The History of Dichromates

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Abstract

The term "dichromates" may have started with Lloyd Cross, all I can recall is that I traded him a pocket full of "dichromates" for a "kiss". We were at the school of holography on the Santa Monica beach at the time. The first recording in Dichromated gelatin that I was privileged to see was made a year earlier by Mike Foster in the city of salt and he may also have used the term "dichromates". Mike and I were both working rock concerts in Utah from about 1965 to 1972 and got together from time to time to discuss science stuff and in particular an article in Popular Science written by Harry Knowles of Metrologic Instruments detailing the procedures for making a simple transmission hologram. I helped Mike prepare a lab and he made the first silver grain hologram I had ever seen. He chose a metal pig borrowed from the desk of weird Harold, who paid for everything at the time. I set up my own sand box lab after that, studied as many holography papers as I could find, made phase gratings, wrote my first paper on holographic gratings and then moved to LA to work at Hughes as an EE. A year later, 1974, I began production of the first dichromate jars, followed by the ubiquitous dichromate pendant, watch face, key fob and belt buckle in 1976. At my first SPIE meeting in San Diego in 1977, I sold dichromates in the halls. I carried a briefcase full of pendants with a covered display on the outside. Sales were brisk and I often had to retreat to my van to restock the briefcase. SPIE policy forbade such activity so I had to move around a lot to avoid Sue Davis. That was pretty much the beginning of a cottage industry.

1. Hooked on Optics

This paper is a brief journey from my first introduction to display optics to a career in holography. It is anecdotal experiences more or less presented in order of occurrence and has no technical merit. It represents my best effort at story telling and may not even be accurate. My journey began at the New York world fair of 1965 at the General Electric exhibit. GE had constructed a huge color organ using Rolux multi-lens sheeting to give the back lit screen a three dimensional appearance. I went home to Utah for my second year at USU and duplicated the device with help from a GE engineer and began selling them to bars. In 1966 I saw my first professional light show produced by Jerry Abrahms called "head lights" and quickly copied his equipment and made up some new effects of my own. Fred Unterseher was a part of Jerry's crew. I had built a large color organ in the likeness of an umbrella over the audience and so I called my show the "Electric Umbrella", a name I continued to use through my early years in holography. This was really fun stuff, I used colored oils and colored water between large clock faces to make dynamic amoeba looking projections onto screens, walls and ceilings. I cut holes in colored gels and rotated them slowly in front of de-focused slide projectors to create a flowing, ever changing colorful background and then superimposed sharp exploding images strobed by faster wheels and multiple projectors. Then I made slides from birefringent tapes and spun polarizers in front of projectors and I had built a few strobe lights from surplus electronics to annoy everyone with. I was probably born to be a photon junkie.

RDR in 1967, operating a light show projector, (oils), in a very tiny projection booth.

Fred Unterseher in 1977, San Diego SPIE

1.1 Mike Foster

There was another light show operator in Utah at that time and I managed to meet him sometime during or between gigs. He was a fascinating and very sharp character named Mike Foster and his show was known as "five fingers on my hand". He had all the right stuff and knew how to use it and his connections were good. Eventually he helped me get a gig with the Steve Miller band in Feb of 1969 and allowed me to play with his new He Ne laser at a Pink Floyd gig in about1970. Light shows went all Laser sometime after that and our projector based shows faded out. In 1972 I was building my first dye laser and Mike had just built an Argon laser (neither laser ever worked). One day he brought in a copy of Popular Science that had an article on how to make a hologram. We built a little black room and placed a granite slab on an inner tube and he made a hologram of a metal pig, borrowed from weird Harold's desk.. I thought it was cool but he saw a future in it. I continued on with EE studies and graduated and moved to LA to work at Hughes where I could play with more lasers and maybe make some that worked. My first trip back to Utah to ski I stopped in to see mike and he had made an 8 x 10 dichromate of David and finally I saw a future in holography.

I had done some initial library research on all that was published up to 1973 and had passed it on to Mike and he had reproduced literally everything and already had developed proprietary and novel methods of making embossing masters. He was way out there.

