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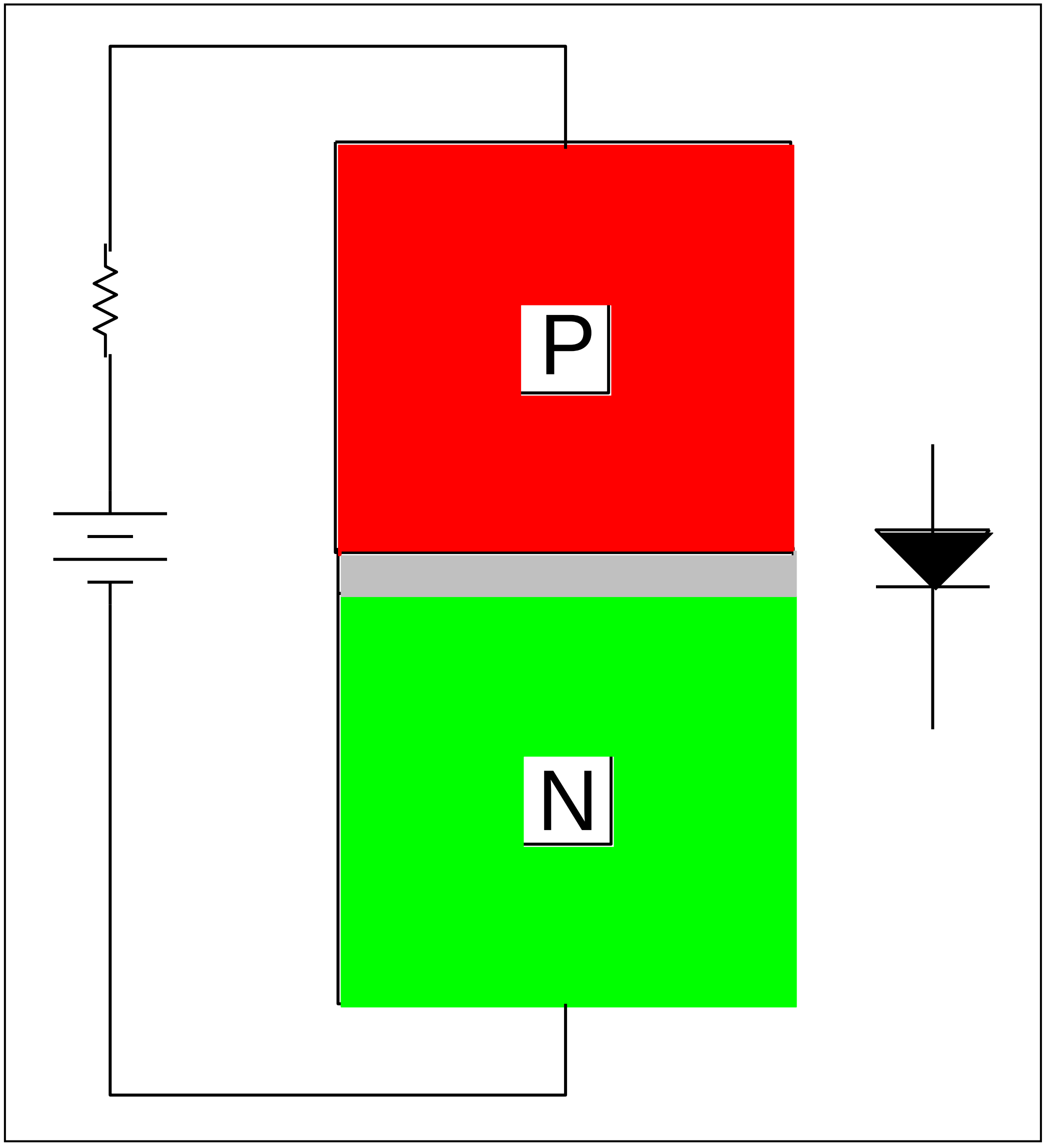
Lesson 08

