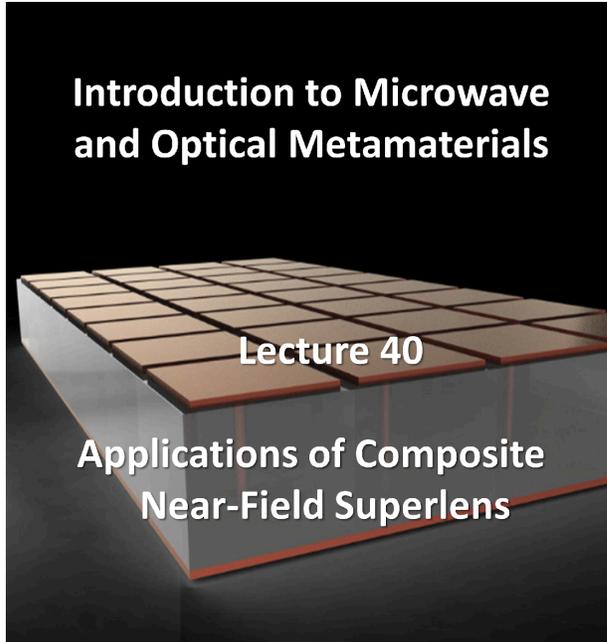


Course Name: Introduction to Microwave and Optical Metamaterials
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Week-8
Lecture-40

Lec 40: Applications of Composite Near-Field Superlens



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Lecture Outline

- Potential Applications of Composite Near-Field Superlens (NFSL)
 - Limitation of NFSLs: Far-Field Imaging
- Far-Field Imaging with Super-Resolution
 - Limitations of Far-Field Superlenses
 - ✓ Optical Hyperlens
 - Challenges & Improvements in Cylindrical Hyperlenses
 - ✓ Plasmonic Hyperlenses: Planar Hyperlenses
 - ✓ Stacked Nanorod Lenses

Hello everyone, welcome to Lecture 40 of the online course on Introduction to Microwave and Optical

Potential Applications of Composite NFSL

- Random **metal-dielectric composite films** show great promise for creating versatile and wavelength-controllable near-field superlenses (NFSLs).
- This tunability is key for applications like:
 - Bio-sensing;
 - Spectroscopy;
 - Sub-wavelength imaging; and
 - Nanolithography.
- **First Application: Surface-Enhanced Remote Bio-Sensing:** Surface-Enhanced Raman Scattering (SERS) for bio-molecules

➤ Conventional SERS:

- SERS requires molecules to be directly on a metal surface to benefit from field enhancement.
- Metal surface with nanoscale roughness enhances Raman scattering.
- Molecules directly contact the metal → risk of undesired modifications (e.g., charge transfer, denaturing).
- Results in spectra represent signatures of metal–molecule complexes, not pure molecules.

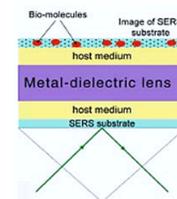


Fig. 1: Application of composite NFSL designs: Remote SERS sensing

Potential Applications of Composite NFSL

- **First Application: Surface-Enhanced Remote Bio-Sensing:** SERS for bio-molecules

- **Composite NFSL-based approach:** (Fig. 1)

- NFSL images SERS-active substrate → high local fields projected to other side of lens.
- Bio-molecules are placed away from metal surface.
- This method has two main advantages:
 1. **Preservation of Molecules:** The bio-molecules are removed from direct contact with the metal, preventing undesired modifications and ensuring the measured spectra accurately represent the molecules.
 2. **Tunability:** The use of a tunable NFSL made from a composite film is more convenient than a pure silver lens, which can only operate at a single UV wavelength.
 - This is especially important since semi-continuous films are more effective for SERS at longer wavelengths, which a pure silver lens cannot achieve.

