Hard Tissue Ablation with Continuous-wave kW Ytterbium Fiber Laser

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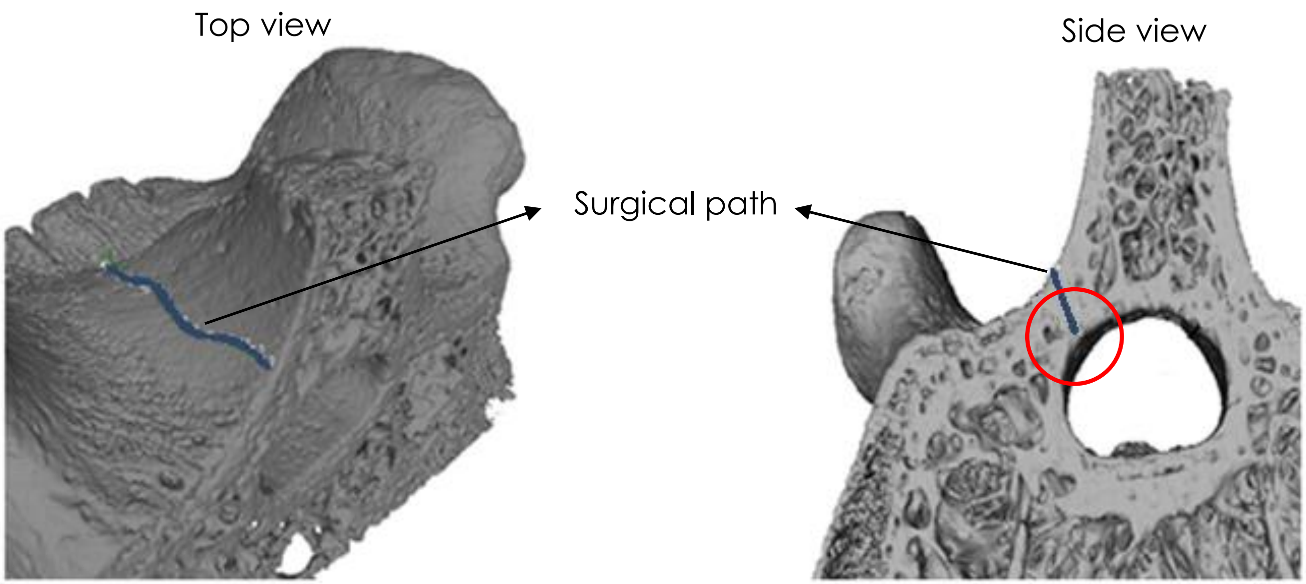
Lasers – New Surgical Tool



SPIE conference proceeding

Traditional method – **mechanical saw**

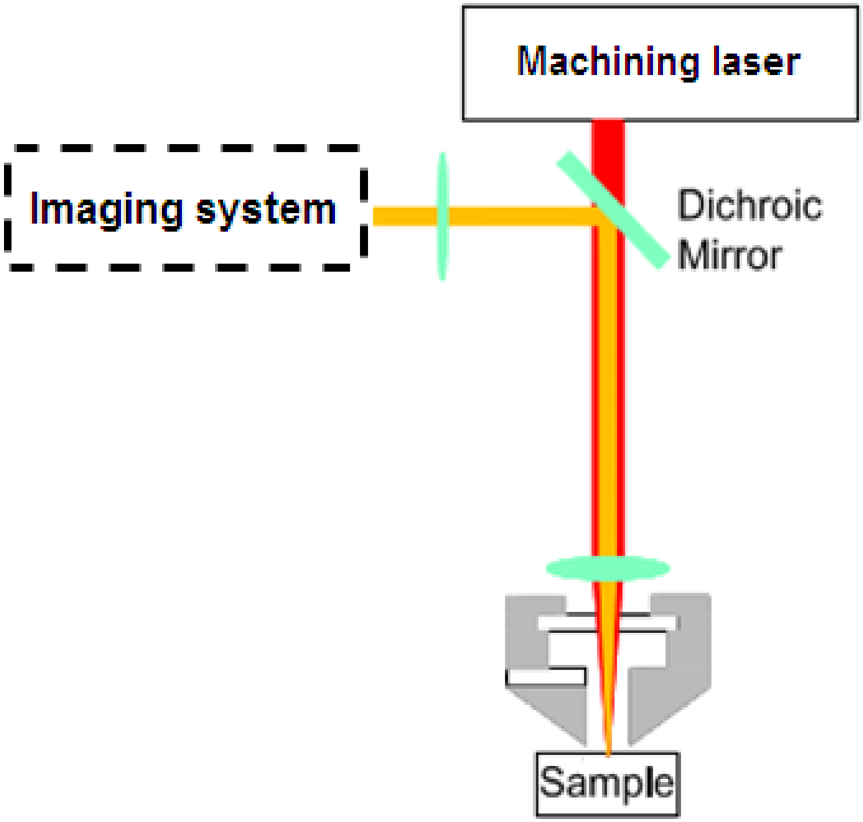
vs

Modern method – **laser beam**

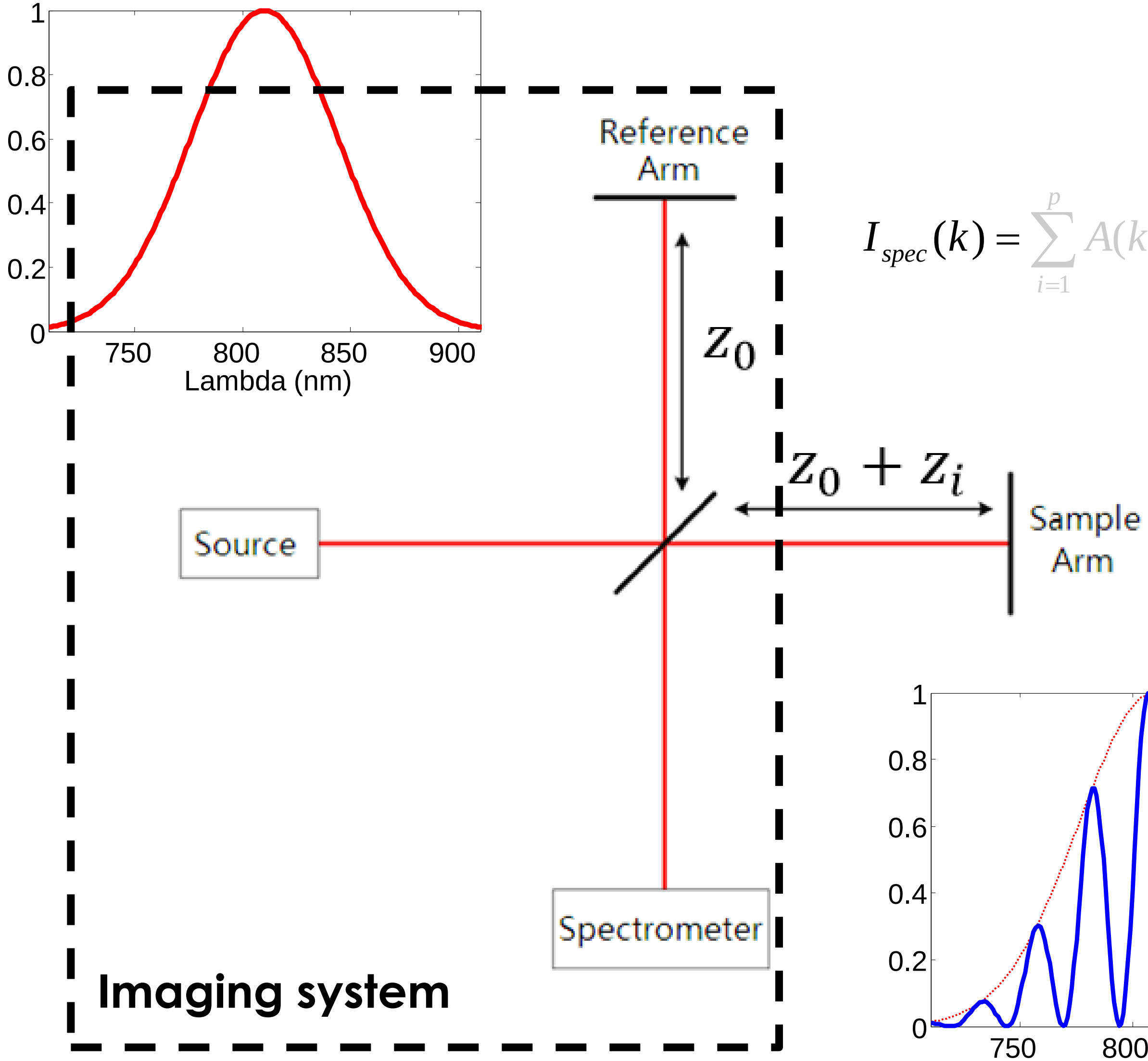
Inline Coherent Imaging (ICI)

Depth control

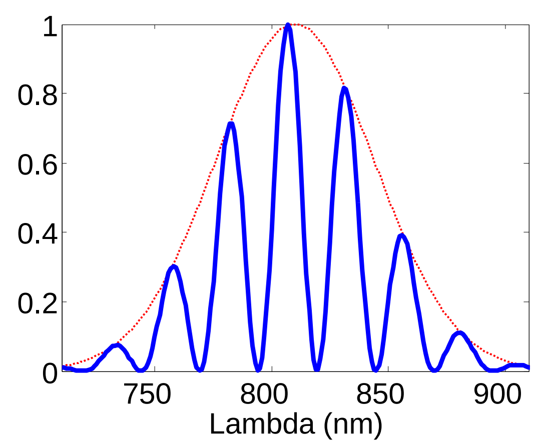
is achieved by monitoring the ablation process in real-time with combined imaging and machining light