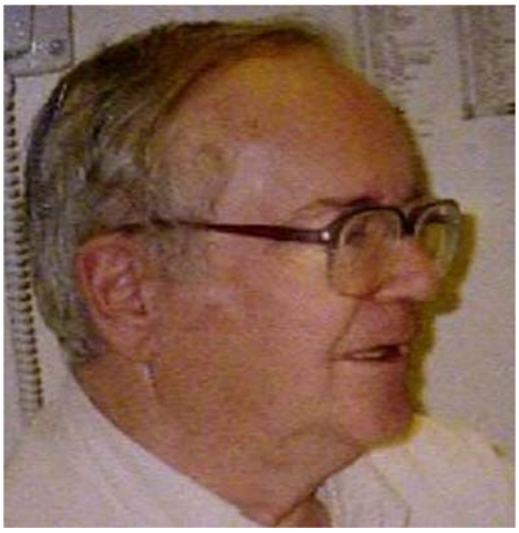
Mike Foster about 1976, SLC

Lloyd Cross 1977, San Diego

1.2 The early dichromate pioneers

In October 1968 T A Shankoff of Bell Labs published the first dichromated gelatin paper followed quickly by L H Lin, then Brandes and Curran also from Bell Labs. The reporting was quite complete and layed the groundwork for all other investigators. In 1971 Milton Chang of Northrop published an improvement using fixer and temperature to reduce milkiness while Pennington and Harper of IBM explored silver grain sensitized DCG. IBM researchers, Fillmore and Tynan found agreement with Lin's earlier work on photo induced index modulation. Meyerhoffer did an independent study at RCA and more clearly defined the micro-structure. About 1973 the torch was passed to Hughes Research labs where Don Close, Andrejs Graube and Gaylord Moss began cooking up HUDs and publishing very thorough research on dye sensitized gels. McCauley put DCG on Plexiglas that year as well. Mike F. visited HRL and made his first DCG in '73. My first followed early in 1974 while working at Hughes Laser Division, Culver City, CA. In 1975 Kubota began publishing red sensitizing followed in 1976 by BJ Chang at ERIM on reprocessing. In 1977 much of this was put in an orange reference book published by Springer, the DCG author was Meyerhoffer. I was tutored by Andrejs Graube from time to time and he visited my first production lab (garage) in the south bay area in 1975. I wrote my first DCG paper in 1979 based on experience with manufacturing and information from Andy, who was the only one of the early researchers that I ever got to know as a close friend. He continued to work in the field and published through 1979 at least. I think I am the only worker in the field, that started before 1975, that still depends mostly on DCG for a living. Every one else graduated from class and moved on and I am still repeating Shankoffs original experiments with hardly any changes into the year 2000. In Russia, Uri Denisyuk invented the single beam reflection geometry way before DCG was discovered. Single beam geometries worked perfectly with DCG because of the easily adjusted absorption and a huge dynamic range. I probably should have been paying him royalties in the seventies because almost everything I made was shot single beam at Brewster's angle. When I finally met Uri, I was relieved to learn that he was not concerned about my popularizing his techniques.

Uri Denisyuk at recent SPIE,
(trying to collect royalties)

