Observations of Brian Josephson’s Effects

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1961 to 1983 Bell Telephone Laboratories
1960
July - Giaever reports NIS tunneling in Al/I/Pb junctions
October - Nicol, Shapiro and Smith report SIS junctions

1961
April - Bell Labs

1962
June - Brian Josephson's letter submitted
August - First notebook entry about his letter

1963
January - Al/I/Pb junction at 0.3K
Supercurrent in Sn/I/Pb junction
May - $I_c(H)$ pattern in Pb/I/Pb junctions
June - Shapiro reports AC Effect

1964
January - The Ford group reports double junction interference
February – Parks and Mochel, Anderson, weak links
"We have resolved the structure in detail and can assign much of it to specific Van Hove singularities expected from neutron measurements of the Pb phonon spectrum."

Rowell, Anderson, and Thomas, Bell Labs, 1963.

d²I/dV² vs V (measured from 2Δ) for a Pb-Pb junction at 1.3K.
The Pairing Mechanism

The tunneling experiment is unique in probing the dynamical structure of the superconducting state and has provided a confirmation of the correctness of the strong coupling theory.”


McMillan and Rowell, Bell Labs, 1964.
“New effects are predicted, due to the possibility that electron pairs may tunnel through the barrier.

Our theory predicts that:
   i) At zero voltage, a DC supercurrent up to a maximum value can occur

   ii) At finite voltages there is an AC supercurrent of frequency $\frac{2eV}{\hbar}$.”

Josephson Experiment

- Need to produce superconductor - superconductor tunnelling in an H = 0 space (H = 1'g actually)
  tested a µ metal can with Joe Dillons meter, apparently < 0.039 and should be 0.10 at helium.

  So RA Chegwidden (x4626, 1A107) suggests take 1/32" 30" wide µ metal and make a can (4-79 Mo Perm 014" is more difficult to work) by overlapping 2½" a spot welding. Then he will anneal to make it go 8 gr. Made can.
Jan 2nd. Saw a Sn–SnOx–In unit at 14.5K. We see a small amount of structure, a dip below $\frac{df}{dn} = 0$, but fine phonon structure almost in noise. Suggested to do that alternative method of diff. Should be used as by Daniels at Princeton.

Jan 3rd. Al–Al$_2$O$_3$–Pb unit (made on 2nd) to be run on Geballe–Cryostat.
June 21

Due to wide variations (resulting in capsules) of
the percentage lead content made by exposure
of the raw material by baking

Thin films (5.000 ft) thick were evaporated
on a sapphire substrate at a temperature
of 250°C in an evacuated sealed thermocouple attached
to the cooled block supporting the sapphire. The
films were taken from the evaporator a placed
on a hot plate at 50°C in a stream of air.

As shown in the notebook of Lance Koff (notebook 31566
the films were exposed for 1 to 2 minutes, replaced
in the evaporator and a coating lead films (3.000 ft)

The coated wafers were used with power
areas 8.5' x 10^(-4), 1.35 x 10^(-3), 2.15 x 10^(-3), 3.5 x 10^(-4)

in air at wind 11 in helium, all good but
have resistance (x11)

On the wafer, a bar magnet or bar magnet
brought up outside the device
destroyed the effect. The effect tended to
be burned out by bringing up
the 300 μm bar characteristic
Jan 24th. Due to wide variations (short to capacitors) of thin tin oxide lead sandwiches made by exposure to air for a few days we will try heating.

- Thin films (~1000 Å) thick were evaporated on a sapphire substrate at a temperature of 3 mV on an chromel-alumel thermocouple attached to the cooled block supporting the sapphire. The slides were taken from the evaporator a placed on a hot plate at 50°C in a stream of dry oxygen.

As shown in the notebook of Herr Kapff (notebook 37566)
As shown in the notebook of Herr Kopf (notebook 37566), the slides were exposed for 1 to 15 minutes, replaced in the evaporator and a covering lead films (2,000 Å) evaporated. The usual masks were used with junction areas 8.5 \times 10^{-10}, 1.35 \times 10^{-3}, 2.1 \times 10^{-3}, 1.35 \times 10^{-3}, 8.5 \times 10^{-4} sq mm.

- HOLDERS 17 in helium, all good but low resistance (<10) All show peculiar low resistance at the origin.

\[
\begin{align*}
I & \quad \text{bar magnet or horseshoe} \\
V & \quad \text{brought up outside the dewar}
\end{align*}
\]

- Destroyed the effect. Need to burn out by going up to 300 mV but characteristic
Jan 22nd.

Mark 18, Sm - Pb.

- high resistance, similar Josephson effect or leak.

Phil Anderson's arguments seem to preclude leaks.

24th - added with expanded voltage scale, came notably considerably below the break.

Jan 29th. Have a 0.5 m read new ballast in hydrogen. That on mixed with kerosen runs not much effect.
“We have observed an anomalous dc tunneling current at or near zero voltage in very thin tin oxide barriers between superconducting Sn and Pb, which we cannot ascribe to superconducting leakage paths across the barrier - - -”

Anderson and Rowell, Bell Labs, 1963.
May 21

Made two Pb-Pb, 7 mm; 15 mm, at 1 to 1.1 mv.

Resistance all = V/R; no room, somewhat higher nitrogen.

Heated at 15 mm at helium.

1) Too peculiar excess current within the gap.

\[ \text{Structure is apparently at} \ \frac{2n}{2}, \ \frac{2n}{3}, \ \frac{2n}{4} \ \text{etc.} \]

2) Measured C voltage current as function of field — no saw.

Oscillates with about 30 mv period = 1.2 gauss.

\[ \text{Flux} = 1.2 \times 2.4 \times 10^{-2} \times 785 \times 10^{-8} \]

\[ \text{Width} = 2 \times \text{pen dust for lead films} \]

\[ = 2.2 \times 10^{-7} = \text{flux quantum.} \]
2) Measured 0 voltage current as function of field - no cure.

