INSIDE JK LASERS

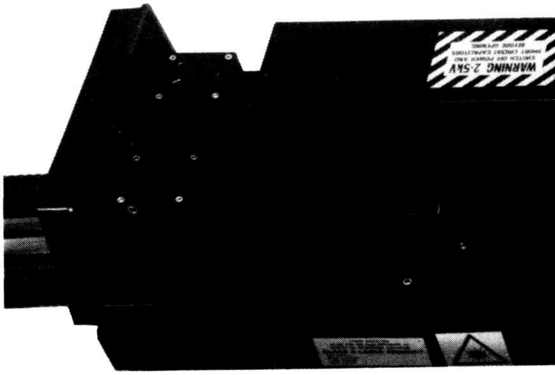


Photo: Courtesy of Lumonics Inc.

Ed Wesly

Even the competition would have to agree that JK Lasers are the very best ruby lasers ever made for holography. The availibility of extremely high quality light from these lasers is the foundation of the coming boom in pulsed laser portraiture. Maybe just the holographers are getting better, but holograms made with these lasers surpass anything made in the past with anything else with the exception perhaps of the Conductron laser.[1,2]

In 1967 the Conductron laser was the first one to record holograms of living people. It used Korad parts in a unique configuration and pumped with enough tender loving care to give enough energy to shoot the famous portrait of Dennis Gabor, the trio of beer-drinking poker players (used in Salvador Dali's "Holos! Holos! Velazquez! Gabor!") and the underwater scene with seven divers, the reference beam coming out of a flashlight held by one of them, amongst other things. It was donated to the Smithsonian Institution, borrowed by Peter Nicholson, and present whereabouts unknown.[3,4]

Ruby lasers belong to the solid state family of lasers, which includes Nd:YAG, Nd:Glass, and Alexandrite. All these lasers are optically pumped; the lasing medium's atoms are raised to a higher energy state by liberal doses of light, rather than by an electrical discharge through the gas, like the more familiar HeNe's and Argons.

They are dubbed solid state because the rods are in that form rather than a gas. Although transisters and diodes are known as solid state devices, laser diodes are usually referred to as semiconductor lasers to avoid confusion.

Ruby was the first material to lase back in May 1960 thanks to T.H. Maiman at Hughes Aircraft. This was quite a surprise, as physicists thought that ruby would not be successful since its quantum efficiency was calculated erroneously to be only about 1%. It really is about 75%, and loves to lase. Even Art Schawlow ended up with egg on his face because he gave a paper in which he commented that ruby wouldn't lase since the ground state would have to be completely depopulated—the rod would have to have every atom pumped up.[5]

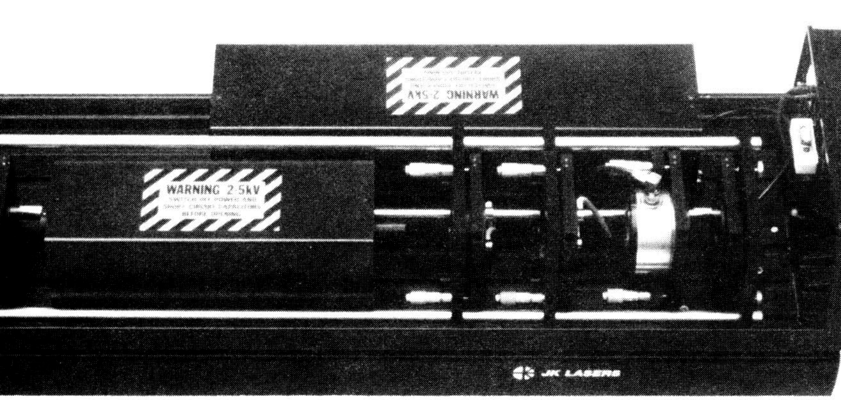
I remember that as a child in about 1960 or 61 I saw Professor Schawlow on "I've Got a Secret" (an early game show) break a colored balloon inside of a clear one using a ruby laser, although I didn't understand that at the time. My parents couldn't explain it, either. But even today, the Nobel Prize Laureate still does that demonstration whenever he gives a talk, using a small ruby rod inside a toy raygun body.