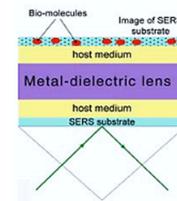


Fig. 1: Application of composite NFSL designs: Remote SERS sensing

Metamaterials. Today's lecture will be on applications of composites for near-field superlenses. We discussed the basic composite near-field superlens in the previous lecture. So, in this lecture, we will look into the potential applications of composite near-field superlenses. What are the limitations of this near-field superlens? in the area of far field imaging and then we will look into far field imaging with super resolution. There, we will also discuss the limitations of far-field superlenses, and then we will move on to optical hyperlenses, okay? Then we move on to discuss challenges and improvements in cylindrical hyperlenses.

We will consider plasmonic hyperlenses, which are planar hyperlenses, and then we will also discuss stacked nanorod lenses. So, let us first focus on the potential applications of composite near-field superlenses. So, random metal dielectric composite films have shown great promise for creating versatile and wavelength controllable near field superlenses, right. So, this tunability is key for applications such as biosensing, spectroscopy, sub wavelength imaging and nanolithography.

So, the first application we will discuss today will be surface-enhanced remote biosensing. So, surface-enhanced raven scattering, which is basically SCRS, can be used for biomolecules. So, in the conventional SCRS, it basically requires the molecules to be directly on the metal surface to benefit from the field enhancement. Now, the metal surface has nanoscale roughness. Act as small nano scatterers, and they can give rise to electric hotspots.

They can basically enhance the Raman scattering effect because the local intensity of the

electric field is amplified several *. However, in this particular case, the molecules basically come in direct contact with the metal. So, that has got the risk of undesired modifications such as you know charge transfer or denaturing ok. So, that basically results in the search spectra uh representing you know signatures of metal molecule complexes not only just of the pure molecule so this is typically the search setup okay you don't have this part so this is where you can use uh this Near-field superlens for SIRS sensing. We will look into this in more detail here.

So, this is the first application we will be discussing today: surface enhanced remote biosensing. So, the SIRS for biomolecules can be done using this kind of a setup where you are basically using a composite near field superlens based approach right. So, this near-field superlens basically images a SIRS-active substrate. So, this is where your substrate is. So this basically allows, this super lens basically allows projection of the high local fields onto the other side of the lens where you can put the biomolecules.

So that is how you can see that the biomolecules are basically placed far from the metal surface. So this particular method has two advantages. First of all, Preservation of the molecules that means you know in this case the biomolecules are not coming in the direct contact of the metal. So you can prevent any undesired modifications, and you can also ensure the measured spectra are basically coming only from the biomolecules, right? And then you can also have tunability in such a system. Okay, so here is your lens; here is the host medium.

So this overall thing basically works as a near-field super lens. So on the other side you say you are basically putting some kind of medium with

Potential Applications of Composite NFSL

- **Second Application: Non-Invasive Intra-Object Imaging** (fig. 2)

- Applications of Metal–Dielectric NFSLs in Biomedicine

- Challenge in Biomedical Imaging:

- ✓ Need: probe internal structures of intact cells/spores with sub-wavelength resolution.

- **NSOM (Near-field Scanning Optical Microscopy):**

- ✓ NSOM can achieve sub-wavelength resolution, but it requires the optical fiber tip to be within a few nanometers of the object being probed.
 - ✓ Limitation: This makes it impossible to probe inside intact cells or biological objects without potentially damaging or destroying them.

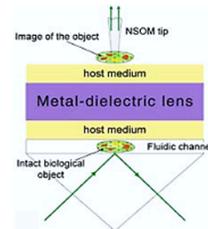


Fig. 2: Application for composite NFSL designs: Non-contact bio-molecule probing

Potential Applications of Composite NFSL

- **Second Application: Non-Invasive Intra-Object Imaging** (fig. 2)

- Applications of Metal–Dielectric NFSLs in Biomedicine

- **Composite NFSL Solution for Non-Invasive Imaging:**

- The proposed solution uses a metal-dielectric superlens to create a non-invasive imaging system.
 - This superlens projects the image of the bio-object onto the other side of the lens.
 - An NSOM tip can then scan this image remotely without ever physically touching the object itself.
 - This technique allows for the observation of internal structures in intact biological samples, which is crucial for biomedical analysis and detection of biological agents.

