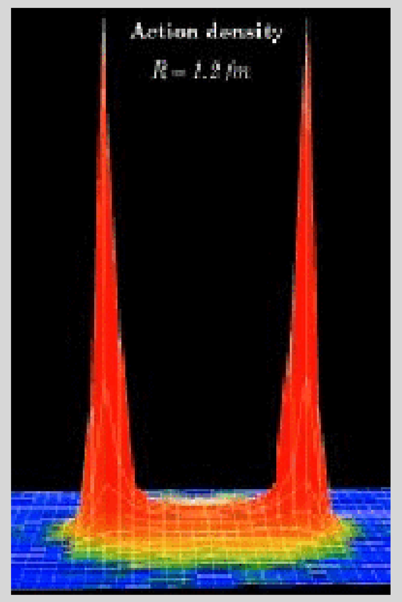
Diamond Radiator Machining with Laser Ablation

Brendan Pratt

University of Connecticut

Abstract

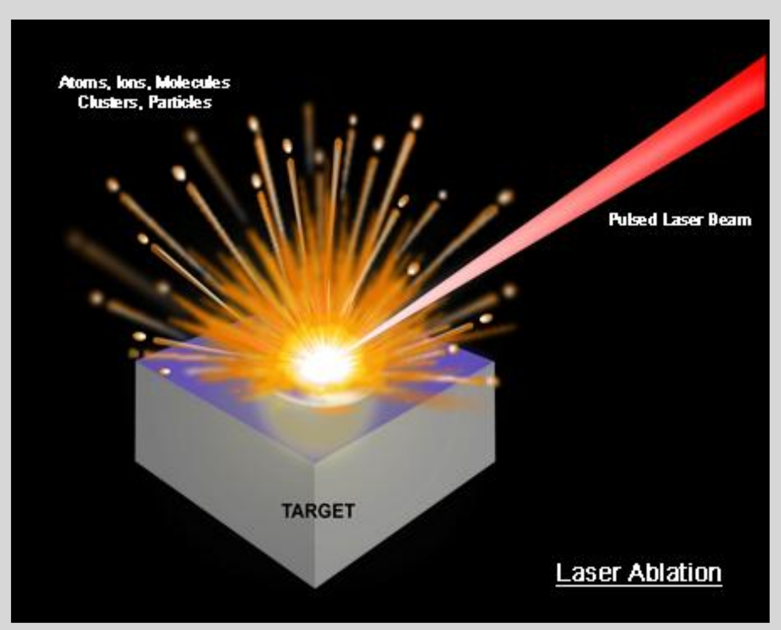


The GlueX experiment at Jefferson Lab in Newport News Virginia is a photonuclear experiment design to explore the excited gluonic bonds between quarks. The excitation of these bonds is induced by the absorption of a high energy photon by a proton in a liquid hydrogen target. The photon beam is created through the process of coherent bremsstrahlung.

A 12GeV electron beam passes through a 20μm thick diamond wafer and undergoes bremsstrahlung releasing energy in the form of high energy polarized gamma rays. To obtain optimum photon beam polarization, the diamond must be nearly perfect in crystalline quality and as thin as possible. The unique properties of diamond are what makes it the best choice for a radiator, but machining single crystal diamond to such small thicknesses requires advanced techniques. We are developing the capability at UConn to mill monocrystalline diamond to arbitrary shape profiles using laser ablation with a high power UV pulsed laser.

The Ablation Process

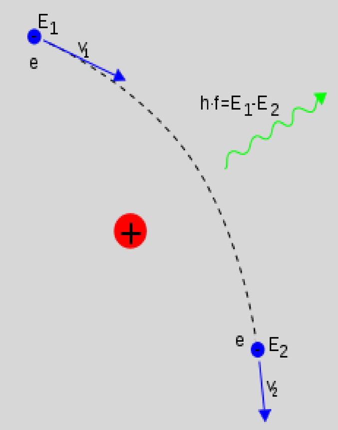
The appeal of using an ablation process to micro machine diamond wafers to 20μm is that it cleanly removes material from the surface without affecting the bulk of the sample.