The JK comes from John Kenneth Wright, one of the founders of the company in 1971. Their goal was to build a wide range of solid state lasers, and at that time the market was ill-defined, so a modular approach of design was adopted, with reliable basic building blocks of optics and electronics which could be assembled to suit the customer needs. But after a while certain specifications were recurrent, setting a standard for particular applications, so that various product lines were developed, integrating certain components into basic models.

The earlier System 2000 ruby lasers used an inverted tee optical rail, on one side of which the optics and mechanical subassemblies were bolted, with the electrical cables and plumbing hoses on the other. The current HLS series uses an optical bed which is more stable, but the cabling arrangement is less convenient as all the connections are made from below.

Also available from JK are a Plasma Ruby model, which is basically identical to the HLS except for the absence of etalons, which are unnecessary for its use in Thompson scattering experiments. JK also make Nd:Yag and Nd:Glass models, based on similar design philosophies.

All ruby lasers start with rods from the same source—Union Carbide. Their KORAD division is history, but they still keep growing the crystals. What separates JK from the rest is extremely sensible engineering. The rod is held in a ceramic pumping chamber with 2, 4 or 6 linear flashlamps parallel to it. Theoretically, helical wrap-around flashlamps should get more of the population inverted and provide a nice round profile, but when the current is dumped into the helix, it tries to unwind the tube, causing premature breakage. The straight tubes do not have that problem. Many manufacturers leave the grounds side of the flashtube in the pumping chamber *in the cooling water*! The JK's lamp ends are outside the chamber. Changing a helical flashlamp requires removing



A view of a 10J, HLS-4 pulsed ruby laser from Lumonics.

the ruby rod. Not so for JK's design. To get the rod nicely pumped up, JK uses a ceramic pumping chamber so that light not going directly to the rod from the lamp hits the wall of the chamber and penetrates the glaze and comes out of it in all directions, diffusely illuminating the rod, so that it is evenly pumped. In practice this arrangement does just fine, as evidenced by the burn patterns taken after a variety of rods pumped by 2,4 or 6 lamps. (figure A). Notice that there are no quadrilateral or hexagonal shpes to the beam profile.

The oscillator is the most complicated part of the laser, and the source of the high quality of the light. It includes a ¼″×4″ rod in its own pumping chamber, with mirrors at either end of the resonating cavity, a pair of etalons, a polarizer and a Pockels cell Q-switch, all held in robust mounts with micrometer adjusters to a trio of ½″ Invar steel rods, for an extremely stable cavity. All the hardware and attachments are of sound design principles. As a testament to that, a klutz like the author has completely taken the oscillators of a couple of these lasers apart for cleaning and returned them to full factory tune. Documentation for the chore is good but, a HeNe alignment laser up the butt of the oscillator is essential for the alignment procedure.

When the flashlamps go off, the ruby rod is flooded with light and starts to glow with a pink florescence. The oscillator rod is positioned between two mirrors in the usual sort of resonating cavity arrangement, so that light can traverse back and forth through it, gaining energy with every pass and coming out of the front one which is 20% transmissive. This light is good enough to burn holes in razor blades but not coherent enough for the demands of holography. Other devices in the resonating cavity purify the output. On the box containing the pumping chamber there is a polarizer on the side toward the rear mirror. After passing through it the light encounters a pair of etalons.