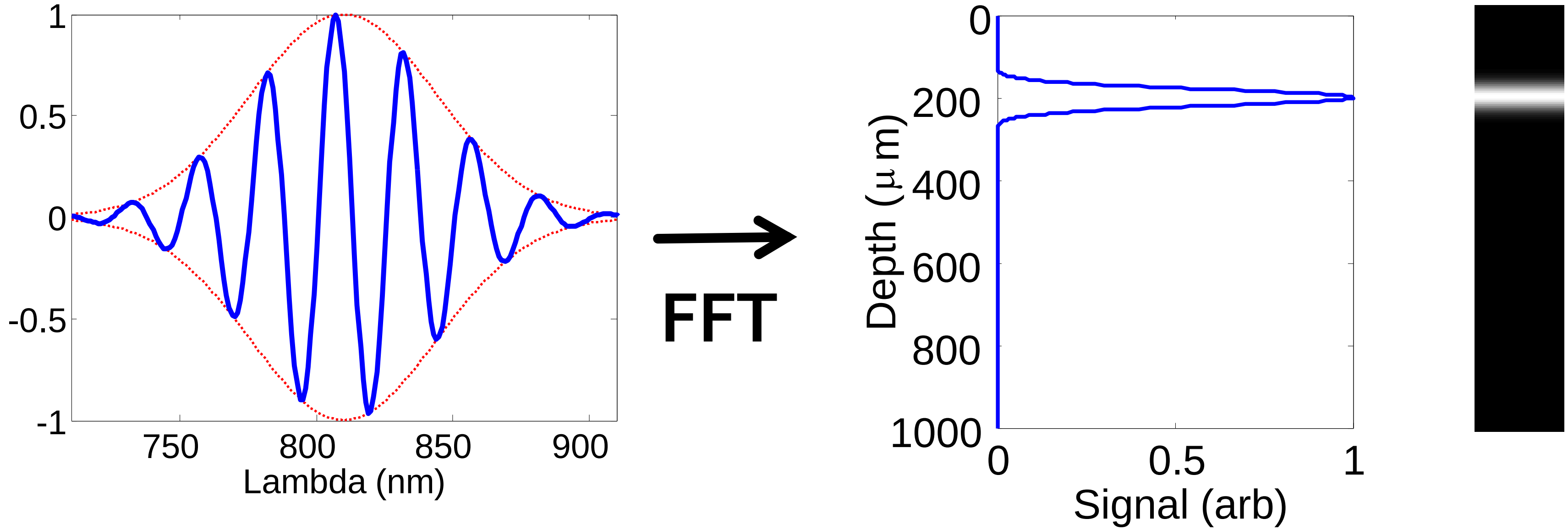
Basics of ICI



$$I_{spec}(k) = \sum_{i=1}^{p} A(k)\left[\frac{I_{ref}}{2p} + \frac{I_i}{2} + \sqrt{I_{ref} I_i}\cos(n z_i (2k))\right]$$

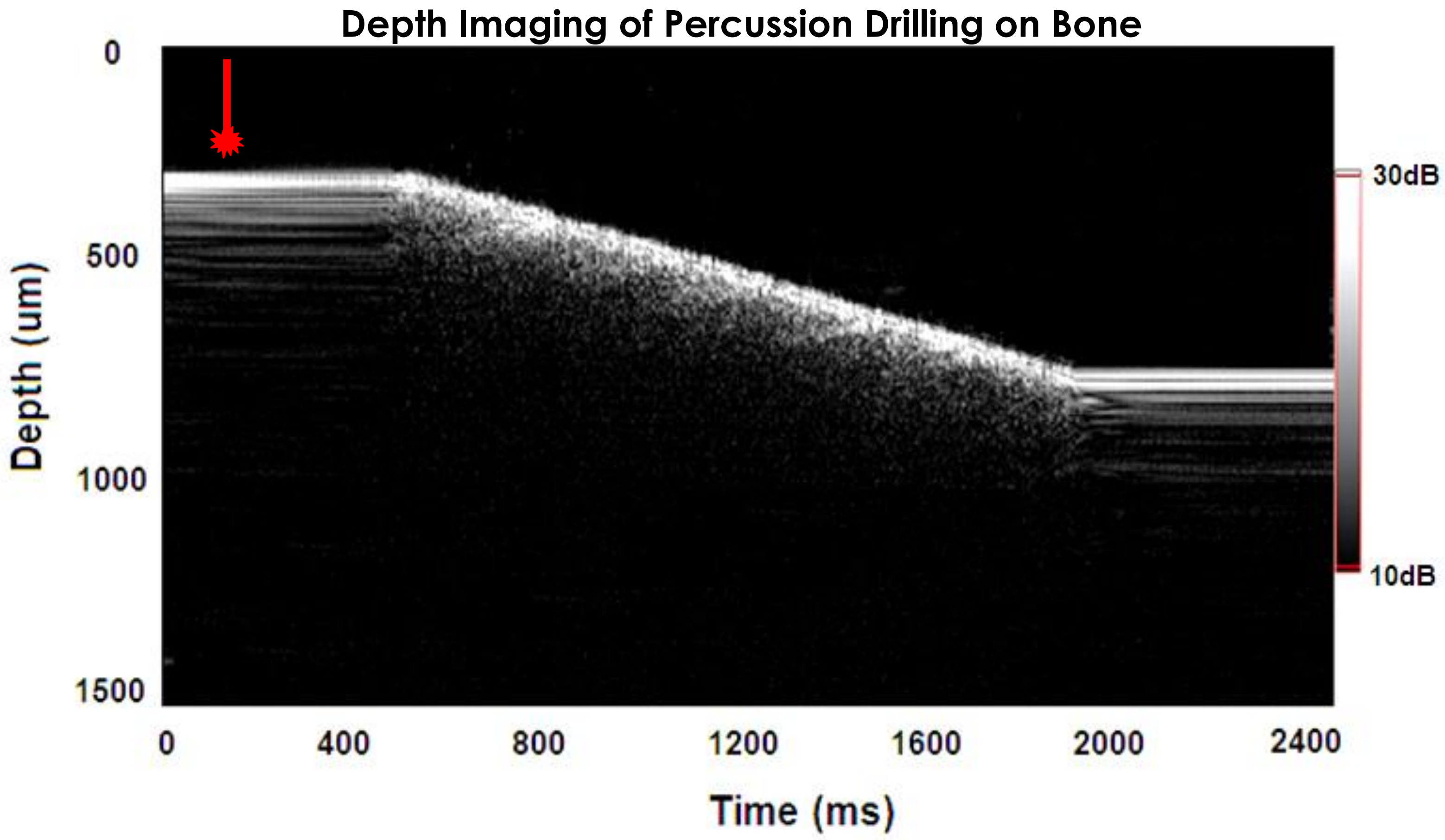


Basics of ICI

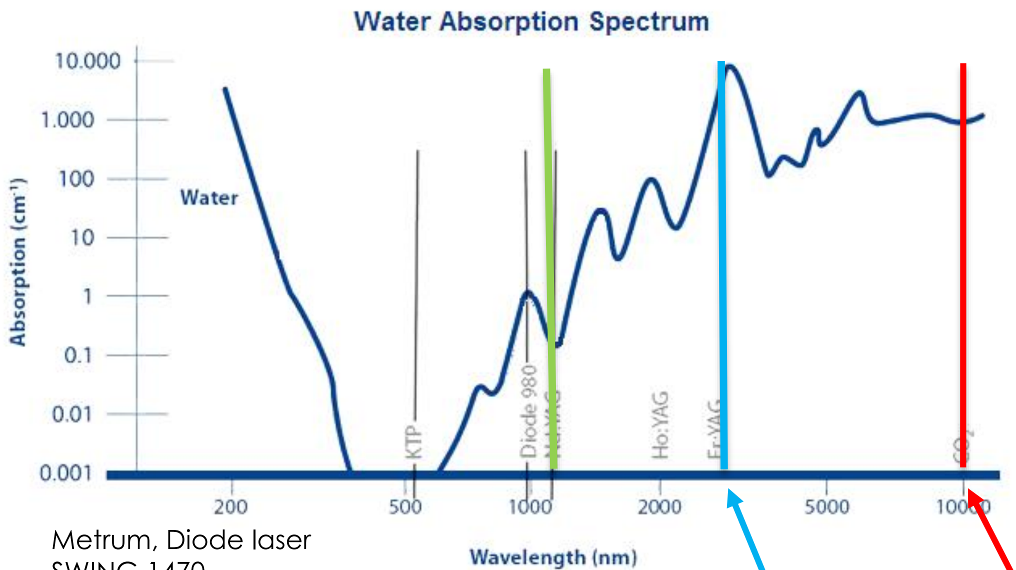


ICI – Combined Imaging and Machining

Example



Hard Tissue Ablation



Metrum, Diode laser SWING 1470

According to water absorption spectrum, Ytterbium fiber lasers at 1070nm is not ideal for hard tissue ablation