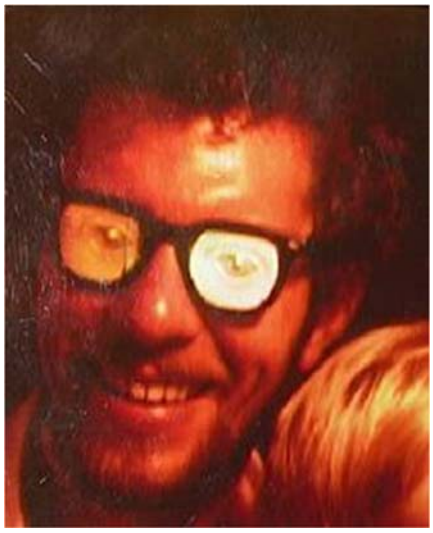


Harry Knowles 1995 at Metrologic

1.3 Serendipity

Back to the story, I returned to Hughes with one of Mike's broken 8 x10 inch dichromates determined to produce my own, Mike was not about to share more of his tricks of the trade so I was on my own. I coated Knox unflavored gelatin "**Jello**" on glass plates in my apartment using a record player built into an old steamer trunk. The dichromate processes described in the literature by Shankoff, Lin and Chang were all too time consuming to suit me. Mike had suggested during a phone conversation that I mix in all the sensitizing dichromate before coating to save some time and that helped. Everything I made initially came out milky white until I accidentally dropped an exposed plate into Milton's hardening fixer prior to soaking it in water. It was only in the fixer for 30 seconds but that proved to be sufficient to harden it enough to take the shock of hot alcohol without precipitation. A short process was immediately at hand. From then on I could make coatings on any glass surface in 5 minutes, expose them in another 5 minutes, process them in another 5 minutes and seal them up in less than 5 minutes. I immediately produced a few boxes full for show and tell and then lit the lab on fire. I managed to keep that trick under my hat until 1982, when Fred Unterseher persuaded me to publish it. I inadvertently also sold it to Steve McGrew (Holosonics) in 1979 and thought he might make it public just as I was selling it to IBM, but he never did publish. What he did publish was a very fine paper on color control in DCG in 1980, one of the first papers useful to artists working in color at the time. My method of controlling the color and clarity of master holograms was not disclosed til 1985. I dropped a developed broadband hologram into a certain bath that was about 75% alcohol and when I retrieved it and dipped it in hot dry alcohol it came back as a low scatter blue hologram. From that day in Nov 1975 I had a fast, tunable way to make bright masters that added almost no noise to the copies and so I finally had all the processes I needed to start making masters and churning out thousands of bright "dichromates" for sale. Which is what I did.

Dichromates, 1977 collection



Spike Stewart designed the first eyeglasses, 1977

1.4 Accidents that counted

The spring of 1974 saw the opening of the LA school of holography on the Santa Monica beach and I finally met Lloyd Cross and many of the other originals from the San Francisco school of holography. I learned what I could from them and swapped dichromates for multiplexes and rainbow holograms. Lloyd gave me a great copy of his "kiss" multiplex for a handful of dichromate gems and I promptly destroyed it in one of my alcohol fires, which also got me thrown out of my slightly charred apartment, which resulted in my subsequent marriage to my wife of 25 years, Ruth Caird, whose prior husband was my office mate at Hughes. My future at Hughes was compromised somewhat by two unplanned attempts to burn down building six while processing dichromates. The last thing I learned to make while still employed there were the dichromate Apothecary jars filled with coins and a watch works nested in each one. These items were picked up by Selwyn Lissack and sold in NYC. I made about 24 of them each week in my garage in Lawndale California. They were made with a 7 mw cadmium laser purchased from the same Harry Knowles that wrote the original hologram article that Mike found. I started every Saturday the same way, mix up and filter a quart of yellow Jello, coat and shoot and process, drink a little wine, and then try to glue the caps on them.

Production of apothecary jars

Original experimental jars and glasses

A little wine and beer caused a few more accidents, like the time I lost control behind a speedboat at about 85 mph and skittered across the water right up on shore losing my ski and the whole back of my pants. Another time I was flying a hang glider behind a boat on the Colorado river when I got too far out to one side and crashed, breaking up the glider and shredding my levis. Then there was the time I rode a bicycle into a reservoir ripping my foot open to the bone, Ruth took me in to get stitched in Fresno which led to getting hitched to her in LA. In between I almost lost my foot to a bone infection which was only discovered when I broke the same leg (sliding down a banister) at Dodger stadium. If I had not broken my leg the infection would have gone undetected long enough to require an amputation. It was as my foot healed that I had my only boiling acetone fire, the landlord asked me to move immediately so I asked Ruth to marry me and help keep me out of trouble and she did. I have never had another alcohol or acetone fire since then and have learned to keep the alcohol in the process tanks and not in me.

Dennis Gabor and wife next to Selwyn Lissack about 1975

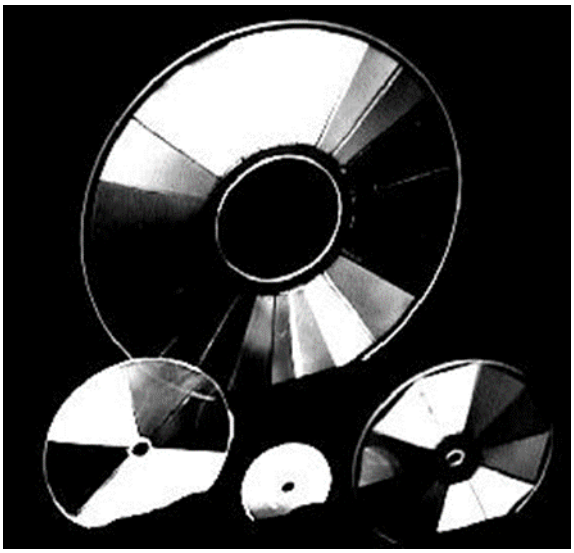
Selwyn says, "I made this dichromate jar just for you."