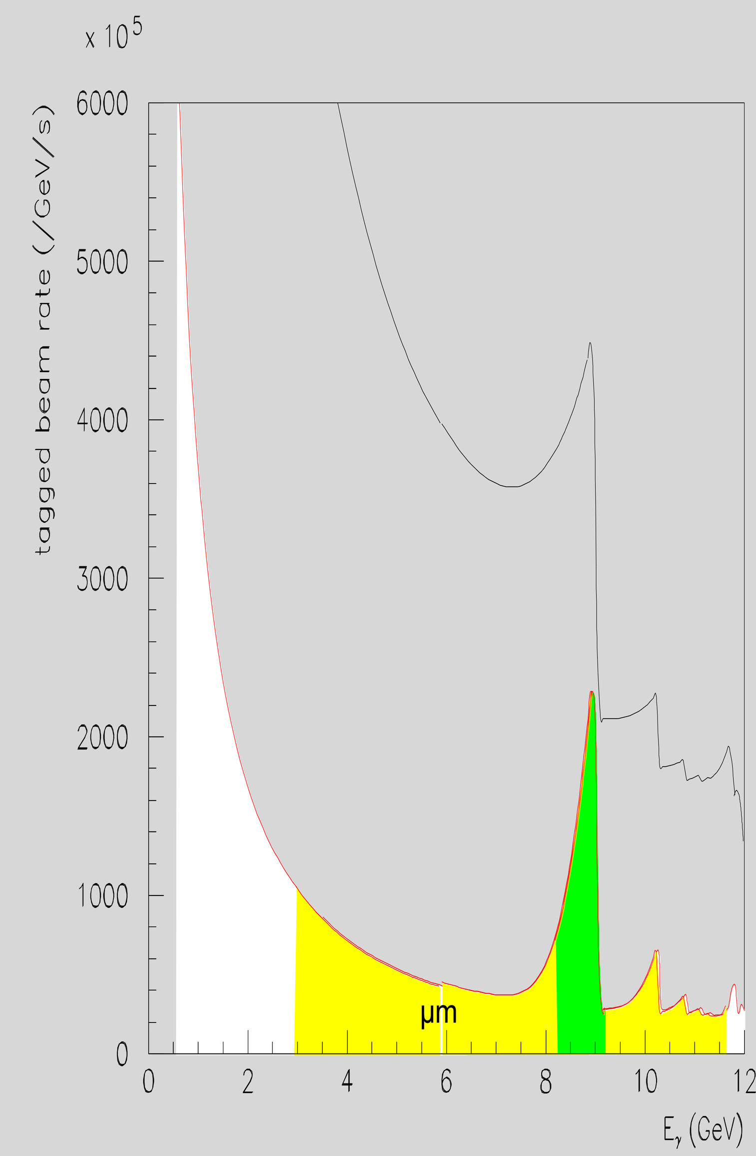
The 193nm ultra violet light is above the band gap for diamond, so it has an extremely short absorption length, confining power absorption to a thin layer at the surface of the sample. At a sufficient power level, the surface layer is transformed into a plasma which comes off the surface in supersonic plume. Traditional milling with a lapping technique is known to result in highly deformed thin diamond films. By leaving a thick frame around the outside and ablating a thin window from the interior region of the diamond, we hope to produce thin radiators without significant deformation.

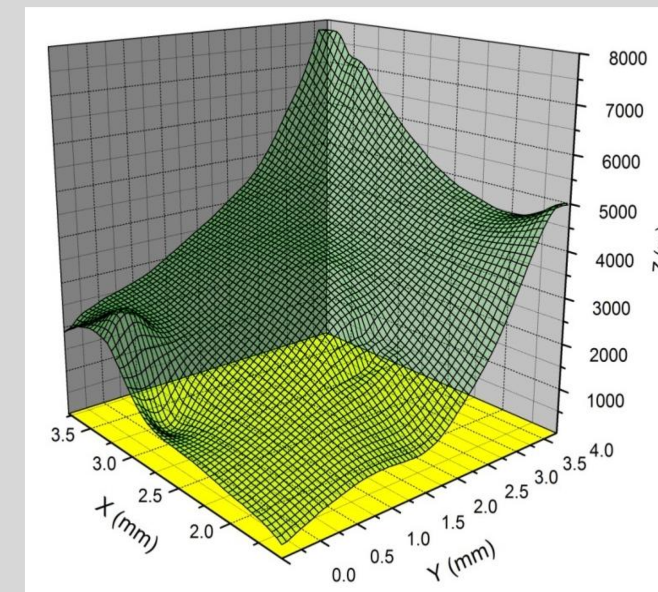
Why Coherent Bremsstrahlung and Why So Thin?