Ytterbium fiber lasers

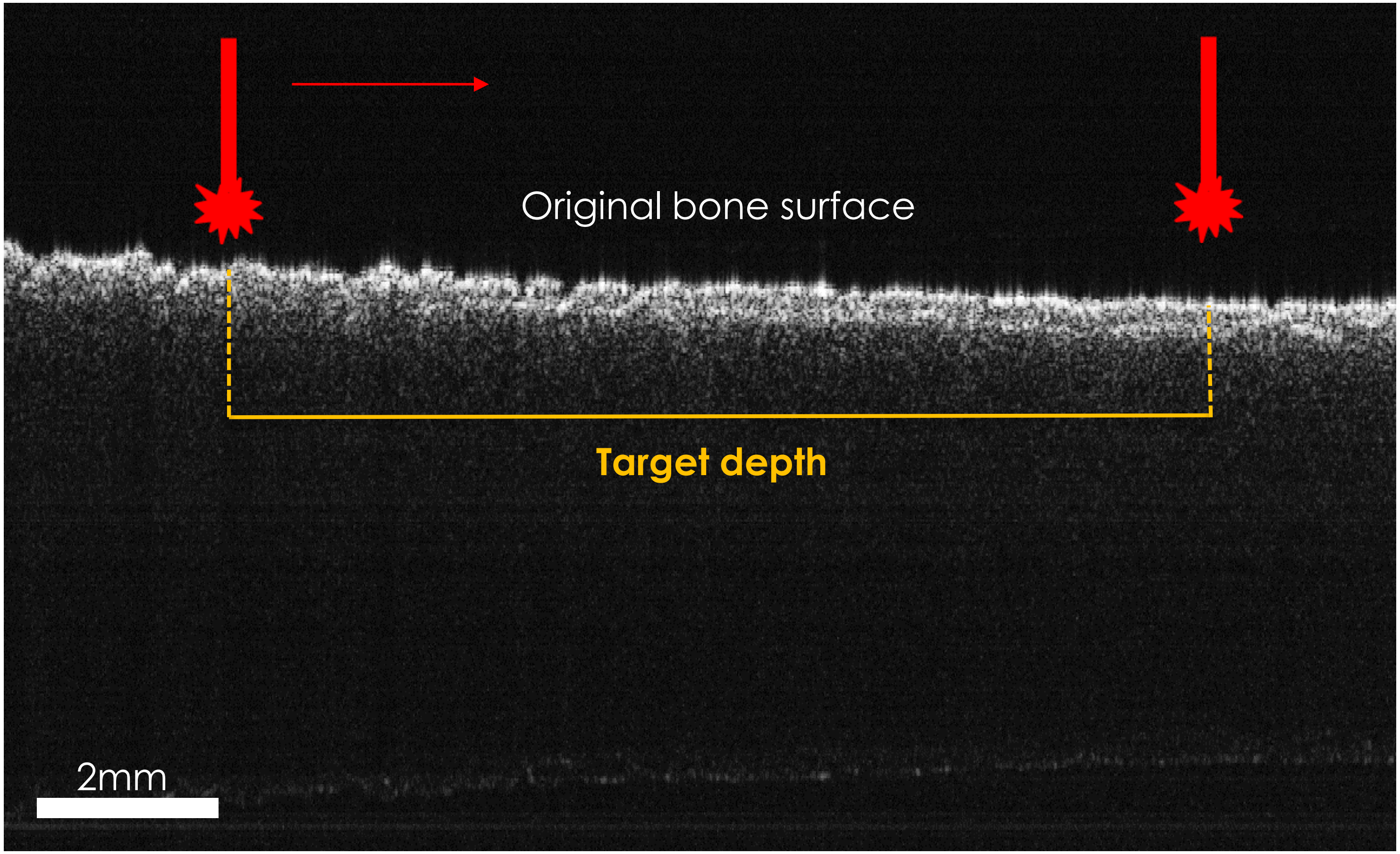
Er:YAG lasers

CO_2 lasers

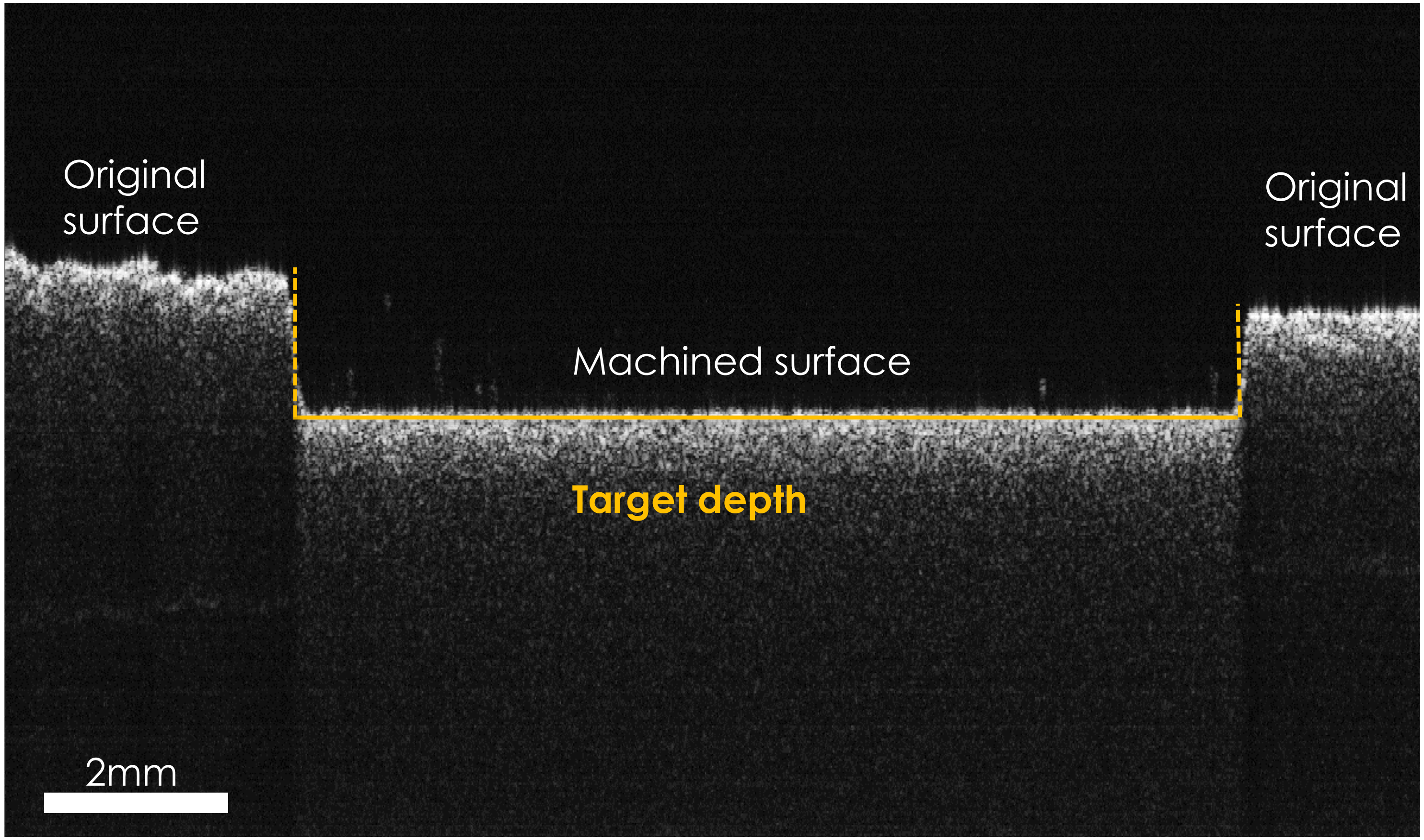
Absorbance in the individual pure bone component [cm^{-1}]	Relative abundance	Wavelength [µm]				
		2.94	9.3	9.6	10.3	10.6
Collagen	27%	1330	502	556	212	222
Water	13%	11850	554	577	709	817
Minerals	60%	648	5200	5494	4572	3475

