Overcoming Optical Resolution Limits in Terahertz Spectroscopy

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Current terahertz technology allows for more efficient imaging methods in fields such as biomedical imaging and microcircuit analysis. In fields such as biomedicine, terahertz radiation exhibits properties similar to x-rays. However, unlike the x-ray, a terahertz ray can be focused and behaves like an optical beam, and because of its low energy levels it is harmless to living tissue. In microcircuit analysis, the radiation emitted from a semiconductor is proportional to the local electric field in an optically excited area. Thus, one can use an imaging device such as a Laser Terahertz Emission Microscope (LTEM) to analyze microcircuits for faults without harming an integrated circuit. My current research project involves firing a Ti sapphire femtosecond laser at Au electrodes on a GaAs substrate; which will cause terahertz waves to be emitted and allow image readings to be performed by the LTEM. One hurdle faced with terahertz spectroscopy is optical resolution. Optical resolution limits are set by the wavelength and the numerical aperture (**NA**). Utilizing equipment with 0.40**NA** and a wavelength of ~800nm, resolutions at Tonouchi Lab have been limited to approximately 4~5 microns. However, these current systems can possibly be improved. Using devices such as a beam expander and a solid immersion lens, the beam may first be expanded and then focused through a solid immersion lens into a smaller spot diameter. In principle, this should allow for resolutions proportionally smaller than have previously been possible. If the results of these experiments are positive, then current systems can be greatly improved at a lesser expense. This ability to achieve smaller resolutions may prove to be beneficial, not only to those labs performing terahertz spectroscopy, but hopefully in other areas of photonic research as well.

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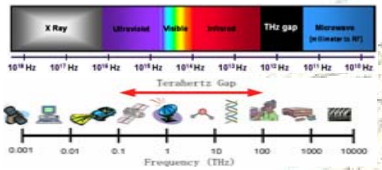
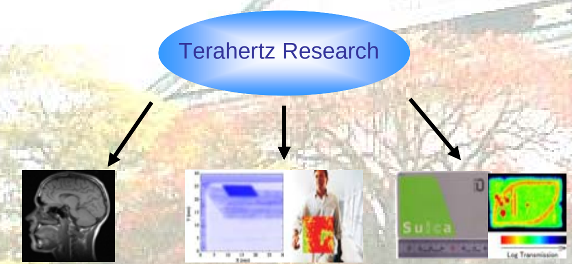
Abstract

Current terahertz technology allows for more efficient imaging methods in fields such as biomedicine and microcircuit analysis. Members at Tonouchi Labs in Osaka University have realized this and have developed a device called a Laser Terahertz Emission Microscope (LTEM) which is capable of detecting terahertz emissions from a device. However, one hurdle faced with terahertz spectroscopy is optical resolution. Optical resolutions at Tonouchi Labs have been limited to approximately 5 microns. The wavelength and the numerical aperture (NA) of an imaging system determine these limits. Thus, installing an objective lens with a high numerical aperture (0.40NA) in the LTEM may possibly improve both resolution and detection in the current system. My research project at Tonouchi Labs entails designing a sample with Au electrode branch pairs on a GaAs substrate. Each branch pair contains a line-space design with diminishing microscopic spatial distances. Projecting a Ti sapphire femtosecond laser through an API 20x objective lens at these electrodes will cause terahertz waves to be emitted. Hopefully, these improvements to the spectroscopy system will allow image readings to be performed by the LTEM and allow for resolutions under 5 microns.

The World of Terahertz: "Terahertz Gap…"



Even a person, who is very unfamiliar with photonics, knows how to turn on a radio, but even most scientists and engineers up to now know very little about phenomena in the terahertz frequency region. Thus, it is called the "Terahertz Gap." The Terahertz Gap, which lies approximately between $3x10^{11}$ Hz and $3x10^{12}$ Hz, is a frequency range in the electromagnetic spectrum where little is known, but promises to be very beneficial in the future. This is because terahertz radiation posesses some very unique qualities.



Safe Bioimaging | Nonintrusive Security | Non-destructive Circuit Analysis

Objectives:

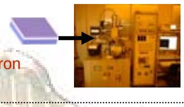
Overcome current LTEM resolution limit of 5μ by:

A. Designing electrodes on GaAs substrate with low spatial widths (10μ-4μ).
B. Testing device on LTEM with and without high NA objective lens.
C. Making any adjustments necessary to sample or LTEM system to achieve higher resolution.

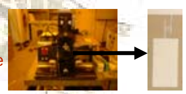
Method

Preparation:

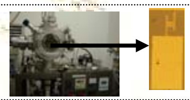
1. Prepare the design using CAD.



2. Prepare a chrome mask using an electron beam gun.



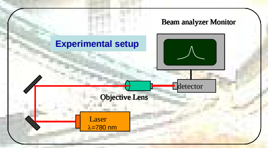
3. Expose ultraviolet rays through the mask onto a photoconductive substrate (gallium arsenide).



4. Sputter gold onto the substrate.

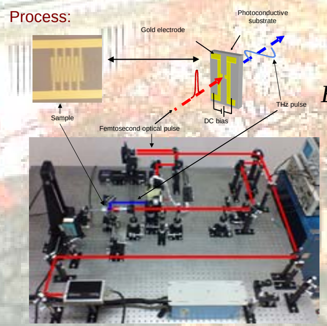
5. Perform femtosecond laser beam profiling with and without objective lens.

Without Objective Lens | With 10x 0.26NA Lens | With 20x 0.40NA Lens



$$d = 0.61 \times \frac{\lambda}{NA}$$

Process:



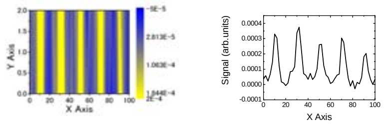
$$E \propto \frac{\partial i(t)}{\partial t} \propto \frac{\partial^2 P(t)}{\partial t^2}$$

Laser Terahertz Emission Microscope (LTEM)

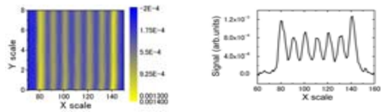
- Sample is mounted onto the LTEM.
- Each electrode branch pair is illuminated by a fs laser.
- Terahertz emission is detected and processed by LTEM.
- Data is plotted by scanning imaging software.

Results

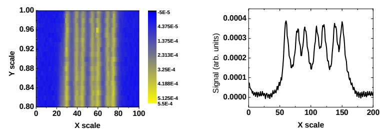
10 micron space using 10x objective lens:



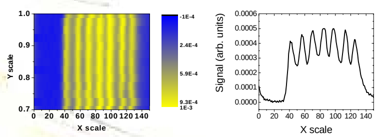
5 micron space using 10x objective lens:



5 micron space using 20x objective lens:



4 micron space using 20x objective lens:



Conclusion:

The 10-micron experiment and the 5-micron experiment came out very well. However, we were most concerned with attaining resolutions under 5 microns, and were able to accomplish this task by arriving at a 4-micron resolution using the 20x lens, thus, attaining terahertz emission readings that have never been achieved before. Such results will allow for improved readings in fields such as microcircuit analysis. Reaching smaller resolutions may prove to be beneficial, not only to those labs performing terahertz spectroscopy, but hopefully in other areas of photonic research as well. With further testing and improvement, I foresee T-rays becoming the new wave in many industries.

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