The etalons, a thick one and a thin one (other manufacturers take note), are about 20mm in diameter and have approximately a 6mm diameter surface exposed, so that if there is any damage a fresh part can be rotated into position. The free spectral range of the ruby has a notoriously wide bandwidth, (lots of different wavelengths can lase simultaneously) but these two little cavities in the bigger cavity really work. Although JK conservatively guarantees one meter coherence for 90% of the shots, they rate this at full pumping. I have seen greater than three to four meters coherence in holograms with the laser being run just above threshhold. The original system 2000 ruby lasers had oven temperature regulated housings; the etalons are tied into the water cooling circuit in the current HLS series.

Normally when the ruby laser is fired, it emits what appears to our eyes a single pulse of light, but really is a series of emissions of about 20 short pulses over the period of a millisecond. These spurts come about because the rod is pumped for a few milliseconds by the flashlamps and as the rod reaches threshhold it emits a little light and loses a little bit of energy, but it is still being pumped so it gains more energy and emits again, and again and again until all the energy in the rod is depleted. But if there is something blocking one of the mirrors, there will be no lasing action until it is removed. This is the job of the Q-switch—to prevent laser action until just the right moment when the rod is pumped up with as much energy as it can take, just raring to let out a big wad of light. The origin of the name "Q-switch" is interesting. In electronic engineeringese the measure of the quality a radio resonator cavity is termed its "Q." By blocking this cavity you spoil its "Q." So at first these things were called Q-spoiling switches, then simply Q-switch.

Any laser can be Q-switched by using a rotating rear mirror. The front and rear mirrors will only be aligned properly for laser action for an instant. This type of arrangement is not very popular as it is difficult mechanically to accomplish.

Another form of a Q-switch was a bleachable dye cell in the resonator place in-between the rod and the rear mirror. This dye was opague until enough light bleached it clear, so that then light could pass through it and off the mirror and back into the rod and off the other mirror and back through the rod again, gaining energy with every pass in a very short length of time and letting out one single giant pulse. This type of Q-switch was first invented by Peter Sorokin in the mid-60's, back when the power of ruby lasers was measured in Gillettes, the number of razor blades a laser could burn through. The dyes are hard to work with, as repeated use destroys them, but they are still used sometimes as they have a slow turn on rate, which allows more passes through the etalons, making them more selective for better coherence.

The JK uses a Q-switch that is electronically controlled, the Pockels cell, for precise timing of emission and double pulse capability. Some crystals exhibit the Pockels effect, which makes them act like retardation plates when the stress of electric current passes through them. Their lattices line up depending on the voltage applied to them, and they can act like ½ or ¼ wave plates for a particular wavelength. JK uses a KDP (Potassium, Deuterium and Phosphorus) crystal, which requires relatively less voltage than others. At the end of the oscillator's pumping chamber is a Brewster stack to vertically polarize the light coming out of it. Then the light passes through the etalons to the Pockels cell whose voltage is adjusted to give it quarter wave properties at the ruby wavelength. A quarter wave plate circularly polarizes light that has already been polarized in one plane. This circularly polarized light reaches the back mirror, is reflected back, still circularly polarized but in the exactly opposite direction. When this circularly polarized light goes back through the Pockels cell, it becomes linearly polarized again, but orthogonal to its original direction, so it is now horizontal. When this horizontally polarized light encounters the vertically oriented Brewster stack, it is rejected. So the Pockels cell acts as a blockade to the light.[6,7]

After a certain delay to ensure full pumping of the rod, the "plug is pulled," so to speak, on the Pockels cell, so that it no longer acts like a ¼ wave plate but as a plain piece of glass. All the light bouncing off the rear mirror goes back into the rod and through it to the front mirror and back and forth and the rod lets go with one short, high peak power pulse. This emission lasts 20 nanoseconds, which is 20 billionths of a second—an incredibly short period of time. (To understand just how short a nanosecond is, consider this analogy. Let one second be equal to one nanosecond. At this scale, one full second would then be one billion seconds, which is greater than 31 years!) It is interesting to note that with pulsed lasers there is a definite beginning and end to the "bolt of light" emitted from them. Taking c to nominally be 300,000,000 meters per second, a 20 nanosecond emission is 6 meters long, thanks to distance=rate times time, or $(3x10^{8})$ m/s $\times$ (20×10^{-9}) s$=60\times10^{-1}$ m or 6 meters. It is to JK's etalons' credit that most, if not all, of their wave train has the same wavelength.