Forrer M, Appl. Phys. B Photophysics Laser

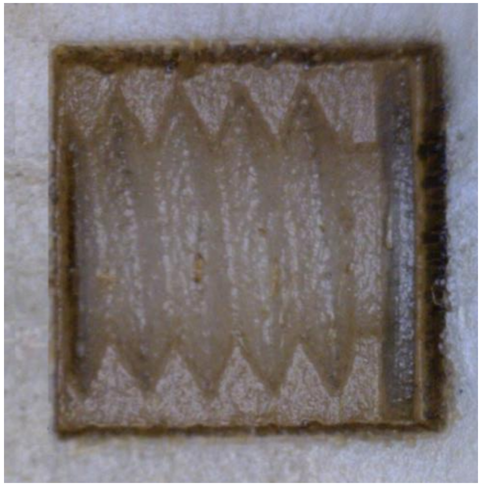
Depth Feedback Control



Depth Feedback Control



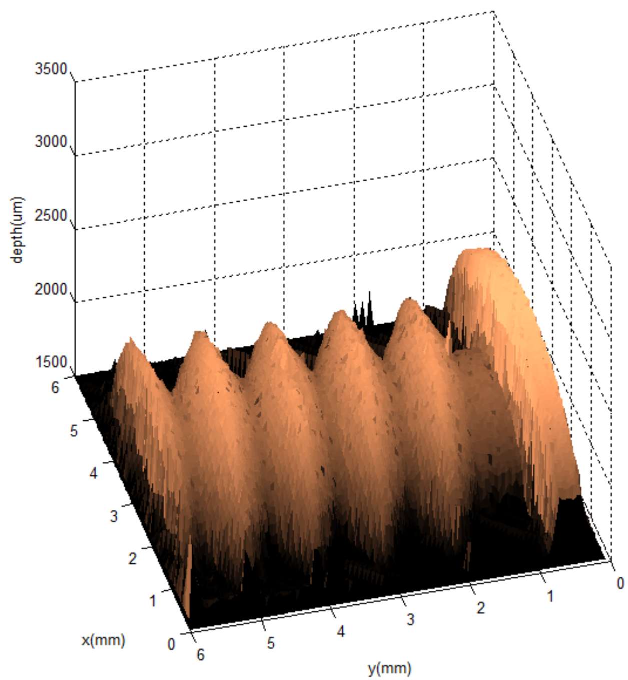
3D "Clean" Bone Machining

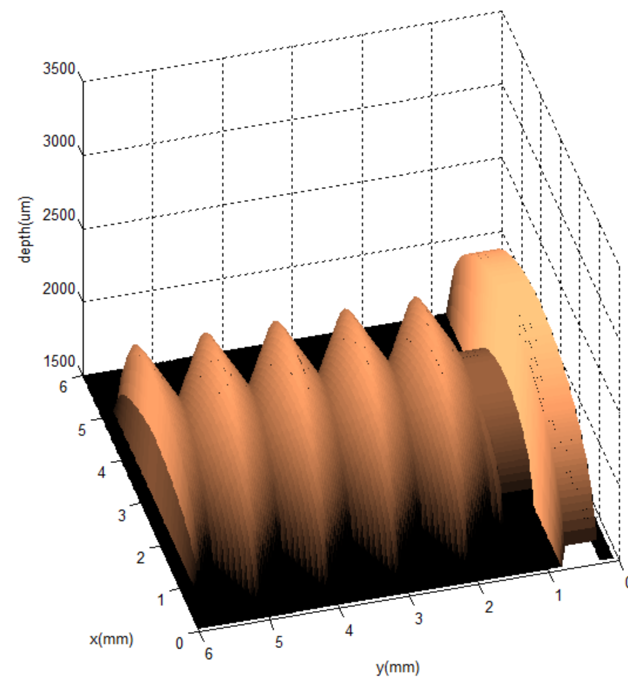


6mmx6mm feature

1mm depth range

Machined Feature **vs** Designed Model



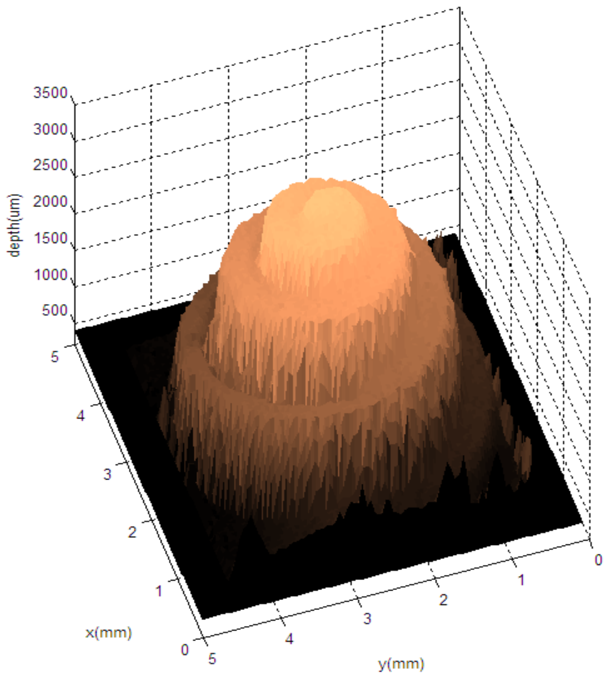


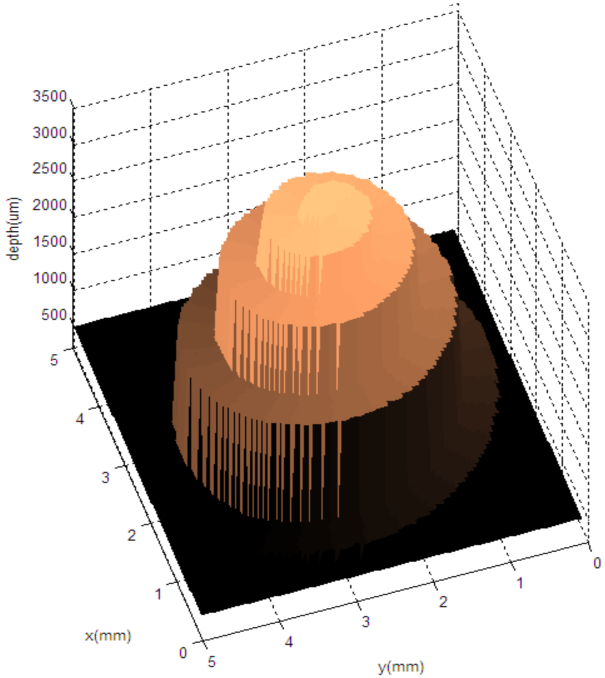
3D "Clean" Bone Machining

6mmx6mm feature

3mm depth range

Machined Feature **vs** Designed Model





Why Did It Work?

...421–434 (1999)

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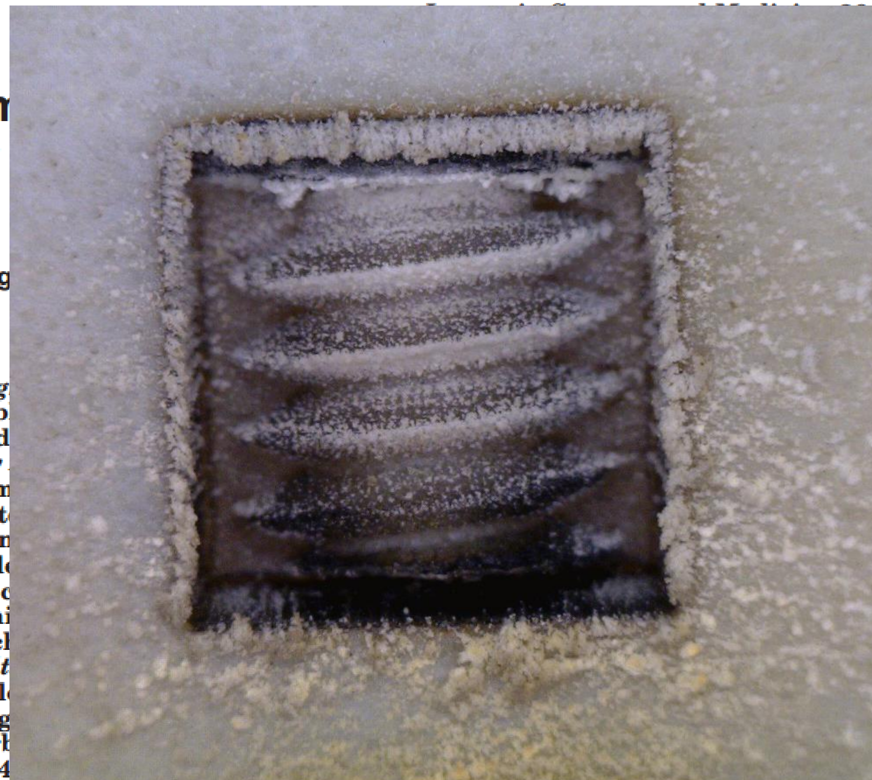
5.9–6.4



Conclusions: The use of wavelengths in the 6.1-μm amide I to 6.45-μm

vious observations that the ablation mechanism below plasma threshold is consistent with an explosive process driven by internal vaporization of water in a confined space and demonstrates that ablation is

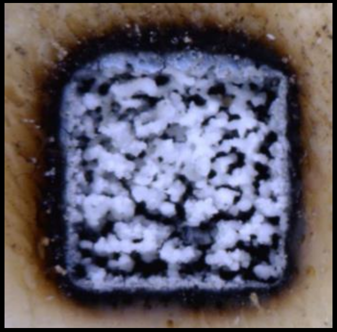
tical bone. Lasers Surg. Med. 25:421–434, 1999.

Hypothesis

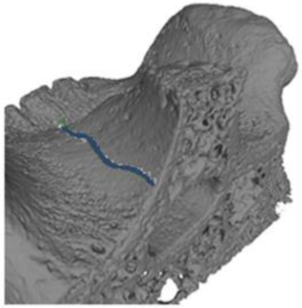
1) Formation of thin carbonization layer

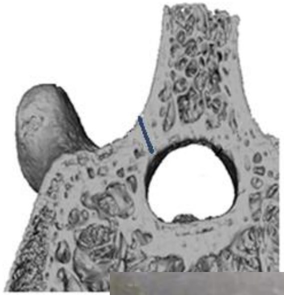
2) Higher absorption of carbonized area

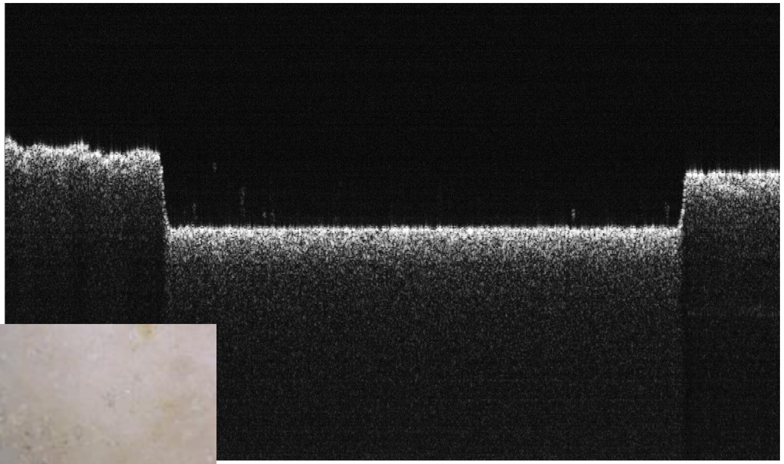
3) *Explosive evaporation* of the molten mineral "cleans up" the carbonized layer

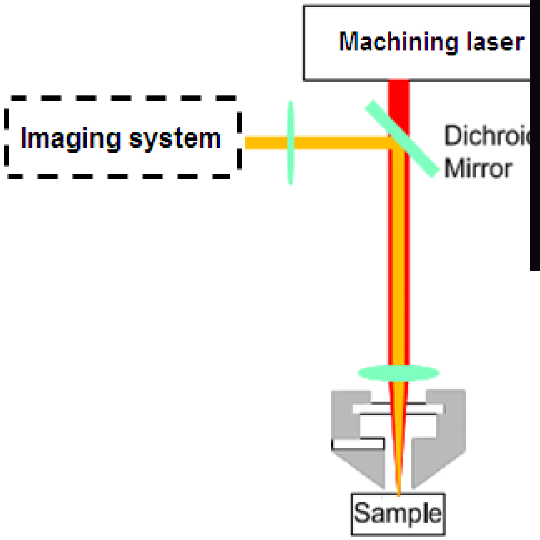


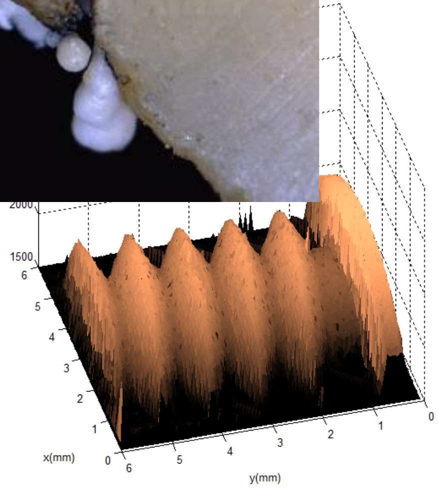
Conclusion

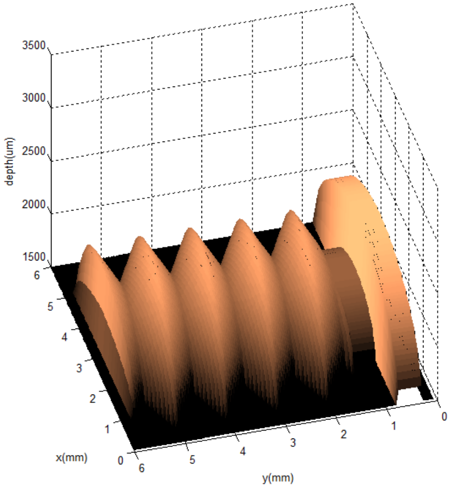







Machining laser
Imaging system
Mirror
Sample

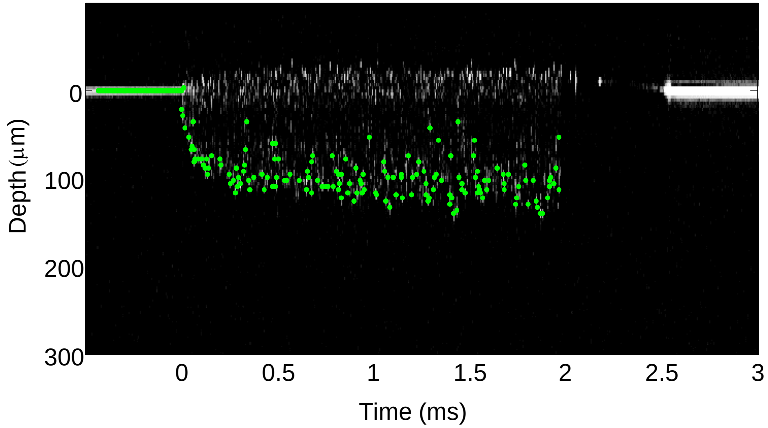

x(mm)
y(mm)