1.5 Leaving LA

In 1975 we moved to Utah to build Argon Lasers at American Laser and Selwyn asked me to make pendants for him. He put me into business single handedly but his early attempts to take credit for the production of the dichromates provided some truly hysterical moments at the SPIE San Diego conference of 1977. By that time I had been selling pendants to the Goldberg boys at Holex and had supplied a few other dealers on the west coast and the museum of holography in New York. Rosemary (Posy) Jackson, of the MOH, turned to me several times during the conference and mouthed out the phrase "I made those dichromates" causing major rib damage from laughter. My first production lab in Utah was in the basement of a house at 3488 E 7590 S, which is more or less at the mouth of Big Cottonwood Canyon and occasionally I would go skiing on a lunch break. We were 11 minutes from the lower chair lift at Snowbird. I can no longer remember who went with me but Jerry Heidt may have been one, we occasionally went cow trail motor cycling and skiing during all the years that he worked in three or four of my labs. Rick Lowe was my first employee and I think Jerry's brother was my second. Rick and I had motor boats and would take everyone to lake Powell for water skiing from time to time. At one time I had 8 to 10 people working in my basement. I never intended to manufacture in the mass production sense and tried farming out the production several times over ten years. It moved to Richland Washington once when patent issues were hot and Holosonics (Holotron) insisted on trying to cash in on what ever I was doing.

In 1979 Lee Dickson came calling from IBM and we made a fine looking holographic scanner for him. I thought I finally had a good reason to want to manufacture something. The first day he visited, he needed a little evidence that we could actually make dichromates in the little suburban house we owned at the time so we took his watch and sat him on the couch upstairs while Rick Lowe and I went down and made a nice reflection hologram of his watch. It took about 15 minutes and then we brought it up and gave it to him, he seemed impressed. We quickly struck a tentative product development deal and moved the operation into a chicken coup in Draper while we built a brand new building just for the

production of holographic scanners. IBM negotiators came out to firm up a technology buy while we were operating in the chicken coup and they came on one of those days when my cat had snuck in and left a load on my desk. They were not impressed. We only asked for $50k to transfer the disc making technology but learned in later years that they were prepared to pay perhaps 10 times that much. Nevertheless, I thought it was a fair price and I found a good friend in Lee Dickson so it was all worthwhile. IBM pulled the plug after nearly two years of development and production. We helped set up a production line in North Carolina where they made their own discs for the next 7 years. We used the new building to make larger plates and pendants and pulse portraits and even took the company public in a lame sort of way. I figured out eventually that I am a sole proprietor type of entrepreneur. The lessons cost me a few friends and partners.



Holographic Scanners for bar code reading

RDR in Australia buying Boomerangs, 1987

1.6 Laser Accidents

Mike and I had a great mutual interest in Lasers and struggled to own and build them as soon as they became available. I tried to make a dye laser from plans in Scientific American by Peter Sorokin. It was mostly built in 1971 and it nearly killed me at least once. I managed to get both index fingers across the flashlamp with the capacitor bank mostly charged. It discharged about 60 joules straight through my heart. I involuntarily threw the laser across the room into a wall and broke the lamp. Mike made an Argon laser and managed to violently blow the bulky Brewster windows off the ends with high Argon pressures.

My best accident was while at Hughes developing a CO2 waveguide laser. The power supply was 10KV at 100ma dc and protected by a painfully slow mechanical breaker. I worked with one hand behind my back but I hardly ever turned off the power to make adjustments because all the surfaces I touched were insulated, or so it appeared. The insulation broke down Nov 23rd 1974 and a kilo-watt of power flowed into my thumb and out of a circular patch on my belly, blowing a section of my shirt right into the air as the current found a ground in a metal cabinet. My legs extended and my arm struck my chest as I flew backward and upward onto a wall 4 or 5 feet behind me. It seemed as though I were looking down a tunnel from somewhere about 20 feet behind my body and I was partially paralyzed. I wrestled with

paralysis for ten or twelve minutes and then felt pain along the track the current took for a few days. I got married 3 days later and was always glad that my belly was closer to the cabinet than was my zipper. The hole in my belly and shirt was the size of a dime and somewhat charred.

I once had a Coherent cadmium laser that had a negative high voltage on each of the mirror mounts and it required frequent fine tuning. The voltage was only about 2Kv and it was possible to use two ball end drivers with plastic handles to do the work as long as you never slipped off the plastic. About the 10th time re-tuning with this head cradled in my lap, I slipped and took the full voltage across my chest again and the poor laser flew across the room into a wall, breaking the tube.