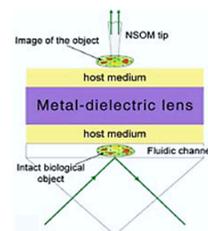


Fig. 2: Application for composite NFSL designs: Non-contact bio-molecule probing

biomolecules and this is where you can get the image of the search substrate. So, this is a glass prism that has this kind of reflection, and some portion is basically getting attached here. So, this is basically a metallic substrate, which is typically a search substrate that people use.

Now, what you get here in terms of tunability because use of this kind of tunable near

field super lens as we discussed in the previous lecture that you can change the volume fraction of the metal and can get this super lens work at a desired frequency right. So, it is much more convenient than a pure silver lens because that silver lens works only at a particular wavelength that is in the UV range. So, this is especially becoming important since semi-continuous films are more effective for ACRS at longer wavelength which a pure silver film or silver lens cannot achieve. Now, the second

Potential Applications of Composite NFSL

Third Application: Applications in Nanofabrication

Nanoscale Optical Manufacturing: (fig.3)

- Tunable NFSL can be used for nanoscale optical manufacturing.
- By using an appropriately designed composite (tunable) NFSL instead of a single-material silver slab, manufacturers can use a variety of available laser sources.
- This makes the nanofabrication process more versatile and less expensive.
- As shown in the schematic, the tunable NFSL projects an image of a mask onto a photoresist layer, with a spatial resolution far below the diffraction limit.
- This capability enables laser-based nano-manufacturing with unprecedented precision.

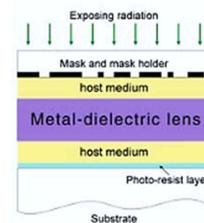


Fig. 3: Application of composite NFSL designs: Nanoscale lithography

Limitation of NFSLs: Far-Field Imaging

Limitation of NFSLs:

- NFSLs are limited to the near-field zone, restricting their use in applications like direct optical imaging with cameras or human eye.
- While a perfect lens could theoretically provide far-field super-resolution, this is not currently possible due to inherent losses in existing negative-index metamaterials (NIMs).
- The following addresses a solution to this problem: achieving far-field subwavelength resolution without using NIMs.

Far-Field Superlensing (FFSL) Mechanism:

- One method to overcome the diffraction limit in the far-field is to convert enhanced evanescent waves from an NFSL into propagating waves.
- This is achieved by adding a **periodic subwavelength grating** to the outer surface of silver superlens, which acts as a coupling element.
- The grating's periodic corrugations facilitate the conversion of some evanescent modes into propagating waves, allowing them to travel into the far-field.

application will be non-invasive intra-object imaging. Now, the setup is shown here for non-contact biomolecule probing using a composite near-field superlens.

So, here we are basically seeing the application of this metal-dielectric near-field superlens in biomedicine. Now what are the challenges in biomedicine, or you can say biomedical imaging? You basically need to probe the internal structures of intact cells or spores with subwavelength resolution. So, normally what you do is NSOM, which is near-field scanning optical microscopy. So, NSOM cannot achieve sub wavelength resolution, but it basically requires the fiber optic tip to be within very few nanometers of the object that is getting probed. So, what are the limitations of this approach? This basically makes it impossible to probe inside an intact cell or biological objects without damaging or destroying them.

Now, if you use this kind of metal-dielectric near-field superlens for biomedicine, what happens? You can use this lens solution for noninvasive imaging. So, how does it work? You can basically use this super lens that can create a non-invasive imaging system, right? So, this super lens can basically project the image of the bio object onto the other, you know. So, this is the intact biological object in a fluidic channel. This super lens can basically you know give you the image of this actual object here okay on the other side and then you can bring a nsum tip to scan that image remotely without ever physically touching the actual object, okay. So, this technique basically allows for observation of the internal structures in intact biological samples which is very crucial for biomedical analysis and also detection of the biomedical agents.

Now, the third application is in the field of nanofabrication. So, here you can see nanoscale optical manufacturing; we are considering nanoscale lithography, where a tunable near-field superlens can be used. So, by using an appropriately designed composite tunable near field superlens instead of using a single material silver slab, manufacturers can use a variety of available laser sources because this is tunable. So, this basically makes the nanofabrication process more versatile, and it becomes less expensive as well. So, as you can see here, because you have this tunable near field super lens that can project the image of a mask which is placed here with spatial resolution which are far below the diffraction limit onto this photoresist layer which is deposited on a substrate.