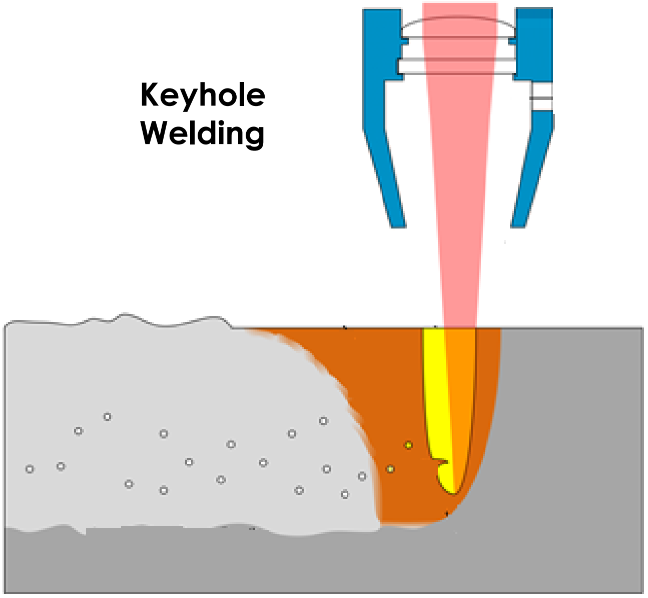

depth(um)
x(mm)
y(mm)

Extra slides

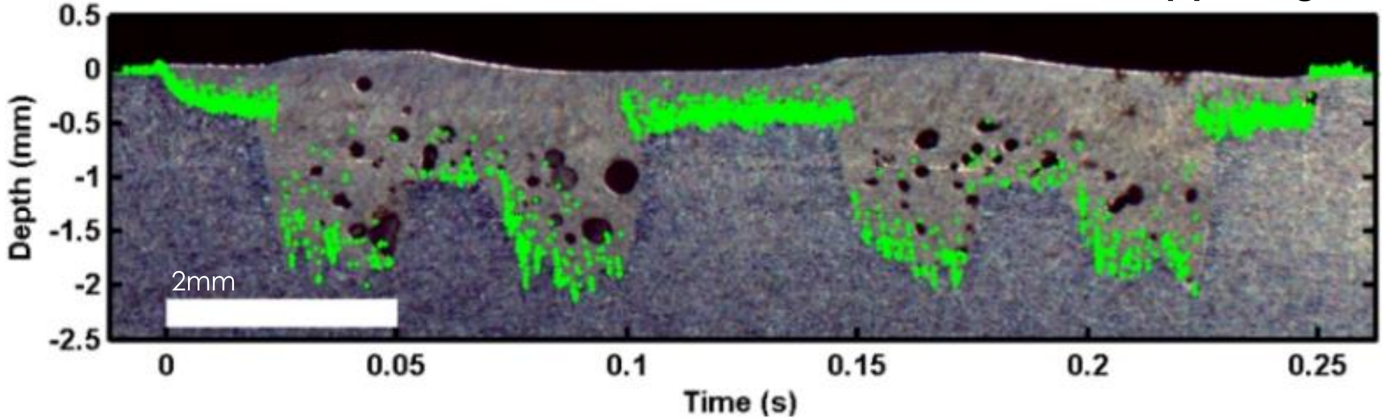
ICI – Combined Imaging and Machining

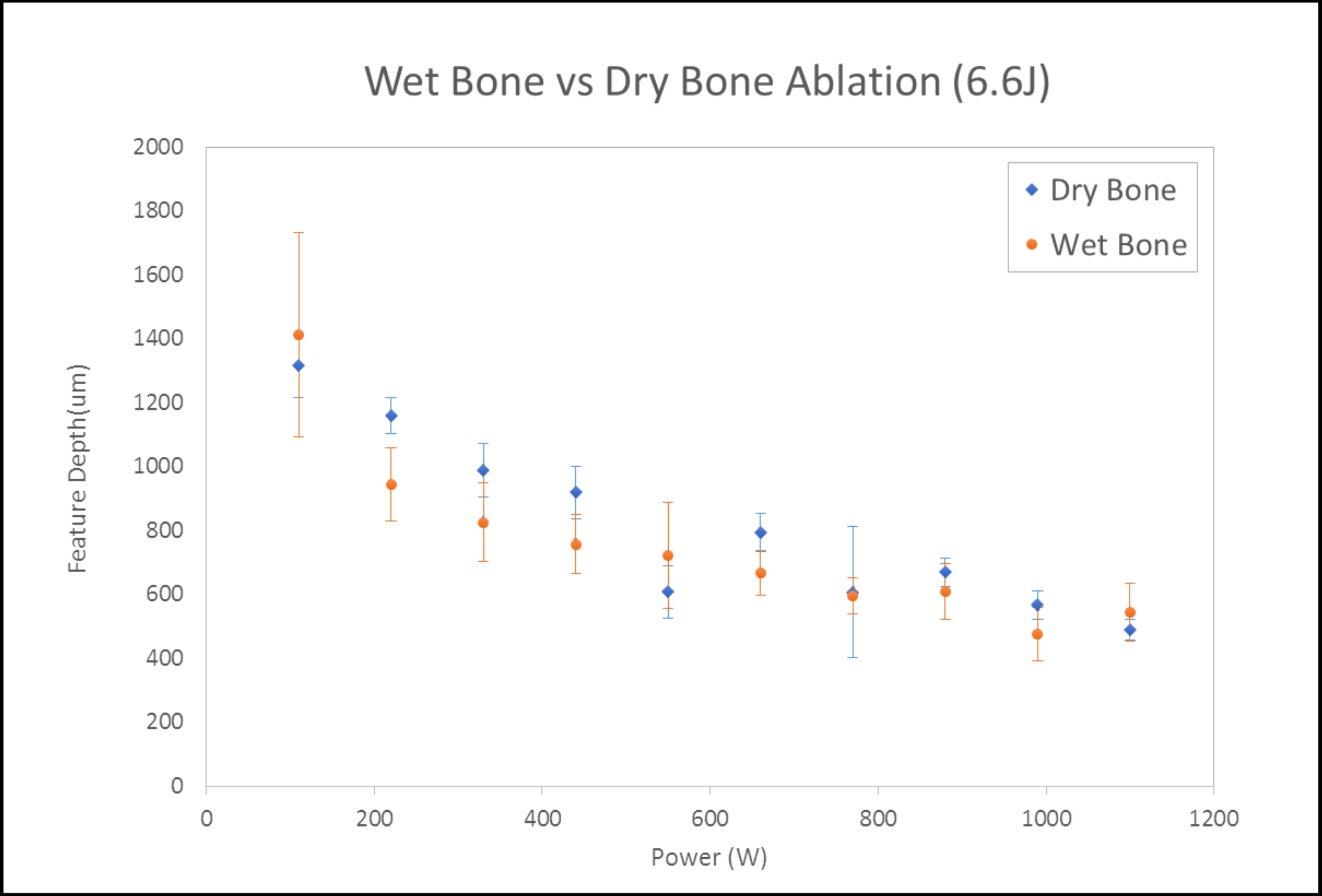
Example #2





ICI-tracked Bottom of a Laser Weld Overlaid on Microscopy Image




Wet Bone vs Dry Bone Ablation (6.6J)
Dry Bone
Wet Bone
Feature Depth(um)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
Power (W)

Ablation of hard bone tissue with pulsed CO_2 lasers

Mikhail Ivanenko[a,*], Martin Werner[b], Said Afilal[a], Manfred Klasing[a], Peter Hering[b]

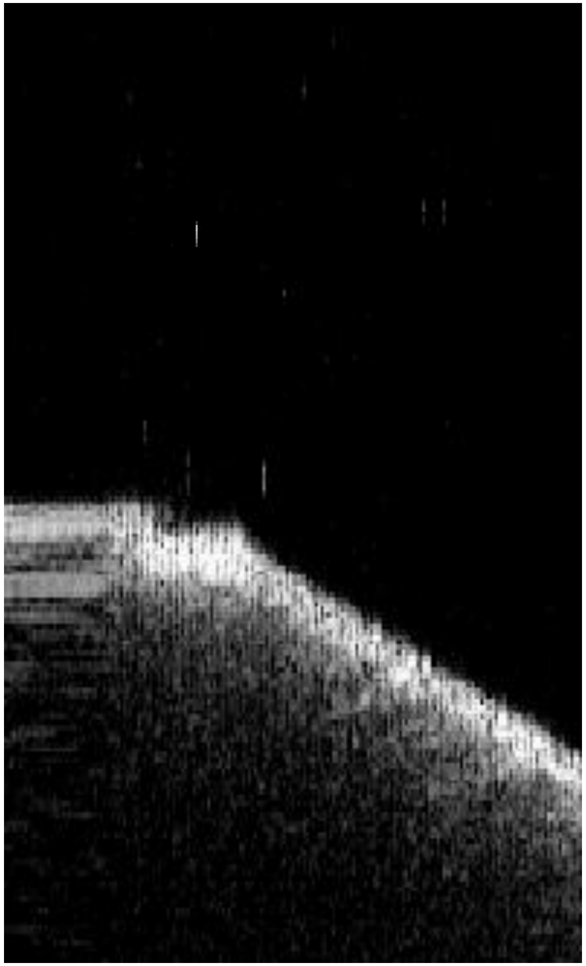
Received 1 January 2005; accepted 1 February 2005