Oscillates with about 30 mV period = 1.29 ms.

\[ \Phi = 1.2 \times 1.2 \times 10^{-2} \times 780 \times 10^{-8} \]

Width = 2x pwr. 1st for lead films.

\[ \Phi = 2.2 \times 10^{-7} \text{ flux quantum.} \]

Peculiarly see 4 dips and then some residual current.

Earth's field complicates near zero.

May 22

Differentiated one of above units.

Find sub harmonics of gap down to \( 2\pi/12 \)!
1) Good Josephson currents go up to over $1/2 \times 20$ current.

2) With field (can in use now) $I_J$ reduces with $H$ and gets very small around 2.4-3.0 mA. Any oscillations are difficult to see because of noisy breaks from 0 V once above 30 mA.

3) Of 3 junctions two have

\[ I \times 10^8 \times 1 \]

\[ 20^2 \]

\[ \text{maybe structure, not diff.} \]

and one has

\[ I \times 10 \times 1 \]

These were with 200 mA in magnet -- should have looked for any changes in characteristic with $H$. 
“Microwave steps” in I-V of Josephson junction

Shapiro, Arthur D. Little, 1963.
“This second period involves a quantum mechanical interference between the currents flowing through separate junctions in direct analogy with double-slit electron beam interference effects.”

Jaklevic, Lambe, Silver, and Mercereau, Ford Lab, 1964.
Feb 3rd 1964. Phil suggests that the structures of Parke - narrow superconducting structures - should (in low H) be weak coupling regime between bulk superconductor should exhibit Josephson effects. In fact he considers Parke's results are Josephson measurements.
Feb 14. Phil suggests that the structures of parts - narrow supercharging section - should (in low 11) be weak, ensuring gaps between bulge 15 to shunt exhaust pressures. Also, exhaust pressures in part the counter 1.0 indicator levels and pressure measurements.

Jay is replaced. Pressure 1.5. 7031 glue was drawn out, drawn to 7.8 mm. Pressure was 1.15 mm. Using aluminum, check tension with continuity on fillet.

Feb 14. 7 mm glue. 7 mm. Break, 0.9 g. Structure about 7.4 square, which is too high.

Job 7

Made 2 square.

by repeating 7.2 mm wide, marking with file, complicating to make grade 7.5 mm long (but could not be good between AT 11.0). Spacing 2 mm. Structure about 1.4 g but not conclusive.

Feb 11. AT through 1.1 microns. Make sure G to for AT film 1.3. 10.00

Feb 11. AT 0.15 microns. 0.8 g to 0.15 mm.

Feb 18. AT 0.15 microns. New data.

Feb 18. Change to 0.15 mm glue. More stable, 0.2 microns. 2.3 g > 10.

Feb 14. AL made at bridge 2 sqaure. 2.4 mm.

Hence, even damp range, no effects except V = I.

Behaviour near transition 0.14.
Josephson Effect in Weak Links

Anderson & Dayem, Bell Labs, 1964
July 23rd. Have suggested use of Josephson oscillation as a device - at $H_0$ it would show a voltage $V_0$ when fields $H_1, H_2, H_3$ were reached, zero voltage between. No interest from Tungsten.
September 11th 1963, wrote up a preliminary survey on Josephson devices. As outlined in 57 to 61, we have two important characteristics:

1) The I-V characteristic alone can be used in a circuit - V appearing when I exceeds Ic.

2) A small lead wrapped around the junction gives Hc - V appearing when H > Hc.

3) The circuit is fed with alternating V through a high series resistance R. V / R = Ic.

Vin is thus a function of applied fields. Once can be used as a logic device. The proposal will be inserted into the notebooks when typed up.

W. Forrest, Ralph A. Lynn, Sept 11, 1963
Before P.W. Anderson left for Japan (Sept 1, 1970), we talked to possible memory storage devices utilizing superconductors. He (and T.A. Fulton) believe the structure of Page 54 is too slow to be of interest as current are essentially being created in normal material. Phil suggests as an alternative a Josephson structure which is depicted on the opposite page (57). It is essentially a long Josephson junction shaped such that a fluxoid will prefer certain locations in the strip. The easy question regarding speed is whether the inductance of such a long structure becomes prohibitive.

P.S. understood.

J. M. Rowell 9/8/70.
In this page is stuck a sketch by Phil Anderson of a long Josephson junction of such a shape that it will move free as a storage register. De Ta Wolf says Ali Daeen will do it, or do you guys will, p.

Sketch of a current + d.c. bias < critical applied to whole structure

- Comprising
- Low resistance tunnel junction
- High "..."

Can fork by...

S.M. Powell
Sep 18 1980
On this page is stuck a sketch by Phil Anderson of a long Josephson junction of such a shape that it will move flux as a storage register. Josephson shift register.

Says Ali Dayer will do if one of you guys will, P
Nov 19th 65 - Today will try to make galvanometer of the type described by Clarke (retired from Cambridge).

Larmor has taken some 20 mil Ta wire which is etched and anodised to blue colour after bending into a loop

\[ \text{anodise} \]

Will try to make two holes in oxide by discharge from a capacitor through an etched Ta needle or

\[ \text{1 pm point} \]

by scratching them in order to see if we can make superconducting shorts through the holes and hence the double interference device.

J. M. Rowell, Nov 19th 65
Summary

Brian Josephson's Effects, predicted in his Physics Letter submitted on June 8 1962, were observed within 12 months.

The DC Effect in January 1963 at Bell Labs

The AC Effect in June 1963 at Arthur D. Little, Inc.

Applications have followed over the past 50 years