One would think that a 20 nanosecond pulse would be able to stop any and all motion. Not so. The quarter wavelength movement tolerance is often bandied about, so let's calculate.

(Figure A) Burn patterns are produced by zapping a piece of blackened photographic paper with laser light.

Rounding 694 nm, the ruby wavelength, to 700 nm for simplicity, then ¼ wavelength becomes 175 nanometers. The velocity, v, for something to move 175 nm in 20 nanoseconds would be given by v=d÷t, so (175×10^{-9})m − (20×10^{-9}) =8.75 meters per second.

A more stringent requirement, one eighth of a wavelength for brighter holograms would be half that, about 4.5 m/s, and in kilometers per hour that is 16.2, which translates to the more familiar 10 miles per hour! For living things sitting still this is fine, but if you notice in the old TRW holograms of bullets they are in silhouette![8] Even shorter pulses are necessary for speedier events. The light is emitted from the oscillator through a mode restricting aperature. This 1.7 mm hole in a stainless steel disk is there to ensure that the beam profile is nice and round—a good Gaussian Tem_{00} shape, using the best light from the center of the rod, as without it the edges are quite ragged, depending on how well the rod is pumped up.

After the beam comes out of the oscillator, it is cleaned-up by a spacial filter, consisting of a 150mm positive lens focusing the light through a 250 micron diamond pinhole. In case of slight misalignment, the diamond is the only material that could take the beating. Normally, we think of the gem cut diamond, nice and transparent, but the material itself in the pinhole looks like a dark grey metal. There is no breakdown of the air here as one would expect, as the spot size is rather large and the energy density is rather low. The spatial filter also starts the beam diverging slowly, to fill up the following amplifying rod(s).

Not only can a ruby rod act as an oscillator, sending out a single frequency signal built up after many round trips inside the resonating cavity, it can also act as a single pass amplifier. When a beam of coherent light from the oscillator passes through another rod that is all pumped up and raring to go, it cuts loose with a vengeance, amplifying the power many times from what it receives. There is no need to enclose the amplifier rod with its own mirrors! It always amazes me that the amplifier rods preserve that single frequency that comes out of the amplifier, but they do it so well that there is as much highly coherent 6943 Angstrom light as you want (or can afford).

This is not to insinuate that amplifier rods are dumb, but they will amplify anything passing through them equally well in either direction. For instance, the reflection from the nicely cleaved end of a 600 micron fiber optic went back into the third amplifier rod of the Fermilab laser, got stronger, through amplifier number two and, even more so, and amplifier number one took it on the chin, so to speak, developing a nice one inch deep crack. Thanks to the conservative filling factor of JK, the oscillator pump beam could be steered around the blistered spot and the laser could be used nevertheless.

It is the amount of amplification that distinguishes the differences between the JK models. Their HLS 1 is simply the oscillator described above, putting out about 50 mJ. This is not enough to do a portrait, but at Northwestern University we have taken 4″×5″ Single Beam Reflection holograms quite comfortably with the oscillator alone, and I believe that the one rod is sufficient to do even 8″×10″s.

An HLS 2 is the oscillator pumping a ⅜″×8″ ruby rod in its own separate chamber surrounded by four flashlamps, emitting one joule. More efficient use is made of the ⅜″ rods of an HLS 2 to pump a final ⅝″×8″ rod for 10 giant joules. All the above lasers come in identical packages, with variations in layout on the optical bed inside. But if ten joules is not enough, then there is the great-granddaddy of them all: the 25 joule HLS 5. I had the fortune of working with the only one made so far at the 15-foot Bubble Chamber at Fermilab for recording physics events with Gabor-type holograms. It has all the rods of an HLS 4 pumping a monster 1″×8″ ruby rod. This is a sinful amount of light. Perfect smoke rings would puff off the burn papers. This laser is a testimonial to the extremely efficient engineering of JK, as it survived all the punishment the physicists would give it over a period of greater than 200,000 shots and is still going strong.