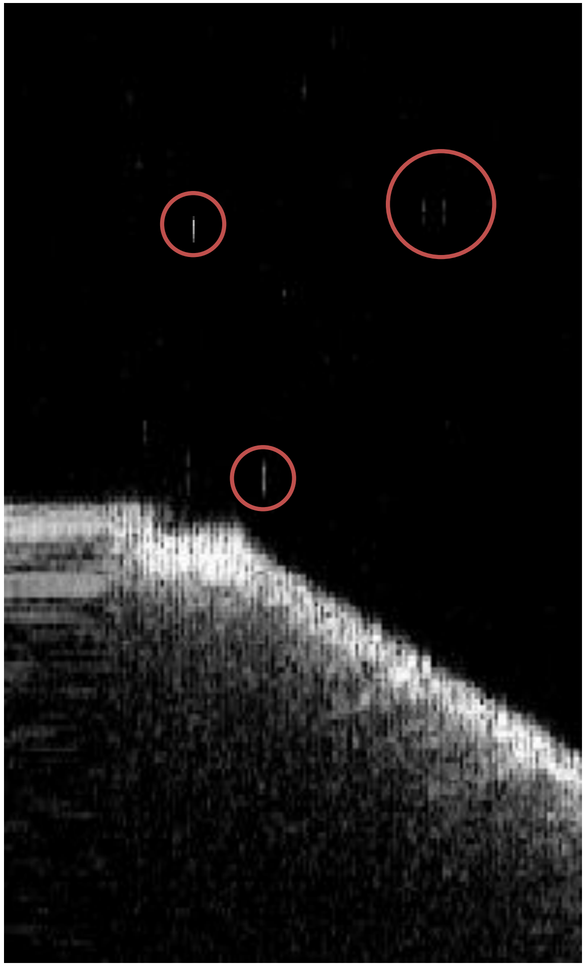
Preconditions for effective and "clean" laser tissue ablation

Ablation of hard tissue with a CO_2 laser follows supposedly similar thermo-mechanical mechanism like with an Er:YAG laser: light absorption in a very thin tissue layer → almost instantaneous conversion of the absorbed energy in heat → evaporation of the liquid, enclosed in the affected layer → mechanical destruction of the hard bone matrix after the internal pressure reaches the ultimate tensile strength of the tissue → ejection of the tissue microfragments and vapour → proceeding of the ablation process into the deeper tissue layers during the laser pulse. The bone absorption at 9–10 μm is mainly due to the mineral component. Nevertheless, the tissue liquid (solution of polysaccharides, salts and other chemical substances in water) can be a driving force of the ablation at this wavelength, thanks both to a strong direct absorption and to very fast heat transfer from the mineral component at a microscopic scale [14]. At high light intensity in the focus the energy will be accumulated very quickly in the tissue and confined initially in a thin absorption layer. If the pressure built-up is much faster than heat diffusion, than most of the energy will be consumed for the ablation process and removed from the tissue with hot ablation products.