Bipolar & Field Effect Transistors

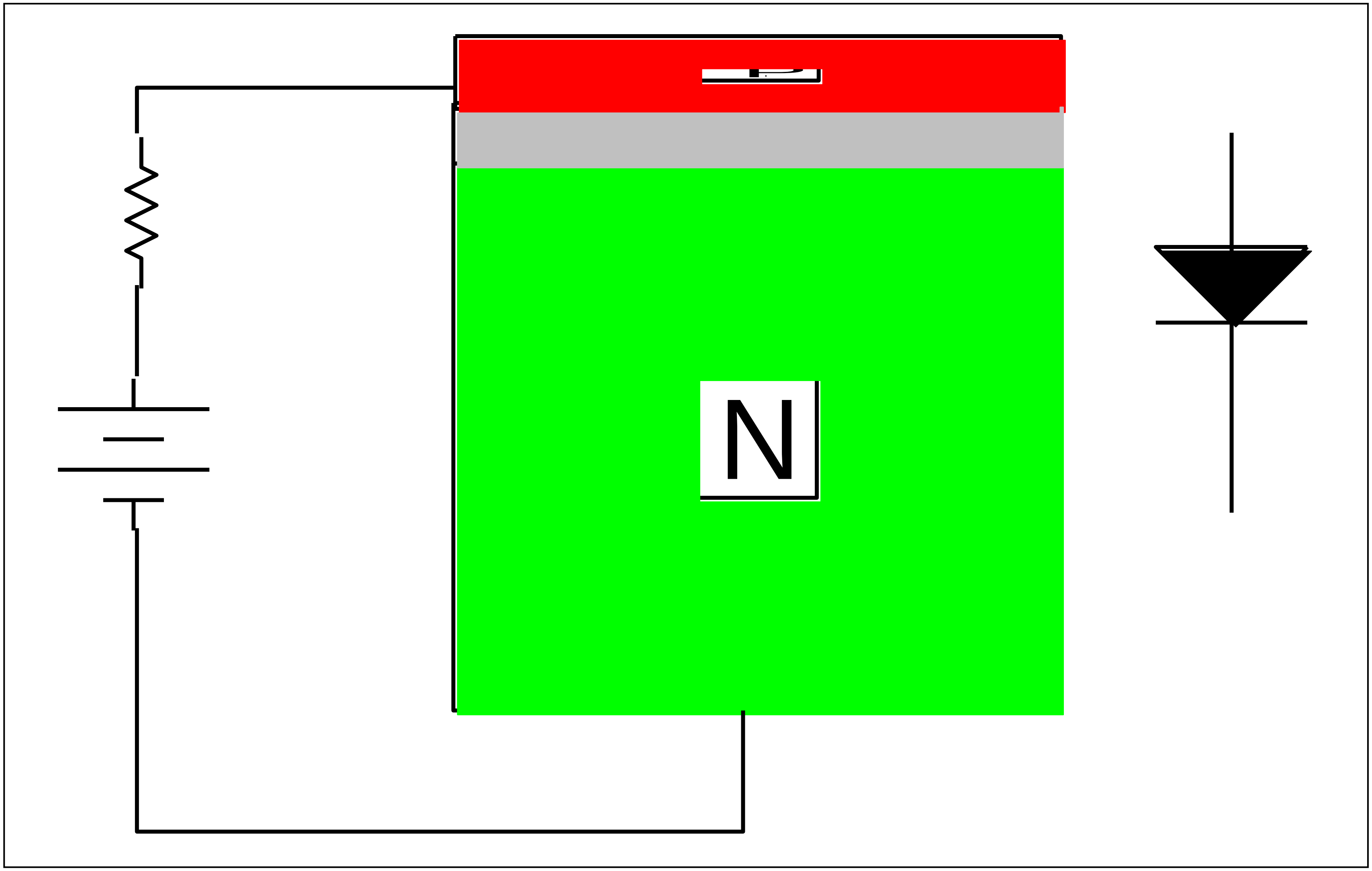
Bipolar Transistors. Bipolar transistors are so named because they have two distinct polarities of semiconductor, P and N. Let's start life off with a simple diode:



