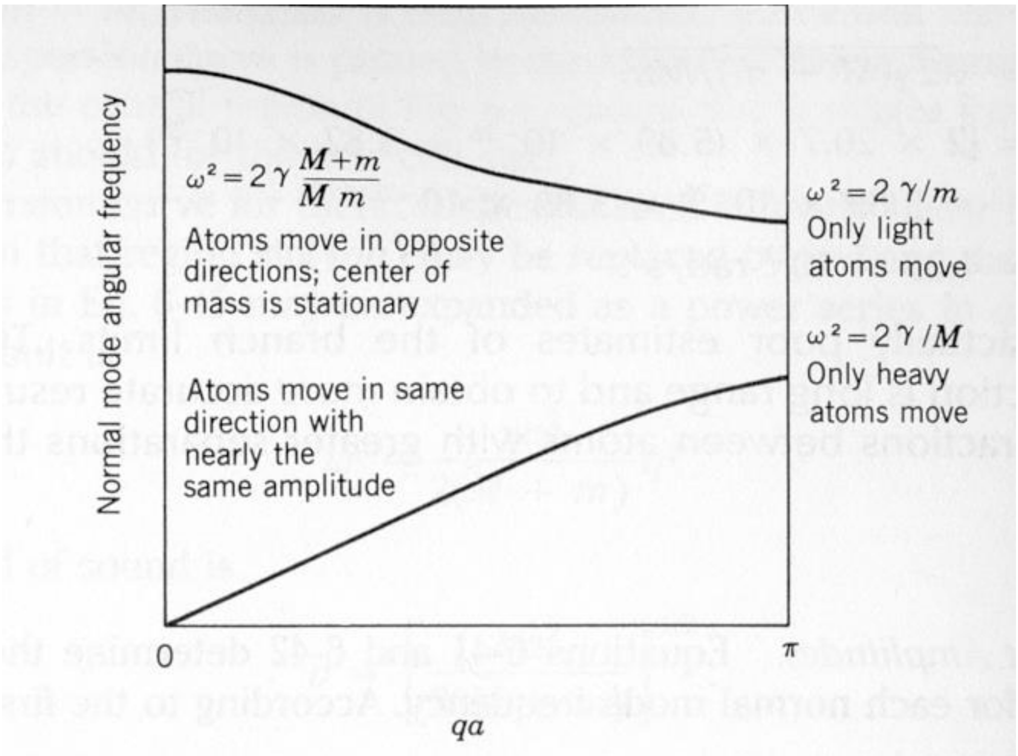


- Consider now increasing the complexity of the model by either:-
  - Changing the mass of alternative atoms - a diatomic chain of atoms e.g. GaAs
  - Changing the spring constant of alternative springs – atoms not at equivalent positions in lattice unit cell e.g. Si
- Dispersion relation has 2 branches
  - In a crystal these would be termed an ACOUSTIC and an OPTIC Phonon branch

Ideal dispersion relation for a diatomic chain

- Upper curve is optic phonon branch
- Lower curve is acoustic phonon branch
- This is essentially the same for a crystal

- If the bond between atoms leaves them slightly charged then there will be a dipole associated with the bond
  - Results in microscopic polarisation
  - Under such circumstances low wavevector, long wavelength, Optical Phonons will interact strongly with EM waves
    - Giving rise to the term Optical Phonon branch