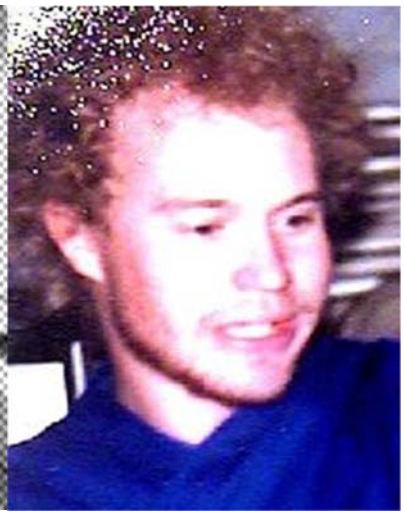
1.7 Throwing in the towel

1984 was my last year making pendants, I had failed as a business manager in multiple ways and made the decision to sell the company to the first interested party with a little cash. I sold it to the wrong group of guys and ended up paying out tens of thousands of dollars in subsequent years just to cover the debts they created for me. I moved to Paradise and started over from scratch, making nothing but holographic optical elements. The original Electric Umbrella went through numerous name changes and ownerships and evolved roughly into Krystal Holographics, now owned by Dupont. Jerry Heidt is the only remnant from the original basement operation. I imagine that if I had been a better manager and had resolved conflicts with Mike and Rick and Jack and Larry and Jerry and Scott and some backers and bankers and candlestick makers that I could have had a much more successful early venture in holography. I have learned those lessons and have determined that too much energy has to go into growing a successful business venture. During the year or so that I tried to capitalize and grow I missed the time in the lab, the study time, the new technologies to be learned. Those things get neglected when business interests dominate. I call myself a lab manager now and that is about the extent of the responsibility that I take on whenever I can get away with it.

(About 1982 or 1983)

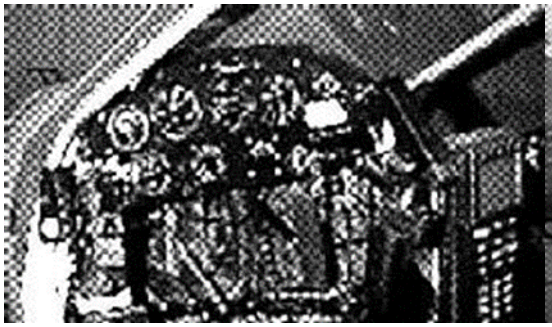
Rick Lowe, first employee, 1976

Jack Worthington, partner



Jerry Heidt, 1980, still at it

1.8 Flying for relaxation



My GT-500

A boy and his 7th airplane

I took up flying once again after moving to Paradise, this time I taught myself to fly ultralight aircraft rather than hang gliders. On one sunny late August afternoon I lifted off to chase water skiers at the local lake in a machine best described as a flying lawn chair. I swooped down on them from behind and above only to pull up sharply as I roared past like a big scary bumblebee. On the last pass I pulled up along side of a skier and while I looked at his startled expression and waved I let my front wheel dip into the water and with a loud slap I hit the water, broke off a wing and proceeded straight to the bottom, landing upside down in thick mud, 22 feet below the surface. It was dark when I regained my senses and I carefully unbuckled my seatbelt and worked my way past the flying wires which were laying in every direction. Then when I was free I tried to swim up but only buried my head in the mud. I had no air in my lungs to float up with so I took my white foam filled helicopter helmet off and held it by the communication cord and let it guide me to the surface. I gulped air just as my vision faded to black. I never experienced a moment of panic and would have died pleasantly in a few more seconds without oxygen. The lake ranger who had been chasing me all summer helped me haul the wreckage out of the water but would not stop laughing the whole way in to shore. I rarely fly that low across water any more and have since survived five more crash landings in various off airport locations. I flew right into a mountain with a passenger, then into a barbed wire fence, cracking a rib, I landed in a tree once and most recently flew into a 7.5 kV power line. It hurt a lot. Earlier that day I had buzzed Sharon McCormack and her boy friend at Hood River and had flown down into Mt St Helens volcano and over Mt Rainier so I was feeling invincible. A thunder storm and a moonless night conspired to keep me from seeing the ground. I hooked the power line with the nose wheel, stripped it off the pole and broke it before free falling into a hay field. My feet went right through the fiberglass shell and aluminum pedals and 6 inches into the dirt.