Now, because this lens is tunable, you can use different lasers. you expose radiation from the top and that images can be formed here. So, you can basically get laser-based nanomanufacturing with unprecedented precision. Now, what are the limitations of this near-field superlens? we could see that they are limited in the field of far field imaging because all the applications we have seen till now that near field super lens as also the

name suggest. It is limited to the near field zone basically restricting their use in applications like direct optical imaging with camera or human eye which are basically far field imaging right.

So, while a perfect lens can theoretically provide fulfilled super resolution, but that is currently not possible due to the inherent losses that exist in the negative index

Far-Field Imaging with Super-Resolution

- **Experimental Demonstration:** (shown in fig. 4)
 - A properly designed subwavelength grating was added to a 35 nm-thick silver superlens.
 - This system operates at surface plasmon frequency of silver-polymer interface (377 nm).
 - This enables to achieve far-field image of a pair of 50 nm-wide nanoslits separated by a 70 nm gap.
 - Without FFSL → conventional microscope fails to resolve.
- **Advantages over Near-Field Microscopy:**
 - Far-field superlens projects subwavelength details into the far-field, allowing for simultaneous image capture.
 - Avoids slow point-by-point scanning (needed in NSOM).

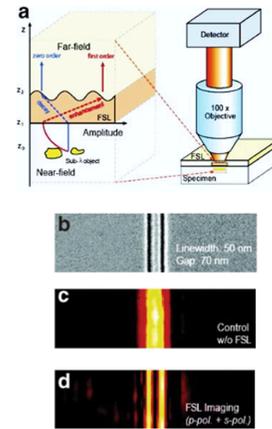


Fig. 4: (a) Schematic of FFSL and its adaptation in a conventional microscope; (b) SEM image of a nanoslit-pair object; (c) Diffraction-limited image of object from a regular optical microscope; (d) FFSL resolves subwavelength details of object.

Limitations of Far-Field Superlens

- **Limitations of Far-Field Superlens:**
 - **Proximity to Specimen:** The specimen must still be placed very close to the superlens surface to prevent the evanescent waves from decaying before they can be converted.
 - **One-Dimensional Features:** The one-dimensional grating only converts evanescent modes along a single direction, limiting the system to resolving subwavelength features of one dimensional objects.
 - ✓ Works well only for 1-D objects (e.g., slit pair).
 - **Intrinsic Wavevector Limitation:** There is an inherent limit to the range of evanescent wavevectors that can be converted.
 - ✓ The system can only retrieve waves with transverse vectors between nk_0 and $nk_0 + k_g$, where n is the refractive index of surrounding material and k_g is the grating wavevector.
 - ✓ This limitation restricts the best achievable resolution. To resolve a wider range of features, more complex methods like using higher-order coupling elements are needed.

Far-Field Imaging with Super-Resolution

- **Optical Hyperlens** - Converting Evanescent to Propagating Waves
 - Concept & Mechanism:
 - An **optical hyperlens** is an alternative to a grating-based superlens i.e.; far-field superlensing.
 - It is a metamaterial that can convert an object's evanescent waves into propagating waves in the far field.
 - Instead of using a periodic grating for coupling, a hyperlens uses its unique cylindrical geometry to gradually reduce the transverse wavevectors of evanescent waves until they fall below free-space light wavevector.
 - This transforms them into propagating waves that can be collectable in far field by conventional optical devices.

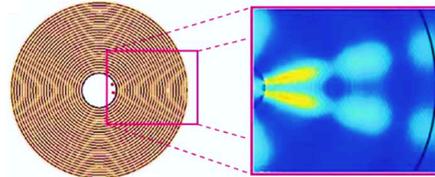


Fig. 5: Magnification and beaming effects in a hyperlens consisting of alternating metal and dielectric layers

metamaterials ok. So, we have discussed this as well because you need material to make those lenses, and they are not lossless. So, the following thing addresses the solution to the problem. So, you can achieve far field super resolution you can achieve far field subwavelength resolution without using the negative index material. So, how do you do that? So, we are now looking into the mechanism of this far-field superlensing.