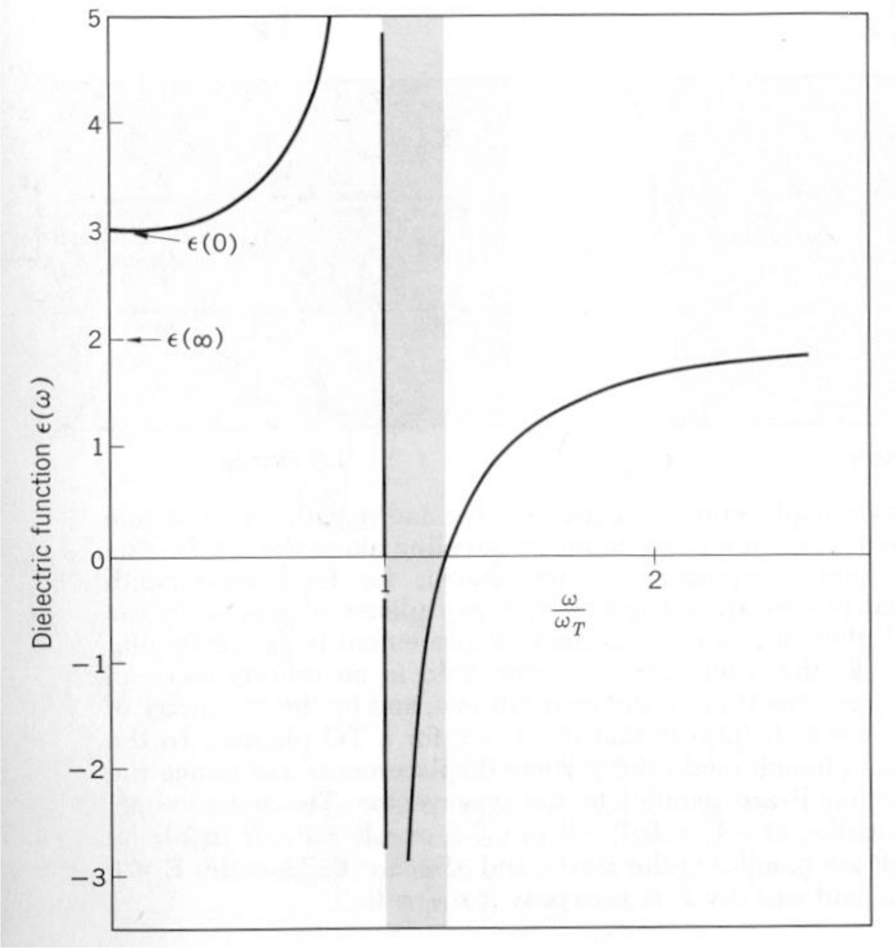


Dispersion relation for a diatomic chain

J.R. Christman Fundamentals of Solid State Physics

Interaction of EM radiation with Optic Mode Phonons

- This interaction will give rise to the dielectric function shown
  - This is the case in the compound semiconductors e.g. GaAs
- Between the TO and LO phonon frequencies EM waves cannot propagate through the crystal
  - The dielectric function is negative
  - The waves will be strongly attenuated
    - They will be evanescent



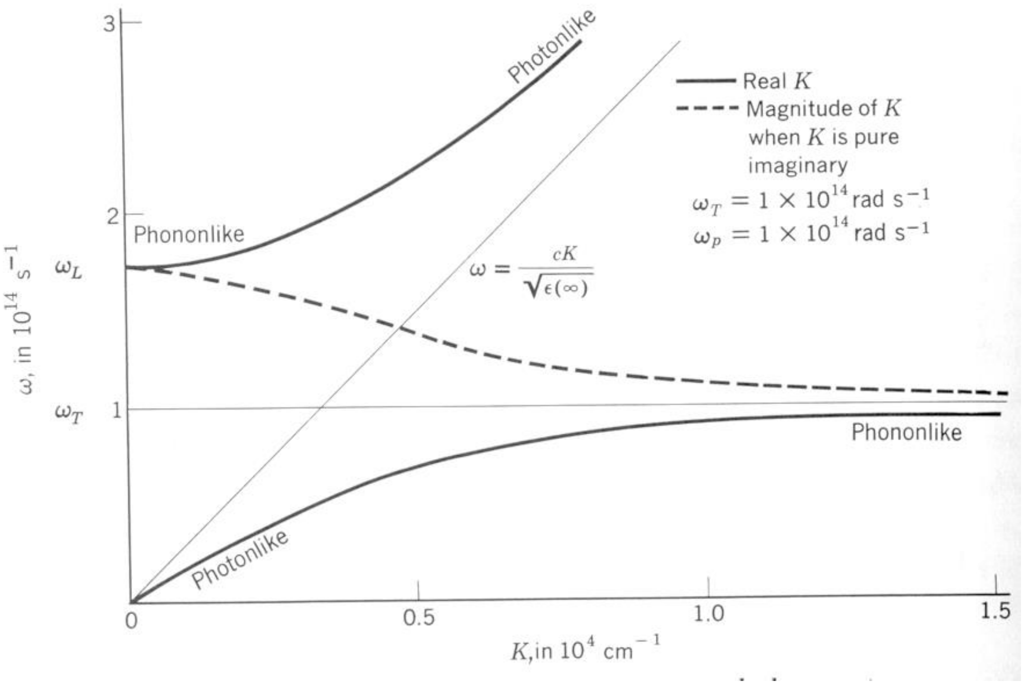
Dielectric function for Optical Phonon mode interaction with an EM Wave

C Kittel Introduction to Solid State Physics

Interaction of EM radiation with Optic Mode Phonons (cont.)