1.9 Outside ventures

Fred and I taught a crew in England (Raven) how to make dichromates and they did a great job of it but could never make enough money to stay in business. I taught a group in Kansas (Portson) once how to do it and they did a good job but had trouble staying in business also. I helped out Paula Dawson for a trip to Australia and some change in 1987 and I taught a lot of people at the annual school at Lake Forest College but none of them have made businesses that I know of. Dichromates have largely been replaced with cheaper mass produced photopolymer holograms. The medium still works best for high

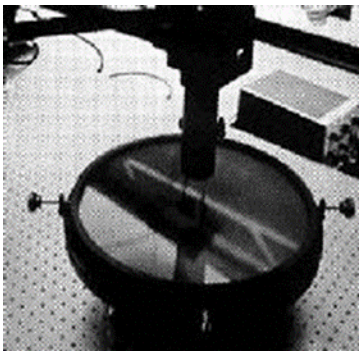
performance diffractive optics and probably will for a long time to come. Bright, clean DCG masters are still made for copying into photo-polymers.

I joined Lee Dickson and two other x IBM engineers in a venture called Holoscan a few years ago and we bought back all the Scanner making technology from IBM. We made some product and then sold the company to Harry Knowles, still the owner and CEO of Metrologic instruments. I became the teacher and taught Harry and his crew how to make dichromated gelatin holograms some 25 years after he taught Mike and I how to make our first holograms. Harry is a really great guy and he runs the only production line I know of today that makes bar code scanners on glass plates using dichromated gelatin. He also sent me a lot of Habanero pepper sauces for Christmas this year, he is very thoughtful (thanks to his wife). I also taught technicians and engineers at APA, Northrop, Process Instruments, Terrasun and Terrabeam and a few other places how to cook yellow Jello.

I also teamed up with a group in Seattle (Virtual I/O) about 1990 and we designed and manufactured head mounted displays (HMDs) for a few years. Eventually the major stockholders discovered we were selling them for less than the cost to manufacture them and they pulled the plug. You can still buy the HMD sets but they cost a lot more now and I don't own any part of the new company. I am still actively involved in a Laser Com business in the Seattle area and have assisted in setting up a production line for Large area holoscope receivers but don't plan to move there any time soon.

My lab has been supported through the 90s with several NASA contracts to make ever larger LIDAR scanners. We are currently doing our best to put out dichromated gelatin HOEs that measure nearly a meter in diameter. These HOEs are being made to conically scan the skies at multiple wavelengths and to have a field of view of only a hundred micro-radians. These are by far the most challenging projects of my career, and therefore the most fun. We have been making HOES of 400 mm diameter for ten years but the year 2000 will be the year of our first meter size optics for use in the near UV region. We have also been making a lot more gratings for spectrographs in the past few years, and the pace appears to be picking up along with the size and the price. I imagine that the business opportunity is now better for me than it ever was before. It is a bit of a shame because I have no desire to even try to grow a business and also don't know anyone else that does. I really enjoy assisting other businesses to make products and plan to just keep on doing that for work and play. I have 4 full time lab jocks and a grad student to keep busy and we are learning how to polish glass and how to operate high vacuum etchers and coaters in a new and larger lab.

Lab addition in 1998, another 4000 sq ft



LIDAR scanner for NASA

1.10 Significant inventions

I have a few patents but they don't cover any of my real inventions. My first invention was a semi automatic jerky chopper and I built it when I was 18 years old. It cost about $90 to build from a furnace blower, a lawn mower and a few metal parts and was used commercially for over ten years. My next invention was a glue mixer. It cost $4.00 in parts and was made from a motorized stage light fixture and a plastic kitchen cup. It mixes glue in paper cups like a concrete mixer and generates no bubbles. Next I invented the first dynamic spatial filter. It consisted of a curved first surface mirror glued to a speaker cone and the speaker was driven by a hard rock radio station. It only worked well for contact copies using a single beam but it did work, and it cost about $10. I made a few odd fringe lockers but would never claim them as an invention. For Pilkington in 1982 I invented the hand held air gate method of making reflective head up displays and several years later another company (Flight Dynamics) patented it. I thought it was too trivial and obvious to ever get patented, but then many of us had to work under the infamous "claim 6", so nothing else that gets patented could ever be a surprise. Most recently I think I invented the "aperture scanner". It enables me to make big clean recordings with little lasers and consists of a rotating tilted window.

Rosemary (Posy) Jackson about, 1976
quote from SPIE, 1977 "Psst!, I made those Dichromates!"

RDR and wife Ruth, recent SPIE meeting.
Mom and Pop running the business.

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