Bremsstrahlung produces electromagnetic radiation when a charged particle is deflected by another particle. In the GlueX experiment, a 12GeV electron will decelerate when it passes through a diamond radiator producing photons with a broad energy spread.



In order to create the sharp peak in the otherwise smeared bremsstrahlung radiation energy spectrum, the diamond is oriented at a specific angle, causing peaks to appear in the bremsstrahlung energy spectrum due to coherent scattering from all of the atoms in the crystal. This coherence is enhanced by collimating the photon beam to a small angle around the forward direction, producing the narrow spike shown in the spectrum on the right.

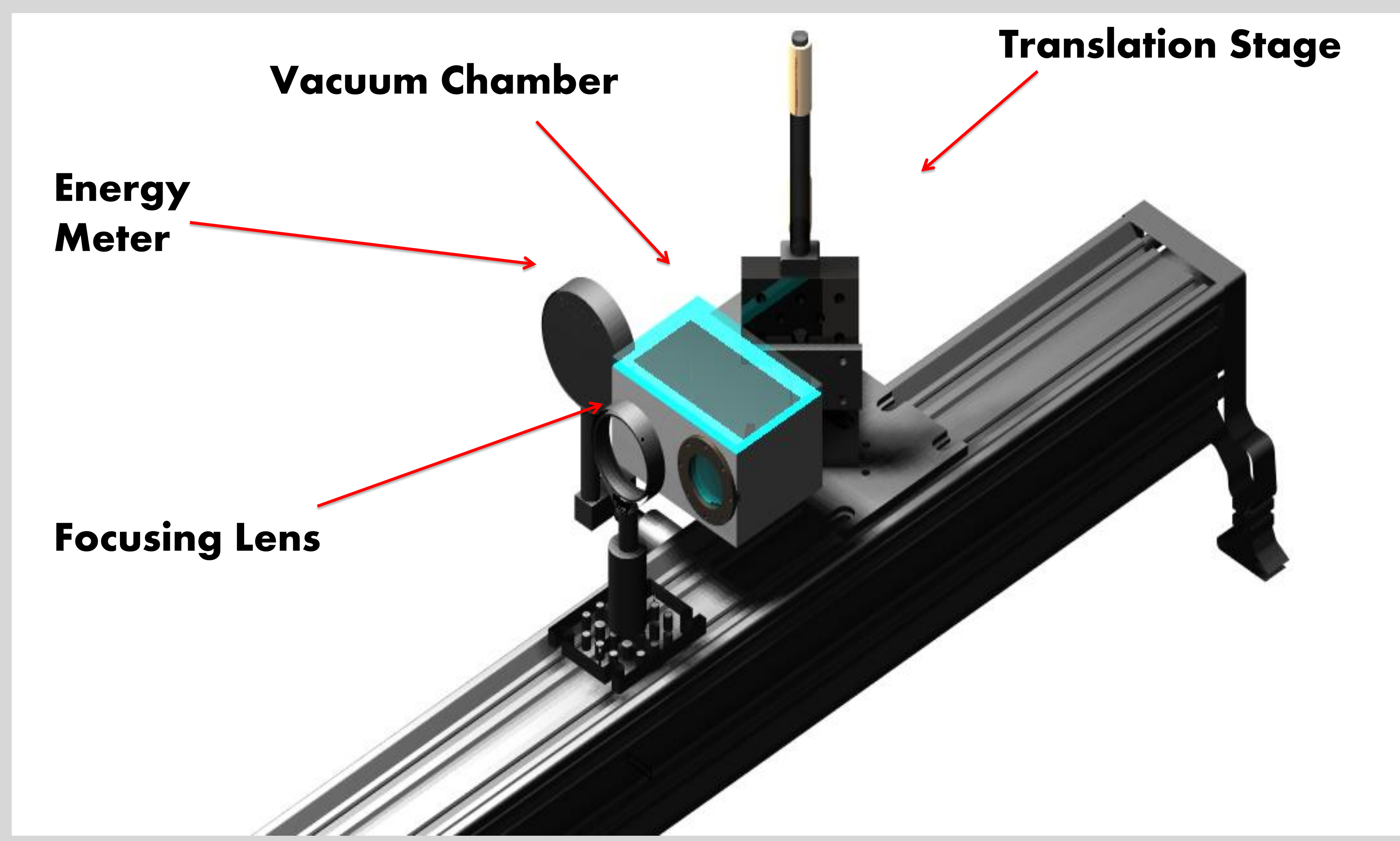




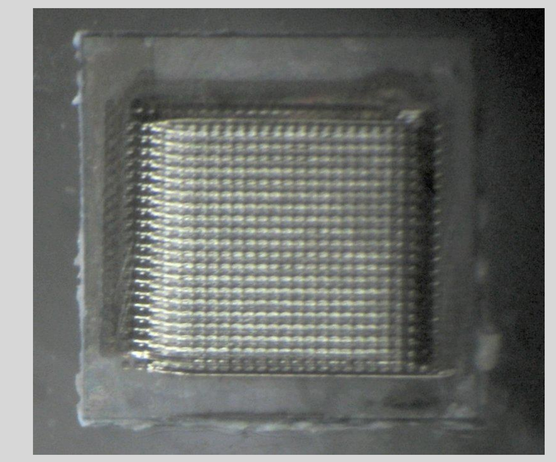