So, one method to overcome the diffraction limit in the far field is to convert enhanced evanescent waves from the near field superlens to propagating wave ok. So, you can actually achieve this by adding a periodic sub wavelength grating to the outer surface of the silver superlens which will basically act as a coupling element. Now, the grating's periodic configuration will facilitate the conversion of some evanescent modes into propagating modes. So, allowing them to basically travel in the far field and that you can use for imaging. So, now let us look into this particular topic in a little bit more detail: far-field imaging with super resolution.

So, figure 4 shows an experimental demonstration of far-field imaging with super resolution. So, A shows the schematic of the far-field superlens and its adaptation in a conventional microscope. You can see the far-field superlens / here. This is how it looks. So, here is the SEM image of the nanoslit pair object.

So, normally if you do with a regular optical microscope you will see you are not able to detect the two slots or the nano slot clearly. Because they are diffraction limited, but when you go for FSL images that means far-field super lens images, you see you are able

to get this subwavelength details, right. So, here are some specifications of this particular fur-filled super lens. So, they have used a properly designed subwavelength grating that was basically added to a 35 nanometer thick silver super lens. And the system basically operates at the surface + bond frequency of the silver polymer interface, which is 377 nanometers, and this is achieved.

or this is enabled to achieve the far-field image of a pair of 50 nanometer wide nano slits which are basically separated by a 70 nanometer gap. So, you can see these values are much smaller than the wavelength involved here. So, without this far-field superlens, you can see that the

Far-Field Imaging with Super-Resolution

Optical Hyperlens

Design Principle:

- A hyperlens is a cylindrical (or spherical) metamaterial made of alternating metal and dielectric layers as shown in fig. 5.
- These layers are arranged concentrically so that the two effective permittivities have opposite signs:
 - ✓ Condition for hyperlens: radial permittivity ($\epsilon_r < 0$), tangential permittivity ($\epsilon_\theta > 0$).
- This condition creates a hyperbolic iso-frequency curve, which gives the hyperlens its unique properties:
 - ✓ Arbitrarily large wavevectors: The hyperbolic surface allows for wavevectors of any size, enabling the collection of sub-wavelength information.
 - ✓ Poynting vectors of Fourier components align radially \rightarrow beamlike outward radiation.
 - ✓ Magnification: The hyperlens magnifies the image of a sub-wavelength object, with:
 - Magnification = (outer radius / inner radius) of hyperlens.
 - ✓ This magnification allows the sub-wavelength features to be enlarged and observed using a conventional optical microscope.

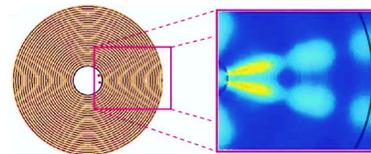


Fig. 5: Magnification and beaming effects in a hyperlens

conventional microscope basically fails to resolve. However, with that you can actually with the far field super lens you can basically resolve. So, what is the advantage of near-field microscopy? In the far field, a superlens that basically projects the sub-wavelength details into the far field.

So, that allows for simultaneous image capture and it basically avoids a slow point-by-point scanning that is needed in the near-field scanning optical microscopy. Now, this also comes with some limitations. So, the limitations of Farfield superlens are that the specimen must still be placed very close to the superlens substrate to prevent the evanescent waves from decaying before they are basically converted into propagating waves by the grating. So, another important aspect is that you know the one-dimensional grating only converts evanescent modes along a single direction. So, you are basically losing some of the information.

So, that limits the system to resolving sub wavelength features of one dimensional objects only right. So, this basically works only for 1D objects, which are like slit pairs. So, when you go for higher-dimensional systems, this 1D grating is not going to work right. So, there is basically an inherent limit to the range of the evanescent wave factors that can be converted. So, the system can basically only retrieve waves with transverse vectors that are between nk_0 and $nk_0 + k_g$.