The dielectric function can be used to produce the dispersion relation shown:-

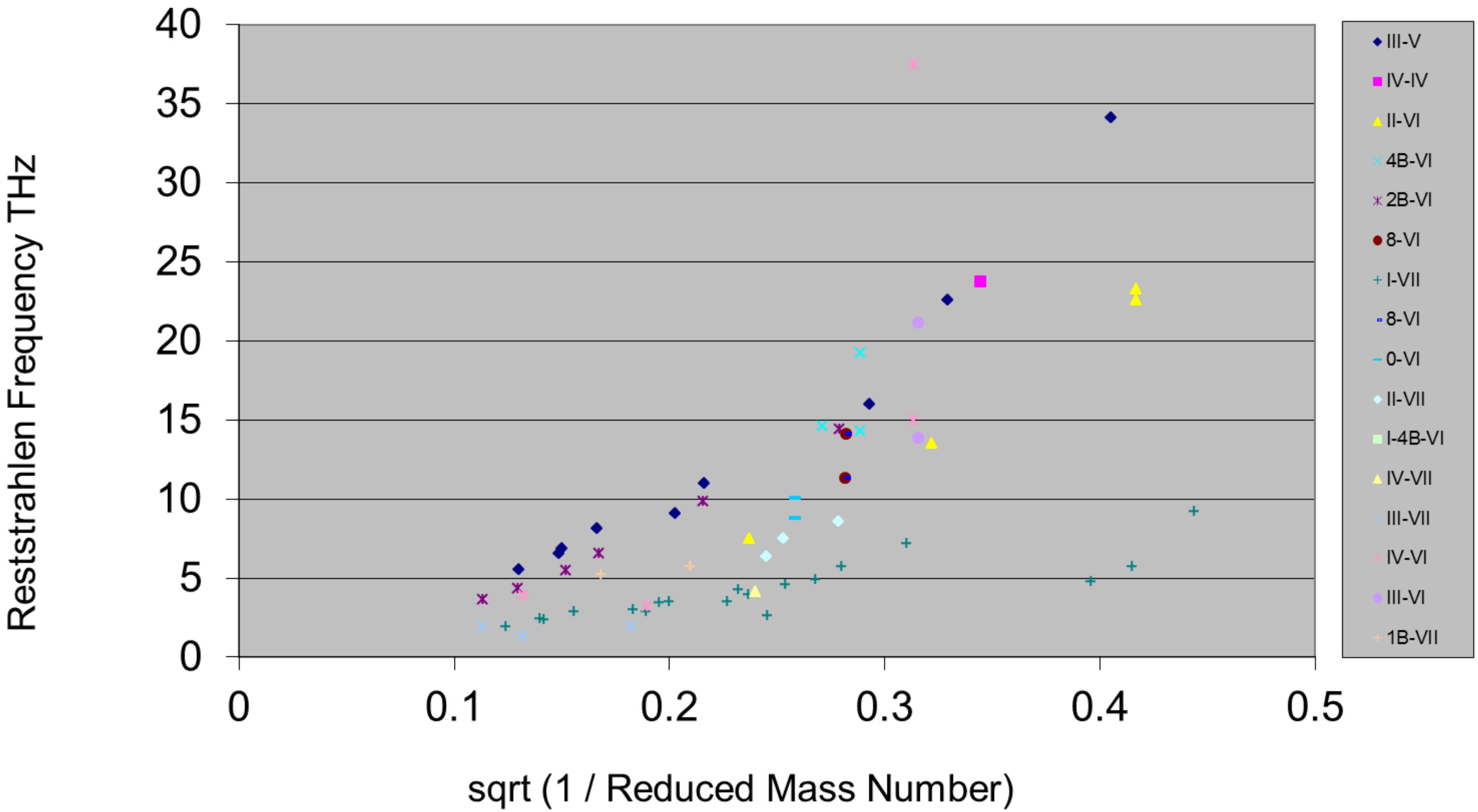
- Between the TO and LO phonon frequencies EM waves cannot propagate through the crystal
  - Phonon Polaritons
  - The dielectric function is negative
  - The waves will be strongly attenuated
    - They will be evanescent
- Waves impinging on the crystal will be strongly reflected
  - Gives rise to the Reststrahlen regions of such materials



Dispersion relation for Optical Phonon mode interaction with an EM Wave

C Kittel Introduction to Solid State Physics

Reststrahlen frequency against reduced mass for various two element combinations



Given that the phonon modes are active in the THz region can they be used to power an emission?