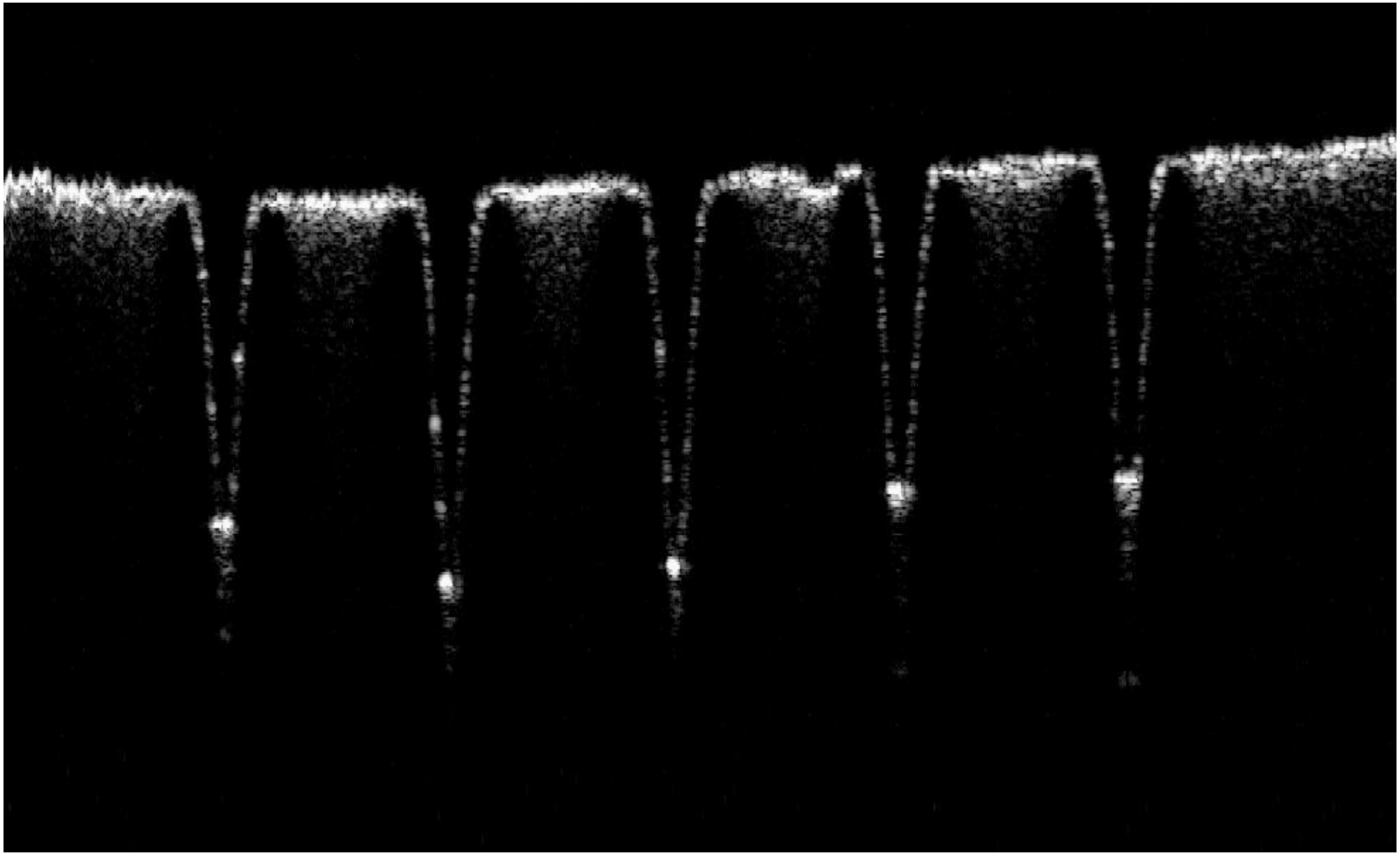
Medical Laser Application

Evidence

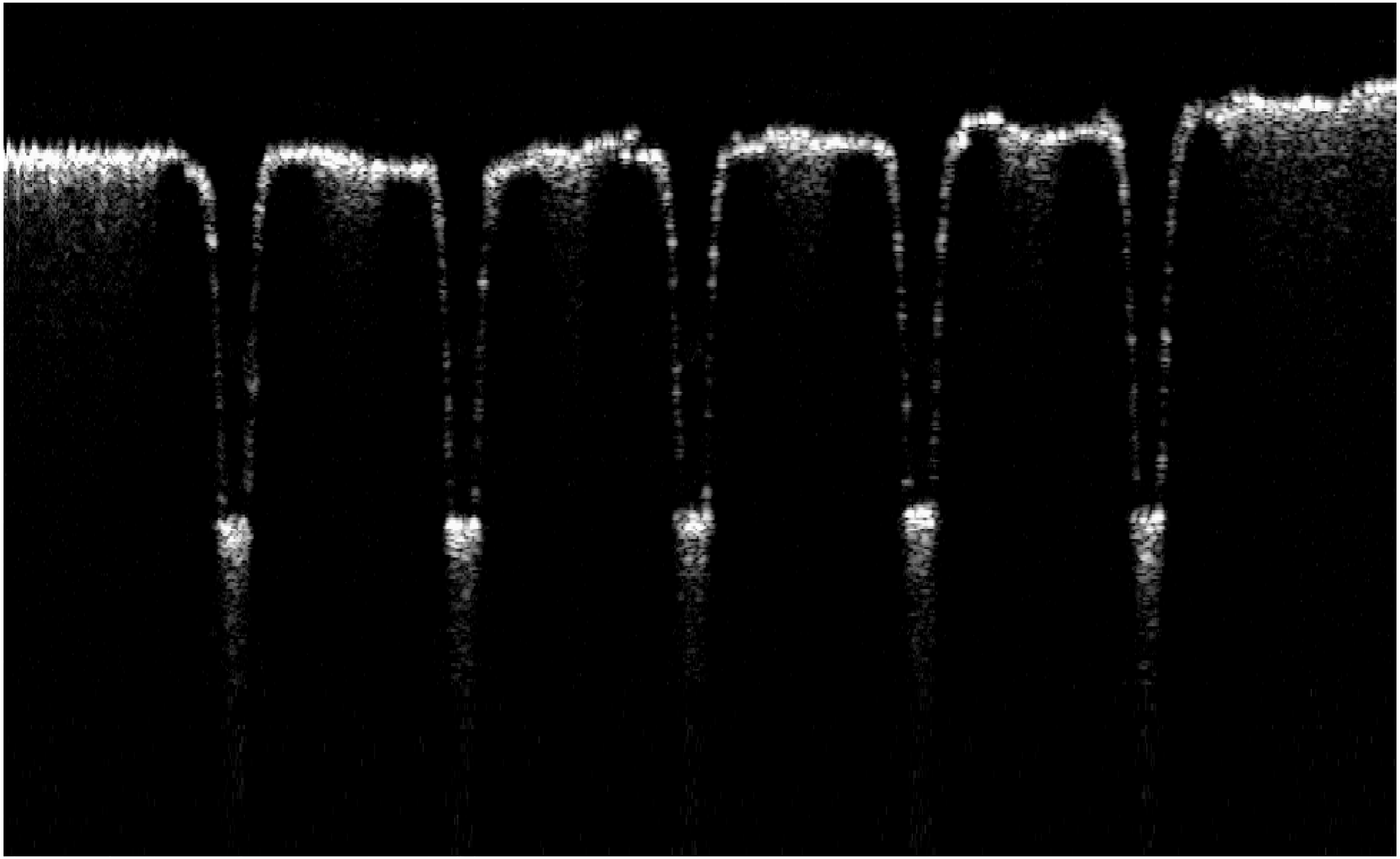




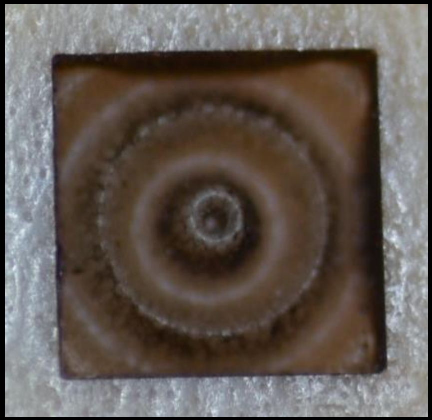
Fixed energy hole drill



Feedback control hole drill



3D "Clean" Bone Machining



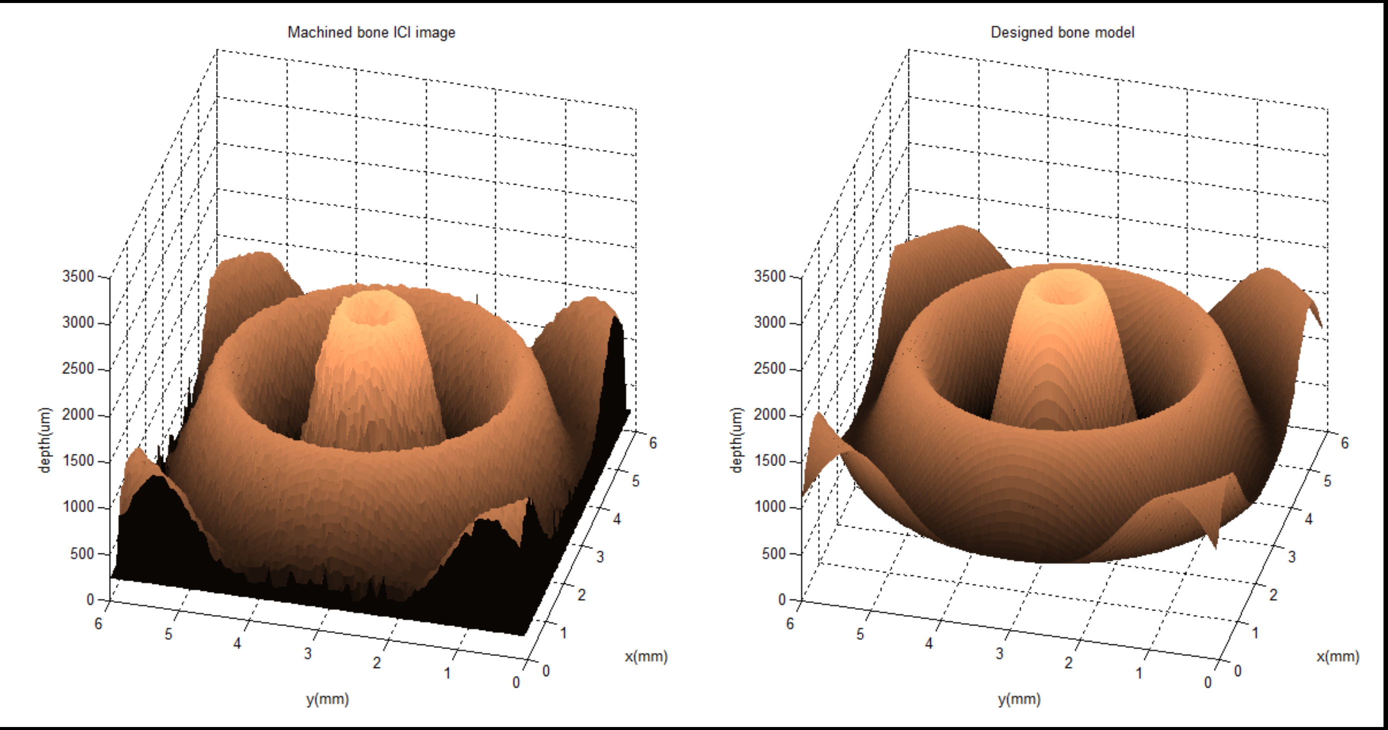
6mmx6mm feature

3mm depth range

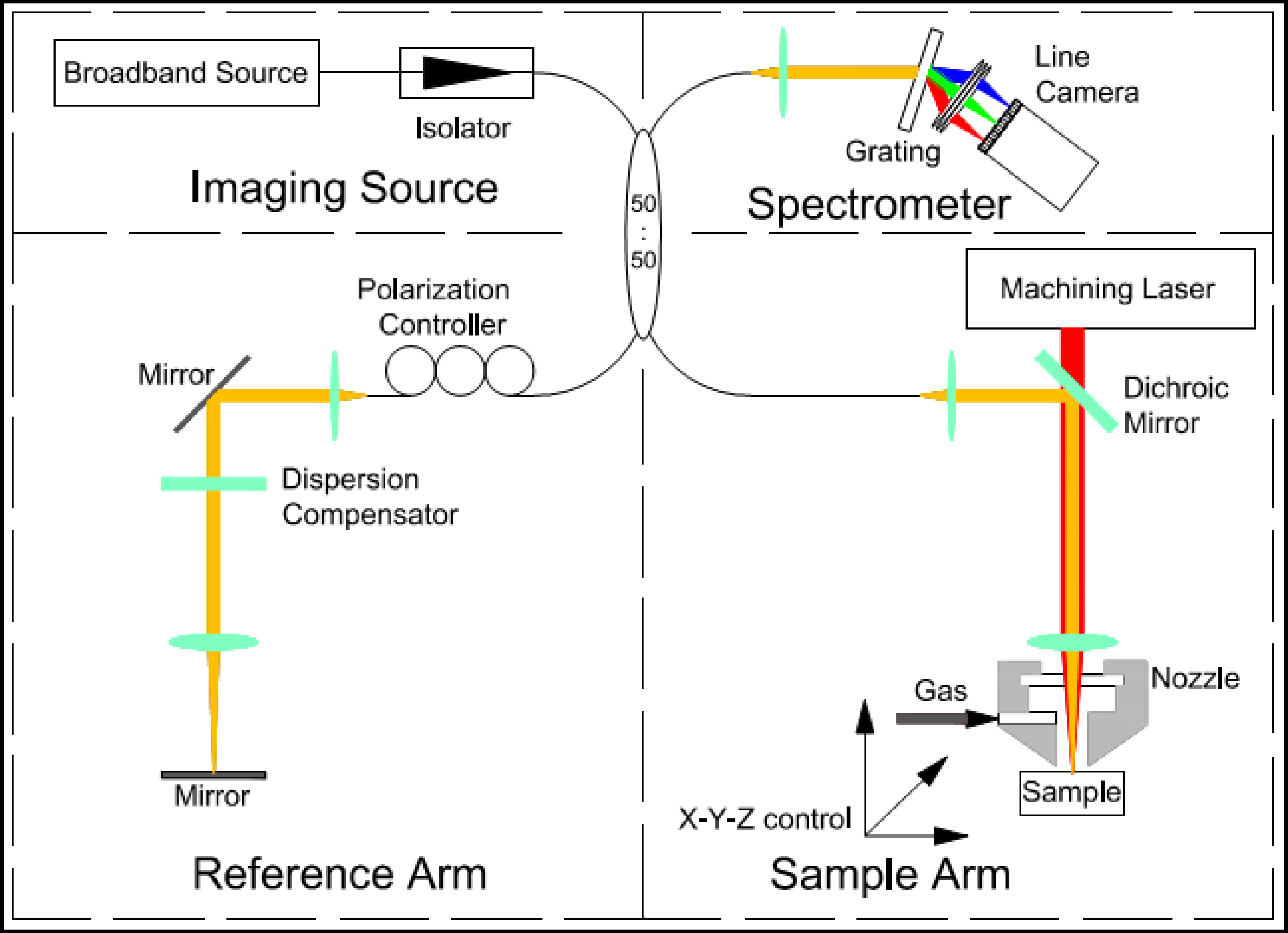
Three 50us pulses

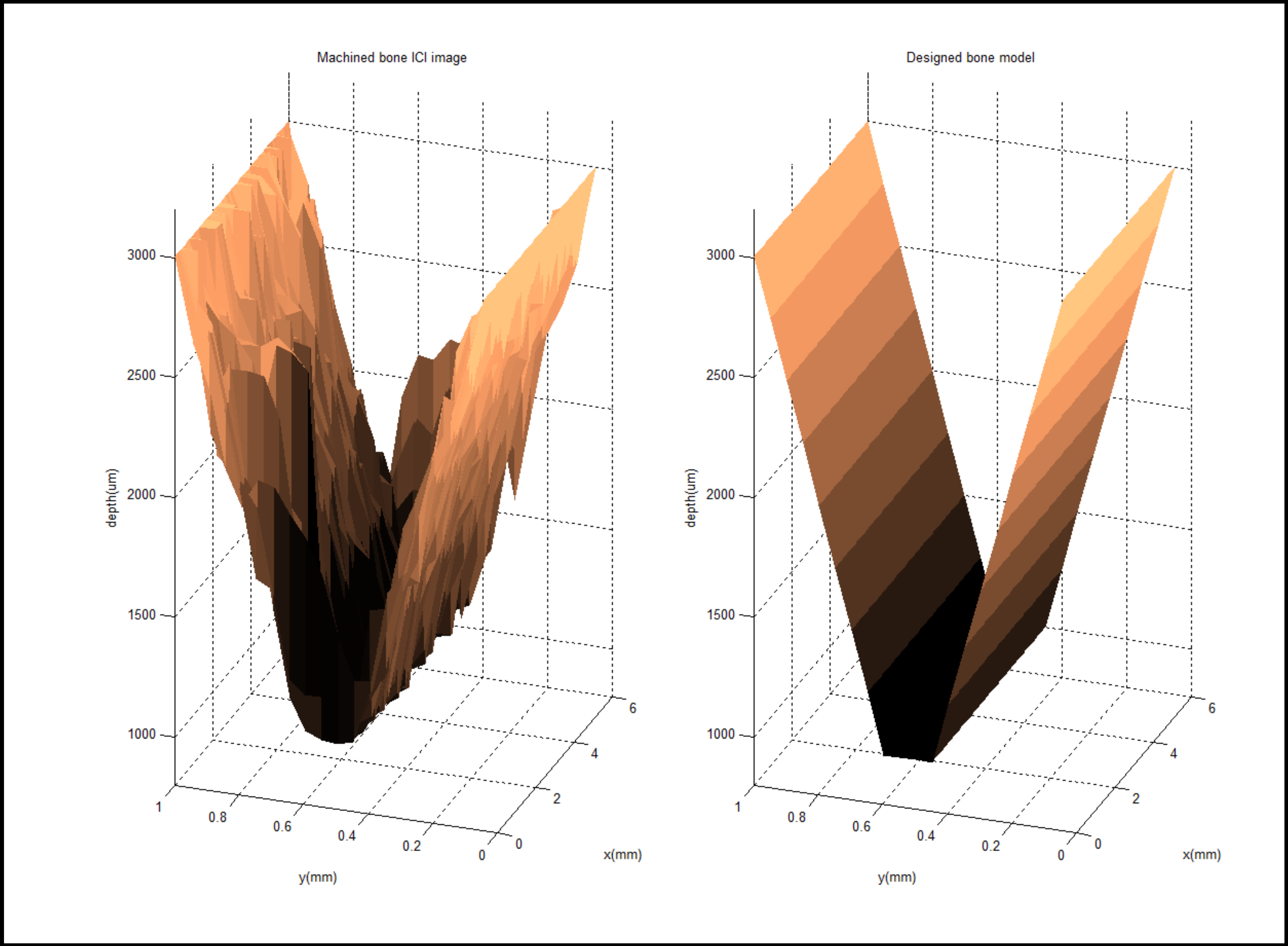
100Hz rep rate

~1hrs



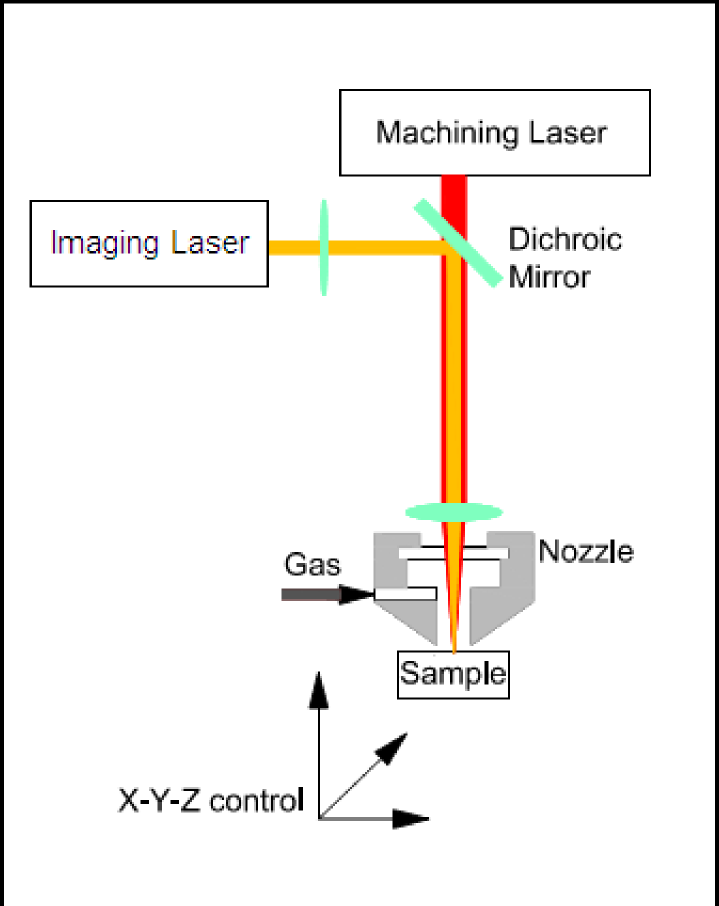
Experimental Set-up

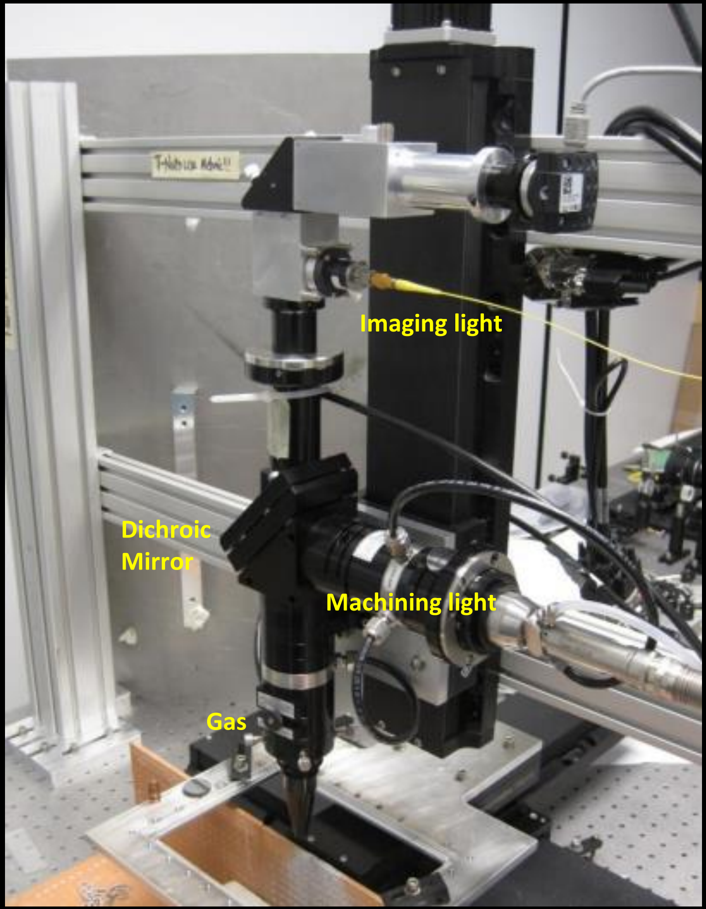



Machined bone ICI image
Designed bone model
depth(um)
3000
2500
2000
1500
1000
y(mm)
1
0.8
0.6
0.4
0.2
0
x(mm)
0
2
4
6

Experimental Set-up

Combined machining and imaging laser beam





Why Laser Cutting Bone?

- Traditional method - mechanical saw/mill
  - **Disadvantages**

    - Broad cut (~1mm) and severe hemorrhage