Originally the System 2000 and HLS series came in a plain Jane vanilla-white and black package. Although the JK personnel weren't too happy about switching over to the Lumonics group colors after their acquisition, it gives them the slickest looking laser in my book, stealing the title away from the old favorite, the Coherent Innova series. It's hard to believe that a navy and powder blue laser with racing stripes would look good, but check out the photograph!

Electronics are not this beam jockey's forte, but from the looks of the tidy power supply cabinets it would appear that they are designed as well as the optics. A box about the size of a huge stereo amplifier controls the timing of the Pockels cell and firing of the flashlamps. Ten digit thumbwheels dial in the voltages supplied to the flashlamps which ultimately sets the output of the laser. This is how exposure of the hologram is controlled, as time is fixed by the Q-switch. This controller sits on top of a refrigerator-sized metal cabinet containing the capacitor banks that store electricity in a manner similar to the way the tank on your toilet stores water. These capacitors are almost the same size as the toilet tank. An efficient "hum" accompanies the charging of the capacitor bank, and their large thirst is the reason that the rep rate is limited to six pulses per minute, except for a special 1 Hz oscillator only model. On demand to flash (or flush), the stored-up juice is released into the Xenon-filled flashlamps with a resultant bright burst of light to pump the ruby rods. Three of these boxes drive the Fermilab laser, and when it was fired the magnetic field set up by the current leaving the cap's sucked in the sides of the cabinet which then resounded like a tympani trio.

The amount of juice stored in the no PCB's is lethal. Thousands of volts at high amperages are necessary to fire the lamps, so all the equipment is safely tucked away behind plexiglass covers. Before removing them, the unit is grounded out with shorting cables to prevent shock. Five kilojoules is the dose the electric chair deals out; ten times that is used to get the 25 joules of light that the biggest delivers, giving some idea of the efficiency of these lasers. Typically, they are wired to plug into 220 volt single phase AC for the states, which is used for electric stoves and household air-conditioning, not like the industrial strength 208 VAC three phase requisite for ion lasers.

But there is no reason for the average user to get into these works. The only problem that I've seen occur with these units are relay contacts frying when an attempt is made to dump the capacitors while they are in the charge cycle, which is not a very bright thing to do. But a safety circuit has been installed to prevent this from happening on more recent models. The only complaint I can register is the inaccessibility of the temperature guage and level checking for the cooling circuit.

The problem with using red laser light for portraiture is its ability to penetrate the skin. Red light doesn't bounce off the surface of tissue but into it a bit and then out. A flashlight beams mainly red light through your hand. Look at the sun or a bright electronic flash and you see red, not because of the blood in the skin but because the red light can penetrate through the tissue while the green and the blue are reflected or absorbed. Take a look at your hand under the gentle HeNe and it is hard to distinguish even the fingerprints. Look at the same thing under the green Wratten #3 safelight and you can certainly see the texture much better. This explains the waxy look of holoportraits. The solution is to, of course, use a pulsed green laser, and the only one that seems suitable for holography is the model SLM (single longitudinal mode) frequency doubled Nd:YAG from JK, with about 200mJ output at 530 nm. Of course then the problem is to find a good green-sensitive recording material, and both Agfa and Ilford have a long ways to go on that.