So, n here is the refractive index of the surrounding material, and k_g is basically the grating wave vector. Now, this limitation basically restricts the best achievable resolution. So, to resolve a wider range of features, more complex methods, such as higher-order coupling elements, will be needed. Now let us look into the methods of performing far-field imaging with super resolution. So you can take the help of optical hyperlens, which are good at converting evanescent waves to propagating waves.

So, what is the concept here? Optical hyperlens is basically an alternative to grating-based superlens that is used for far-field superlensing. So, a hyperlens is basically a

Far-Field Imaging with Super-Resolution

Optical Hyperlens

- Experimental Demonstration (Berkeley group, 2007): Fig. 6
 - Structure: Half-cylinder quartz substrate with 16 alternating layers of Ag/Al_2O_3 , each 35 nm thick.
 - Object: Nanoscale chrome patterns on inner surface.
 - Hyperlens operated at an UV wavelength of 365 nm and provided a magnification of : $\sim 2.3\times$.
 - Sub-diffraction resolution achieved: 130 nm
 - Example: Successfully imaged an "ON" pattern with a line width of 40 nm (see fig. 6(b)) .
- Potential Improvements:
 - Using a spherical geometry instead of a cylindrical one could further improve performance by uniformly magnifying and faithfully restoring the object's image on the outer surface.

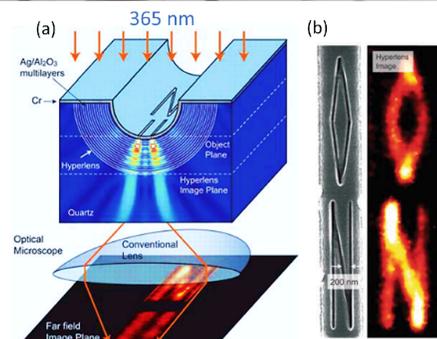


Fig. 6: (a) Schematic of hyperlens demonstrated by the Berkeley group; (b) An arbitrary object (the text "ON") and its hyperlens image with sub-diffraction resolution

metamaterial that can convert an object's evanescent waves into propagating waves in the far field. So, instead of using a periodic grating for coupling, A hyperlens uses a unique cylindrical geometry that gradually reduces the transverse wave vector of the evanescent waves until they fall below the surface. Free space light wave vector. And this basically transforms them into propagating waves that can be collected in the far field using conventional optical devices, right? So, this is one example of the magnification and beaming effect that you see in a superlens.

So, these are the two objects which are in sub wavelength spacing that can be magnified ok and then you can come out of the sub wavelength domain because of this magnified objects ok and these are created by alternating metal dielectric layers. So, we can look into the design principle in more detail in this particular slide. So, here you see a hyperlens is a cylindrical or spherical metamaterial that is made of alternating metal and dielectric layers as you can see here ok. So, these layers are basically arranged concentrically. So, these are basically concentrically repeated layers.

So, you basically need to make sure that the two effective permittivities have opposite signs. So, the condition for the hyperlens is such that the radial permittivity is negative and the tangential permittivity is positive. That is, ϵ_r will be negative, and ϵ_θ will be positive. Now this condition basically creates the hyperbolic isofrequency curve. So that means you have a hyperlens that has some unique properties.

Now when you have hyperbola as your isofrequency curve what is the exciting thing there you can actually achieve arbitrarily large wave vector ok because the hyperbolic surface will allow wave vector of any size. So, if your wave vector is very very large your wavelength can be very very small that means it enables the collection of sub wavelength information. The next thing is that the pointing vectors of the Fourier components basically align radially. You will get a beam-like outward radiation. So, how can you use that? You can use this feature for magnification, which means the hyperlens basically magnifies the image of a sub-wavelength object.

So, where the magnification is basically obtained by dividing the outer radius by the inner radius of the hyperlens. So, this magnification allows the sub-wavelength features to be enlarged and, you know, observed using a conventional optical microscope. So, if you zoom in and make those features large enough. so that they no longer remain sub wavelength then they can be picked up by the normal optical devices, right. So, here is one example of a hyperlens being used for this kind of application.