- All crystals will emit radiation in this frequency range
  - Black Body radiation
    - Generally they will not emit as well as a black body source
      - Surface emissivity
- Phonon Polariton dispersion relation does not cross the free space dispersion relation
  - Phonon Polariton modes are non-radiative
    - A periodic pattern on the surface is required to enable the phonon polaritons to emit
    - A grating pattern would also have the benefit of acting as a wave guide for the waves near the surface
- A surface will support longitudinal waves if

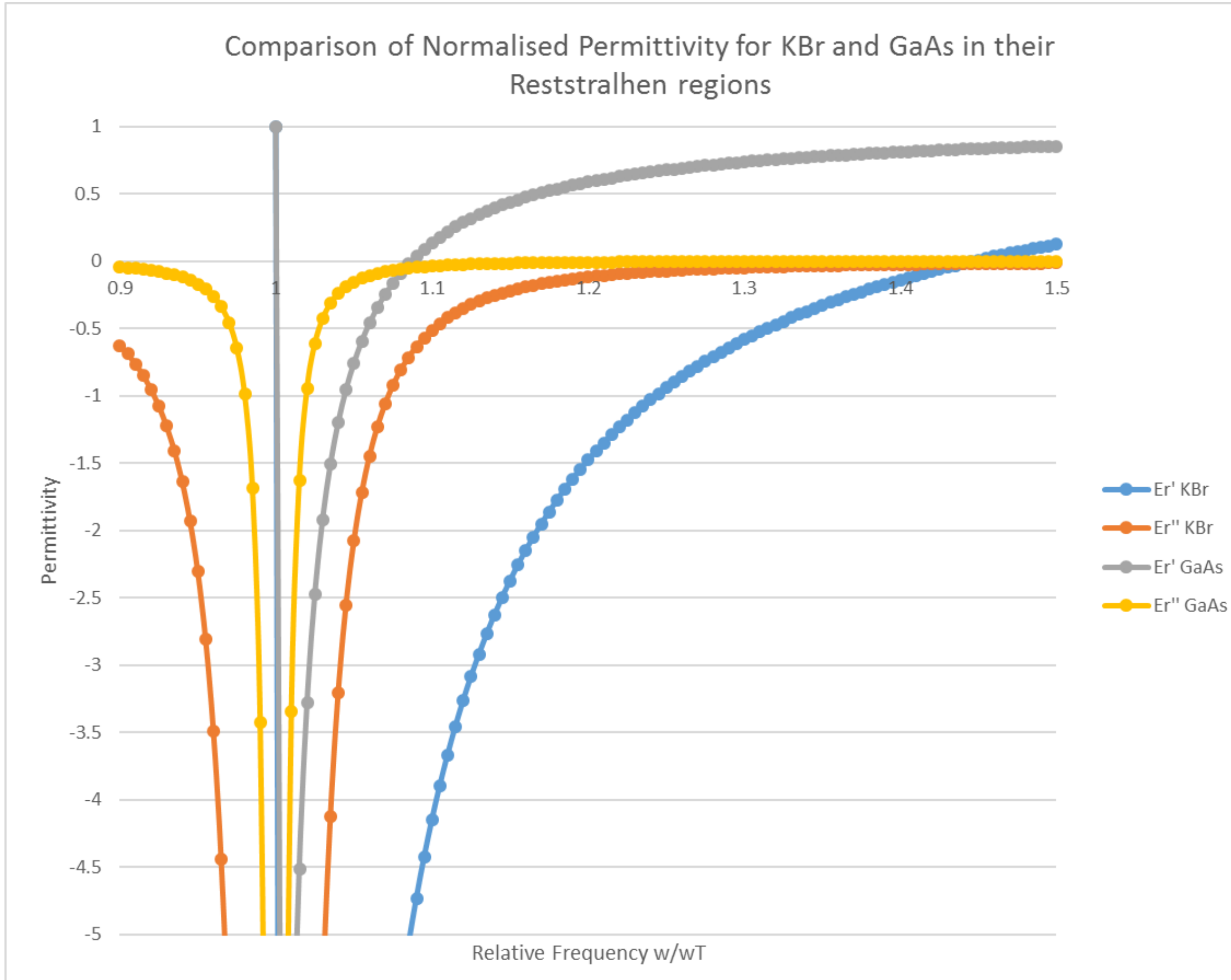
$$\varepsilon_1 = -\varepsilon_2$$

$\varepsilon_1 = 1$ air then $\varepsilon_2 \approx -1$

  - Thus a surface wave should be supported in the Reststrahlen region
  - The distance that the wave is supported for on the surface will determine the effectiveness of the source
      - Strength of the emission
      - Angular confinement of the emission