FOR YOUR INFORMATION

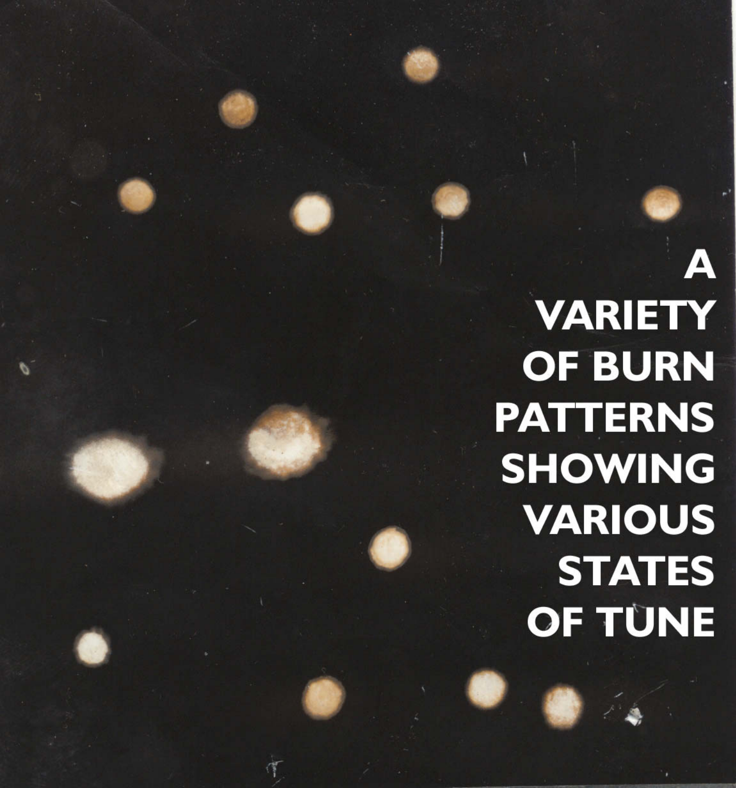
A joule is a measure of energy—one watt second. It is the product of power (watts) over a period of time in seconds. For instance, to feel the effect of one joule, I devised a test of strength where a one-watt Argon laser beam would be shuttered so that it would hit a callous on my palm for one second. Needless to say, I flunked it as I jerked my hand out of there immediately, with a nice blister to boot. So one joule=1 watt for 1 second, or 10 watts for $\frac{1}{10}$ of a second, 100 watts for $\frac{1}{100}$ second.... One joule in the 20 nanosecond Q-switched realm means a peak power of 50 MV—read that with a capital "M" for Mega which means Million!

For more information contact: Lumonics Inc. Ontario, Canada (613) 592-1460

Footnotes

1) *D.A. Ansley, "Techniques for Pulsed Laser Holography of People",* Applied Optics. *Vol. 9 #4, p.815.*
2) *Collier, Burkhardt, Lin.* Optical Holography. *Academic Press, chapter 11.*
3) *"Center for Experimental Holography Completes First Phase of Research".* holosphere, *January 1978. p.4.*
4) *"Nicholson to Offer Pulsed Holograms to Advertisers/Sales Promoters".* holosphere, *June 1980. p.1.*
5) *Laser Pioneer Interviews, Editors of* Lasers and Applications, *Theodore H. Maiman interview. pp 85-99.*
6) *For a discussion of the isolating properties of quarter wave plates, see Melles Griot* Optics Guide 3, *pp 303-304.*
7) *For more details, see* Light Modulator and Q-Switch Operations Manual *from Lasermetrics, Englewood, New Jersey.*
8) *R.E. Brooks, et al., "Holographic Photography of High-Speed Phenomena with Conventional and Q-switched Ruby Lasers",* Applied Physics Letters, *Vol. 7 #4. p. 92.*


3/8" BY 8" FIRST AMPLIFIER
5/8" BY 8" SECOND AMPLIFIER
1/4" BY 4" OSCILLATOR
OUTPUT
A BETTER
VIEW OF A
10 JOULE JK
RUBY LASER


A VARIETY OF BURN PATTERNS SHOWING VARIOUS STATES OF TUNE