

Hello, everyone. My name is Rachit Sood. So today, my presentation topic is design of zinc selenide QPM for wide transparency sensing and laser applications. So I am doing my PhD from University of Maryland, Baltimore County. My work is being supported by NASA Marshall Space Flight Center.

These would be the contents of my presentation. I will go to the objectives, and I will show some previous research as well as background approaches for laser development. Moving further, I will show the experimental approach to develop the QPM templates. Finally, ended this presentation with the results and discussion.

So before moving on to the objective, I want to emphasize on QPM. So QPM is a technique where we achieve phase matching using a periodic structure. So here we used an approach similar to what we published in photonic fest last year where we fabricate nanostructures for midinfrared AR applications. So here we have created a gratings of gap 230 micrometer and 35 micrometer on a silicon and gallium arsenide wafers. In the experimental section, we will show the fabrication of it and the results.

So there are many different paths to develop mid-wave and long-wave infrared lasers. Some of it are frequency conversion using second harmonic, third harmonic, or fourth harmonic generations. Then comes QCL approach or periodically poled crystals and quasi-phase matched materials like zinc selenide and it has low absorption and large transparency. So we will be presenting a novel approach of template development for QPM on the silicon and gallium arsenide wafers.

Background. So huge number of papers are being published using the technique discussed in the last slide. But the materials have their own issues, like the thermal optical properties vary a lot. These crystals have small crystal fields, which results in emission red shifting.

Moreover, the fabrication is expensive as well as time consuming. So our approach can potentially replace these techniques to develop a mid-wave and long-wave infrared lasers. This is the gold coated growth and polishing facility in Technology Research Center in UMBC.

Performance of thallium arsenic selenide crystal. So this is the 6-inch long the TAS crystal. As you can see from figure tree, the crystal is generating so much power that it is trying to melt the wall in front of it.

But it has some issue. As it is a bulk crystal, fabricating takes a lot of time and money. And moreover, it is direction oriented, meaning the power is generated in a certain

direction only. So these are the example of other 2D crystal like gallium selenide. As you can see, the crystal is being fabricated without any void as well as bubble for mid-wave and long-wave infrared lasers.

So this is the other example of 2D crystal. This is the compound of gallium. So in the literature, the fabrication steps are demonstrated step-by-step, and moreover, it is the high quality crystal growth compound.

Even the pure gallium selenide has a large NLO merit as well as it is efficient as you can see on this graph. But the thing is it feels like mica. So it is very difficult to grow any other compound on this crystal.

Another literature work by Singh et al [INAUDIBLE] fabricate orientation pattern zinc selenide devices, which enables the frequency conversion from visible to long-wave infrared wavelength. The device enables scaling of power and spectral range of transparency of around 0.6. to 20 micron, and also enables the lower intrinsic absorption. This new material can potentially be used for remote sensing applications.

Here I show the sample geometry where we are trying to grow a 2-mm thick layer of zinc selenide. As you can see in the geometry, we have [INAUDIBLE]. [INAUDIBLE] presents the regular orientations, [INAUDIBLE] represents the reverse orientation. So the main challenge here is that it is hard to grow zinc selenide on the reverse orientation in this case.

Now, in order to solve the reverse orientation issue, I looked into the PhD thesis of two students from Stanford University where they use the gallium arsenide as a substitute and an intermediate layer of germanium. As you know zinc selenide lattice matches with the gallium arsenide. So they tried to grow zinc selenide on top of gallium arsenide. Here they demonstrated the growth of zinc selenide on gallium arsenide. Now, it is easier to grow zinc selenide towards minus 110 direction.

So even though in the last slide we have seen that the growth of zinc selenide in reverse orientation is possible, but it is not uniform in the reverse orientation direction. As you can see in this SEM picture, one is the grainy side and one is the smooth side. So the grainy side represents the reverse side and the smooth side represents the regular side. So the growth on reverse side is not as uniform as it is on the regular side.

So here I show the etching profile of different orientation patterning for different gratings. For example 35 micron, we see the dark yellow and the light yellow color. So the dark yellow represents the regular side, while the light yellow represents the reverse side.

As we can see, the light yellow starts to diminish as we grow more and more zinc selenide. So it means that the growth on reverse side is not uniform as it is on the regular side. So here also for the 115 micrometer, we see the same thing. As it is hard to see here, so I have shown the higher magnification image in the next slide.

So this is the orientation patterning of 115 microns. So as you can see, the light and the dark color. So the dark color is the reverse. So it starts to diminish as we grow more and more zinc selenide. In spite of all the problems we have seen in the last few slides like the growth of zinc selenide in the reverse orientation, we still able to demonstrate the nonlinear optical effects in oriented pattern zinc selenide.

So now, moving on to the experimental setup, so this is the flow chart showing the fabrication steps to fabricate the [? UPM ?] template. So we start with the CAD design where we design the gratings of 230 micron and 35 microns. Then the CAD design was sent to photomask company, which uses the e-beam lithography to generate a photomask.

On silicon and gallium arsenide wafers, we spin the positive photoresist. Then the gratings was exposed under UV light followed by development of around five to six seconds to the develop the gratings on the wafers. Finally, by the combination of wet and dry etching, we were able to achieve the gratings on the wafers.

So this is the image of photomask generated from a CAD design using the e-beam lithography. On the top, that gratings are of 230 micron and on the gratings are of 35 micron. On the right, this is the silicon wafer before any fabrication.

So we started with silicon wafer. So this is how the wafer looks after the UV photolithography. On the top, you can see the gratings are 230 microns, and on the bottom the gratings are 35 micron. It is hard to see the gratings of 35 micron with the naked eye. But in the next slide, I will be showing some of the images-- some of the microscopic images of 35 micron gratings.

So these are the microscope images of gratings of 35 micron. So the pictures were taken before the wet and dry etching. So this graph shows the depth of the 35 micrometer gratings. So this graph was taken using the [? broken ?] machine and cleanroom.

We put the silicon wafer in the machine and the pen was moved over the gratings, which gave us the depth of around 1.5 micrometer.

So this is the image of 35 micron gratings after the wet and the dry etching. The bubbles on the grating shows that the gratings have the defects. So we are trying to optimize to remove these defects in the future.

These are the images of 230 micron gratings. This graph again shows the depth of 230 micron gratings. So the depth is around 2.5 microns. So the reason being the depth is more than the 35 micron gratings is because it is easier to develop the 230 micron gratings as compared to 35 micron gratings.

This slide shows the comparison of 35 micron with the 230 micron gratings on the top. These are 35 micron gratings on the bottom. The gratings are of 230 micron. In the previous slides, we were not able to see the 35 micron grating with the naked eye, but somehow we were able to see that 230 micron grating. So here we show some of the more microscope images of 35 micron gratings.

Summary, QPM using zinc selenide provides a great technology for laser development. And because zinc selenide has a wide transparency, so it is a promising crystal for high power nonlinear optical frequency conversion. In this work, we presented a novel approach for QPM template where we fabricate the gratings of 35 micron and 230 micron.

Now, we are trying to grow zinc selenide film on these gratings. Once we get some good results, we will present these in the upcoming conference. Also orientation pattern can be replicated using the gallium arsenide wafer instead of silicon wafer .

This is the end of my presentation. Thank you so much for listening to me. And if you have any questions, you can post it in the forum, and I will try to answer it as soon as possible. Thank you again.