Proposed Source

- Aim is to pattern a grating on a alkali halide (KBr)
  - Support surface wave at ~ 4.3THz
- Depending on range of surface waves, expect
  - Quasi monochromatic emissions
  - power <10 uW
  - Angular confinement < 1°



SiC Thermal Source

- Different grating pattern dimension leads to a different radiation pattern
- Single emission lobe more appropriate for a source

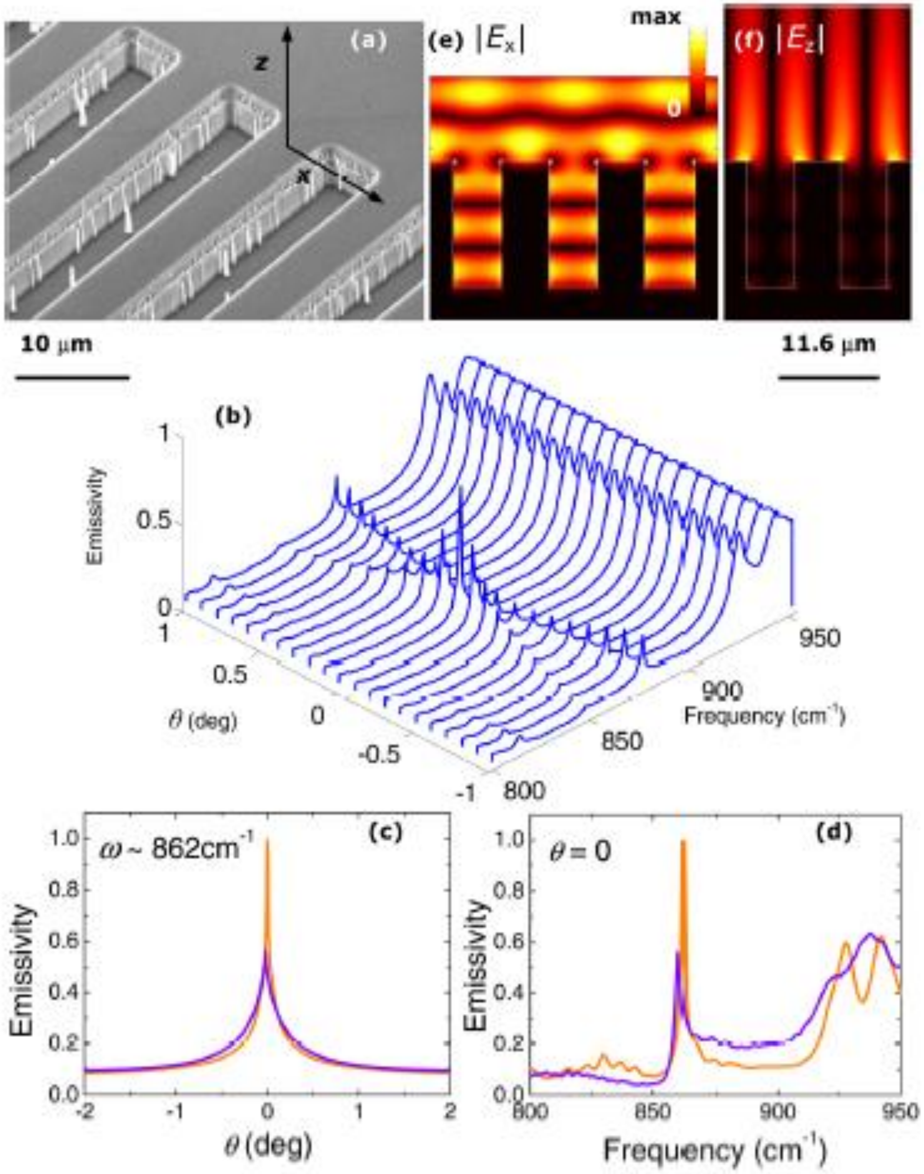


Fig. 2 (a) SEM image of CRC structure upon SiC, with period of 11.6 μm, fill factor 0.56, and cavity depth of 4.6 μm. (b) Theoretical emissivity distribution as a function of frequency and observation angle θ. (c) Calculated (orange) and experimental (purple) directional emissivity at the peak frequency and (d) spectral emissivity in the normal direction. (e) Calculated electric field distribution in the x-z plane, $|E_x|$ and (f) $|E_z|$.

Hasman E., Kleiner V., Dahan N., Gorodetski Y., Frischwasser K., Balin I.; 'Manipulation of Thermal Emission by use of Micro and Nanoscale Structures'; Journal of Heat Transfer; Vol 134; 031023