    - Large damaged region in surrounding tissues

    - Deposits of metal shavings

    - Mechanical vibration limits precision

Why Laser Cutting Bone?

- Modern method – "light cutting"
  - **Advantages**

    - Non-contact cutting

    - Narrow incision with tightly focused laser beam

    - Small heated affected zone

    - **Micron-precision depth control**

How To Control Laser Machining?

- Position control
  - Focused laser beam → high transverse resolution
  - Sub-micron precision motion stage

- Depth control
  - In-situ depth imaging → Inline Coherent Imaging(ICI)
  - High axial resolution (~16um)

Queen's University

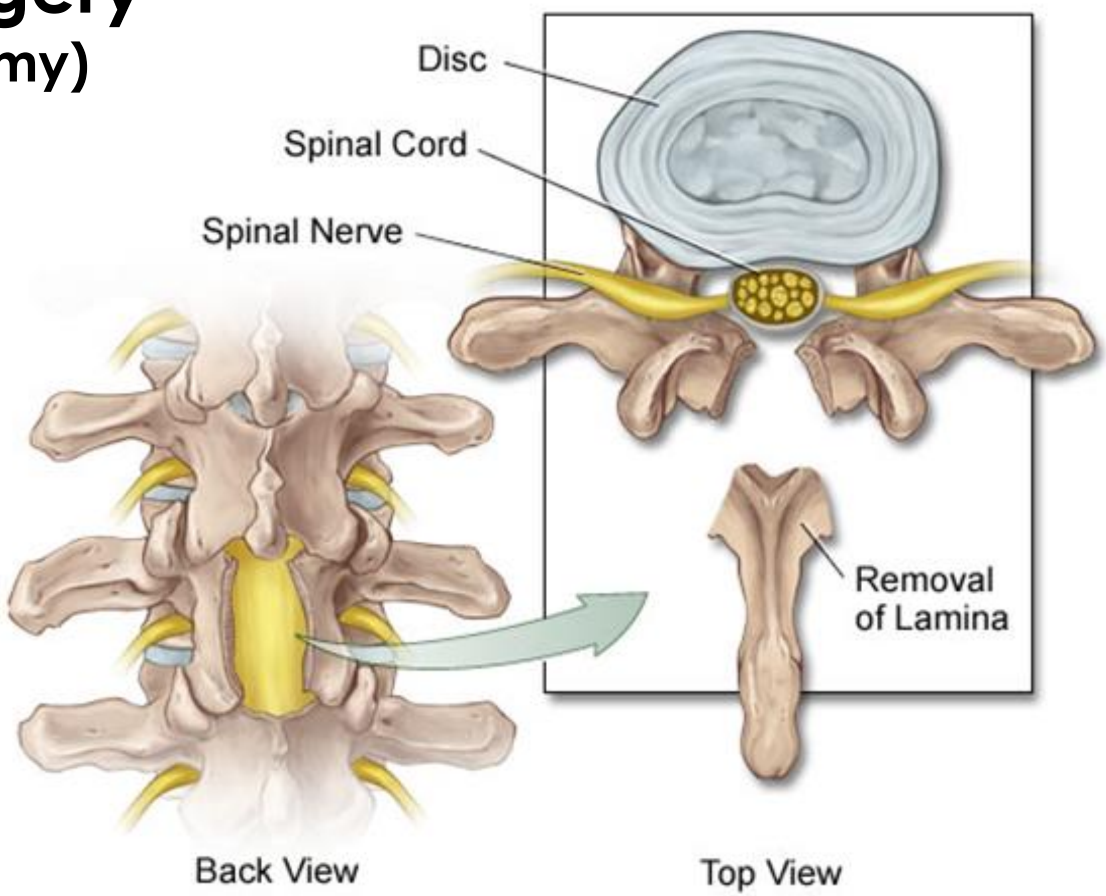
Department of Physics, Engineering Physics & Astronomy

NSERC CRSNG

LaserDepth Dynamics

Motivation

Spinal Surgery
(Laminectomy)



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