So, this is a hyperlens demonstrated by the Berkeley group in 2007. So, the structure here is basically a half-cylinder. with quartz substrate ok now this half cylinder has got 16 alternating layers of silver and alumina each being 35 nanometer thick ok and what is the pattern you can see some nano scale chrome patterns on the inner substrate And then this hyperlens operates at a UV wavelength of 365 nanometer and you can see that this feature is enhanced because of this hyperlens by almost 2.3 * okay and the sub The diffraction resolution that can be achieved was around 130 nanometers. So, you can successfully you know get this on pattern imaged using this kind of concept because after it is done you can put a conventional lens and then a you know of the optical microscope

and then you can create the far-field image plane and you can see this beautiful on pattern
As an image, okay.

So, what is happening the subwavelength pattern is basically first enlarged using hyperlens and once it is large enough it is picked up by conventional lenses and then you can use your traditional imaging to image this right. So, what are the potential improvements? So, if you use a spherical geometry instead of this cylindrical one, you could improve the performance further by doing uniform magnification and faithfully restoring the object's image on the outer surface, right. So, there are some challenges and issues with these

Challenges & Improvements in Cylindrical Hyperlenses

- **Issues in Cylindrical Hyperlenses :**
 - Strong reflections at inner/outer surfaces → reduced throughput.
 - Requires cylindrical symmetry → hard to fabricate, limits object placement.

- **Improvements:** Solution with Transformation Optics
 - Nonperiodic layer thickness → better performance.
 - Impedance matching via local EM control.
 - Proposal for a planar hyperlens (using transformation optics):
 - Converts evanescent waves to propagating modes in flat geometry.
 - Allows direct integration with conventional microscopes.
 - Potential for biological imaging (cells, viruses, DNA).

cylindrical

Far-Field Imaging with Super-Resolution

Plasmonic Hyperlenses: Planar Hyperlenses and Optical Fiber-like Systems

- Device: Concentric polymer rings on gold surface as shown in fig. 7(a).
- Operational Mechanism: Opposite dispersion slopes at gold–polymer and gold–air interfaces → alternating positive & negative effective indices for plasmons.
- In fig. 7(b); frequency range marked by the box, PMMA has negative refractive index as perceived by plasmons, whereas the gold–vacuum interface looks like a medium with positive refractive index.
- Operation (fig. 7): at wavelength of 500 nm
 - ✓ The plasmons generated by the phase-matching structure illuminate the sample positioned near the center of the superlens.
 - ✓ The lateral distance between the images produced by the alternating layers of materials with positive and negative refractive index grows with distance along the radius.
 - ✓ The magnified images are viewed by a regular microscope.
- Demonstration: Rows of polymer dots imaged, achieved sub-wavelength resolution of ~ 70 nm.

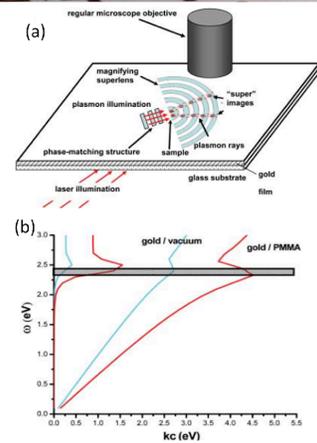


Fig. 7: (a) Schematic of magnifying superlens integrated into a conventional microscope; (b) Real and imaginary parts of surface plasmon wave vector k at gold-PMMA and gold-vacuum interfaces as a function of frequency.

hyperlenses. The first thing is that you know there are strong reflections at the outer and inner surfaces that basically reduce the throughput. And because it requires cylindrical symmetry, it is not easy to fabricate.