X-ray rocking curve topography of a diamond thinned using the lapping technique, interpreted in terms of deformation of the shape of the planes in the crystal. Curvature of the planes distorts the kinematics of the coherent bremsstrahlung process and degrades the quality of the beam. The laser ablation project was launched to overcome these difficulties.

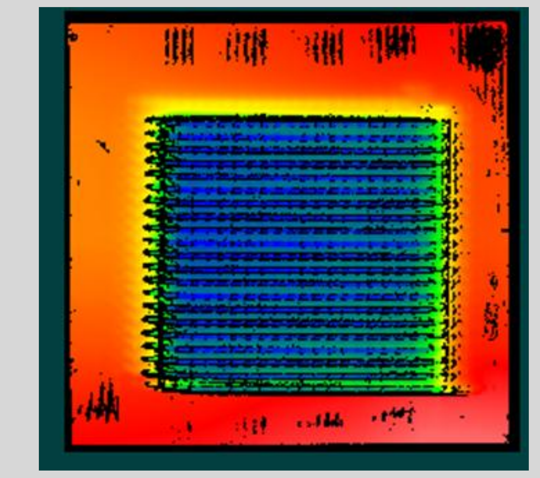
Laser Ablation Facility

The laser ablation facility at UConn consists of a 193nm ArF Lambda Physik excimer laser. The beam is focused through a sequence of spherical lenses, through the fused silica entrance window of the ablation vacuum chamber, onto the surface of the diamond sample. The energy of each pulse is monitored using an inline energy meter. If the threshold energy for ablation is exceeded, the translation stage moves the entire chamber a small amount to the next milling site. The laser pulse, energy monitor, and translation stage are all computer-controlled through custom electronics and LabView programs.