And it also limits object placement. So what improvements can people make in this aspect? You can think of solutions using transformation optics. You can think of non-periodic layer thicknesses that can give better performance. You can also think about impedance matching via local electromagnetic control and you can also come up with a proposal for planar hyperlens using the transformation optics which can convert the evanescent waves into propagating mode, but with a flat geometry. So, that would basically allow integration, direct integration with the

Far-Field Imaging with Super-Resolution

Stacked Nanorod Lenses:

- Mechanism: A different approach uses a lens made of stacked silver nanorods as shown in fig. 8 (a).
 - ✓ These nanorod chains, which support weakly damped plasmon resonances, transfer images from one end to the other in a pixel-to-pixel fashion, similar to a conventional fiber image waveguide.
- Super-Resolution: Unlike fiber bundles where each pixel is diffraction-limited, each nanorod chain can capture and transmit local features with a size of only tens of nanometers, thus providing sub-diffraction limited resolution.
- Color Imaging: The nanorod chains can be designed to support multiple plasmon resonance modes (RGB-like principle) at multiple wavelengths simultaneously (fig. 8(b)).
- Magnification: Tapered nanorod arrays can be used to provide magnification, allowing the resolution to be large enough for observation with conventional optics.

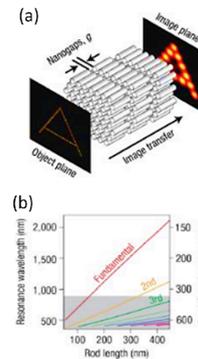


Fig. 8: Metallic nanolens with chains of silver nanorods. (a) Schematic of far-field imaging with stacked arrangement of silver nanorod arrays; (b) spectral dependence of plasmon resonance modes as a function of rod length

conventional microscopes and they will have the potential for biological imaging of cells, viruses and even DNA.

Right. So next we look into plasmonic hyperlenses. These are basically planar hyperlenses and optical fiber-like systems. Right. So the device here, as you can see, is basically concentric polymer rings on a gold surface. So this is the gold surface, and then you have polymer rings like this. So, what is the operational mechanism here that opposite dispersion slopes at gold polymer and the gold air interface that allows to form the hyperlens or the superlens effect.

So, you can see in this particular figure, which is basically plotting the ω/k at the gold vacuum and gold PMMA interface. So here, you can see that the frequency is being marked. So PMMA has basically got negative refractive index as perceived by the plasmons where the gold vacuum interface basically looks like a medium with positive refractive index. Now, this particular thing you have is a laser illumination at a λ_{500} nanometer wavelength, and then you have this phase matching structure. So, here the plasmas are basically getting generated by this phase matching structure when illuminated this structure will basically illuminate the samples which are basically positioned at the center of this superlens.

So, this is basically your magnifying super lens. And the lateral distance between the images that are produced by this alternating layers of materials of positive and negative refractive index basically grows the distance. So, the separation will basically grow with the distance along the radius, and they will not be here now. So, these are called the super

images of these two samples, and they can be picked up by a regular microscope. So, this is basically a demonstration of polymer dots that were imaged, and they could achieve sub-wavelength resolution of 70 nanometers.

Another application was shown using stacked nanorods. So, these are basically metallic nanolens which are made with chains of silver nanorod. So, this is a different approach because here the lens is basically made of stacked silver nanorod as you can see. So, these nanorod chains can support weakly damped plasmon resonances and they can transfer. So, this is the object plane; this is the image plane. So, they can basically transfer images from one end to another in a pixel-to-pixel fashion, similar to the conventional fiber image waveguides.

Right. So, the super resolution is basically coming from the fact that unlike fiber bundles, each pixel is basically diffraction limited. Here each nano-rod chain can capture and transmit the local features with a size of only say tens of nanometers and they can provide the subwavelength resolution. And color imaging is also possible because the nanorod chains are designed or they can be designed to support multiple plasmon resonance modes something like RGB principle. So, this particular figure shows the spectral dependence of the plasmon resonance modes as a function of the rod length. So, these are the resonance wavelength, this is the resonant frequency, this is the fundamental one and then you can get the second, third and the other resonance modes here.

So, this tells you that you are receiving multiple wavelengths simultaneously. So, you can get the magnification by using tapered nanorod arrays that can be used for magnifying the images and that allows the resolution to be large enough for observation using the conventional optics. So, with that we conclude this lecture and we will start discussing about hyperbolic metamaterials and super resolution hyperlens imaging in the upcoming lecture. So, if you have got any queries regarding this, you can drop an email to this email address mentioning the course name and the lecture number on the subject line. Thank you.



Thank You

Slides inserted by fallback (review if needed):



Thank You