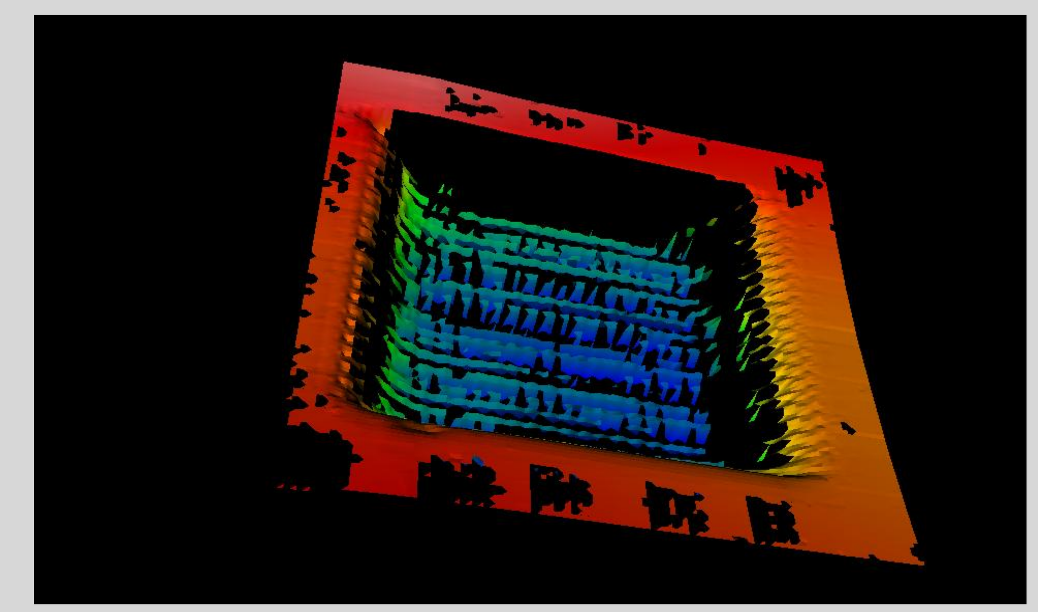


Initial Results

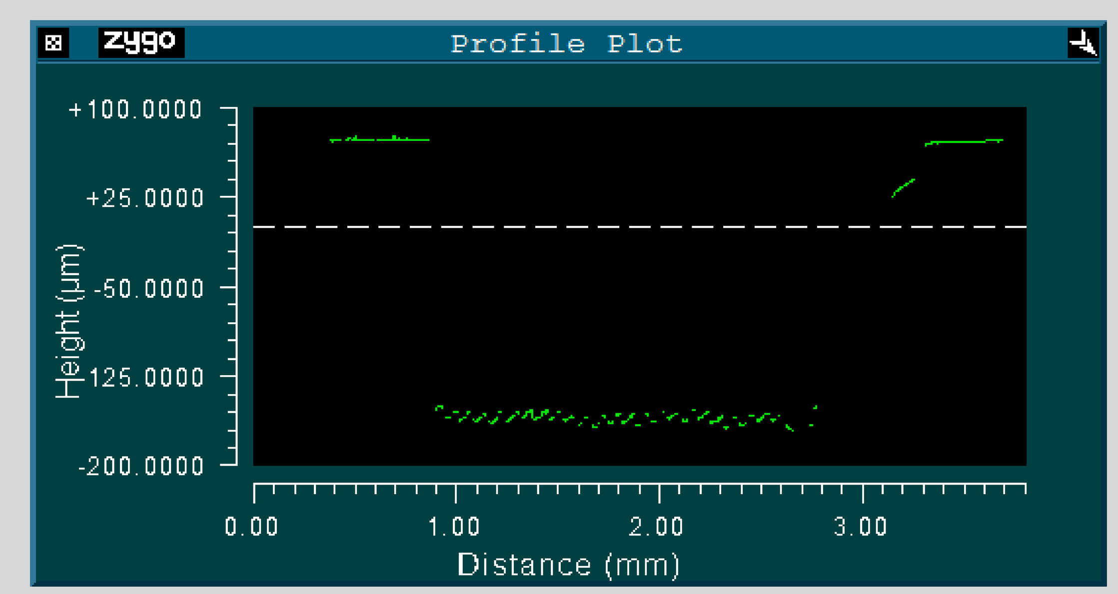




A 2x2mm area milled into the surface of a 3.2 x 3.2mm CVD diamond, as imaged by a regular microscope and a white light Zygo surface profilimeter. A total of about 200μm has been milled away from the original surface. The visible cross hatching was a result of rasterizing the diamond with a 0.1mm step size. Repeated passes would be required to thin the diamond all the way to 20μm.



A 3D image of the ablated diamond taken with the Zygo.



A 2-D cut through the above 3-D image , showing the profile of the trench cut by the laser with nm resolution.

Citations

1. The GlueX Experiment, (http://www.gluex.org).
2. Richard T. Jones, *Diagnostics of Deformation in Thin Diamonds for Coherent Bremsstrahlung Radiators*
3. Zeus.phys.uconn.edu/wiki/