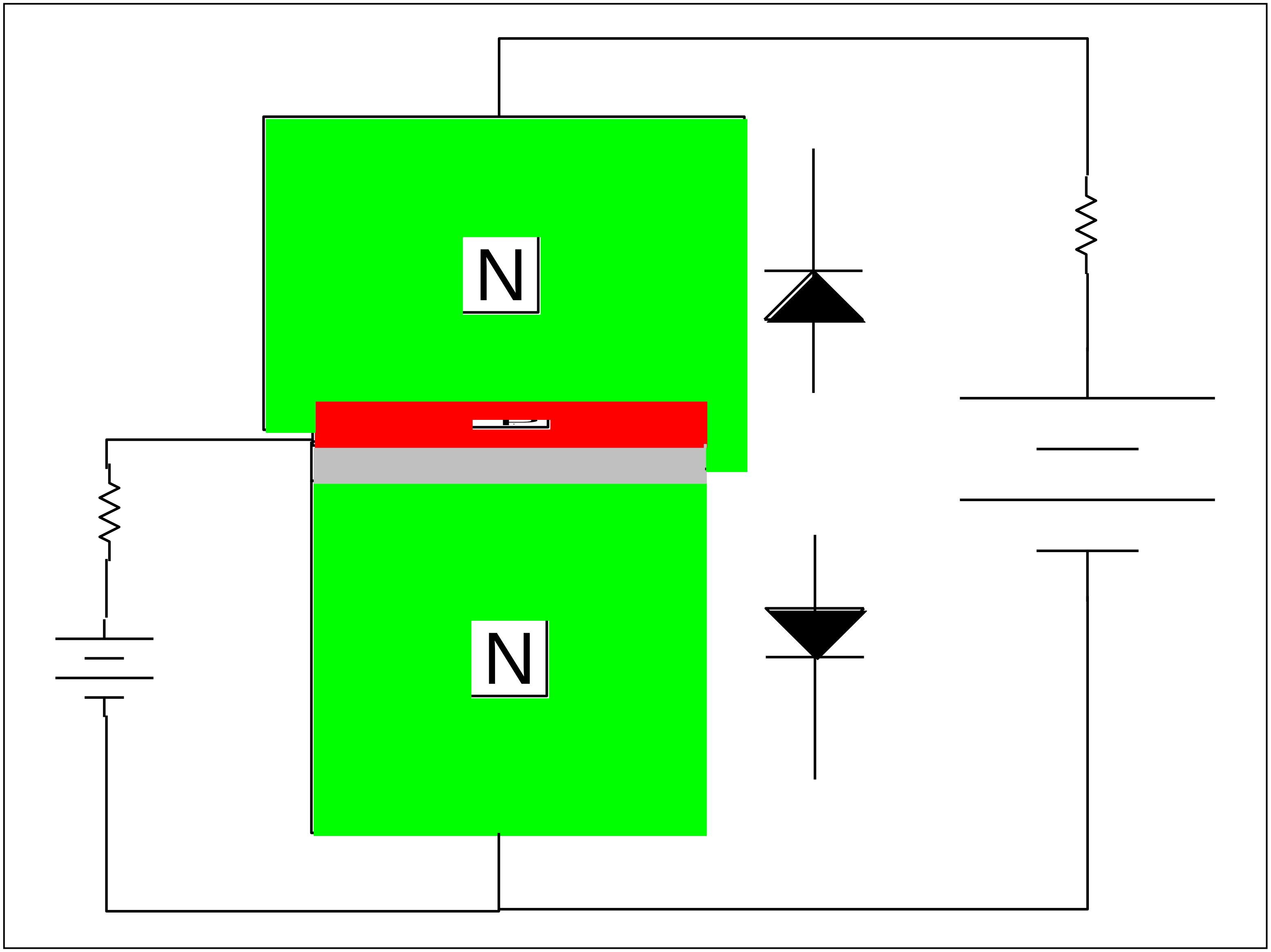
Here we see a regular old silicon diode. An N layer and a P layer separated by an intrinsic layer. As we increase the battery voltage (somewhere around 0.4 to 0.6 of a volt) the intrinsic layer disappears and we have a diode in full forward conduction.

I think it is rather obvious that the N and the P layers do not have to be the same thickness for our diode to work. Nor do I have to inject the current into the end of the layers. For instance, I could make a diode like this and it would work every bit as well as a diode with equal sides.

We had been creating diodes like this for ten or twenty years before 1947 and they were fairly well perfected.



And here is where Bardeen, Brittain, and Shockley got the Nobel. What they said was that we should create a HUGE layer that completely surrounds the small red center layer.   Now so as not to be confused with "layers, let's call the bottom N layer the "emitter", the center small P area the "base" and the upper huge N layer the "collector".



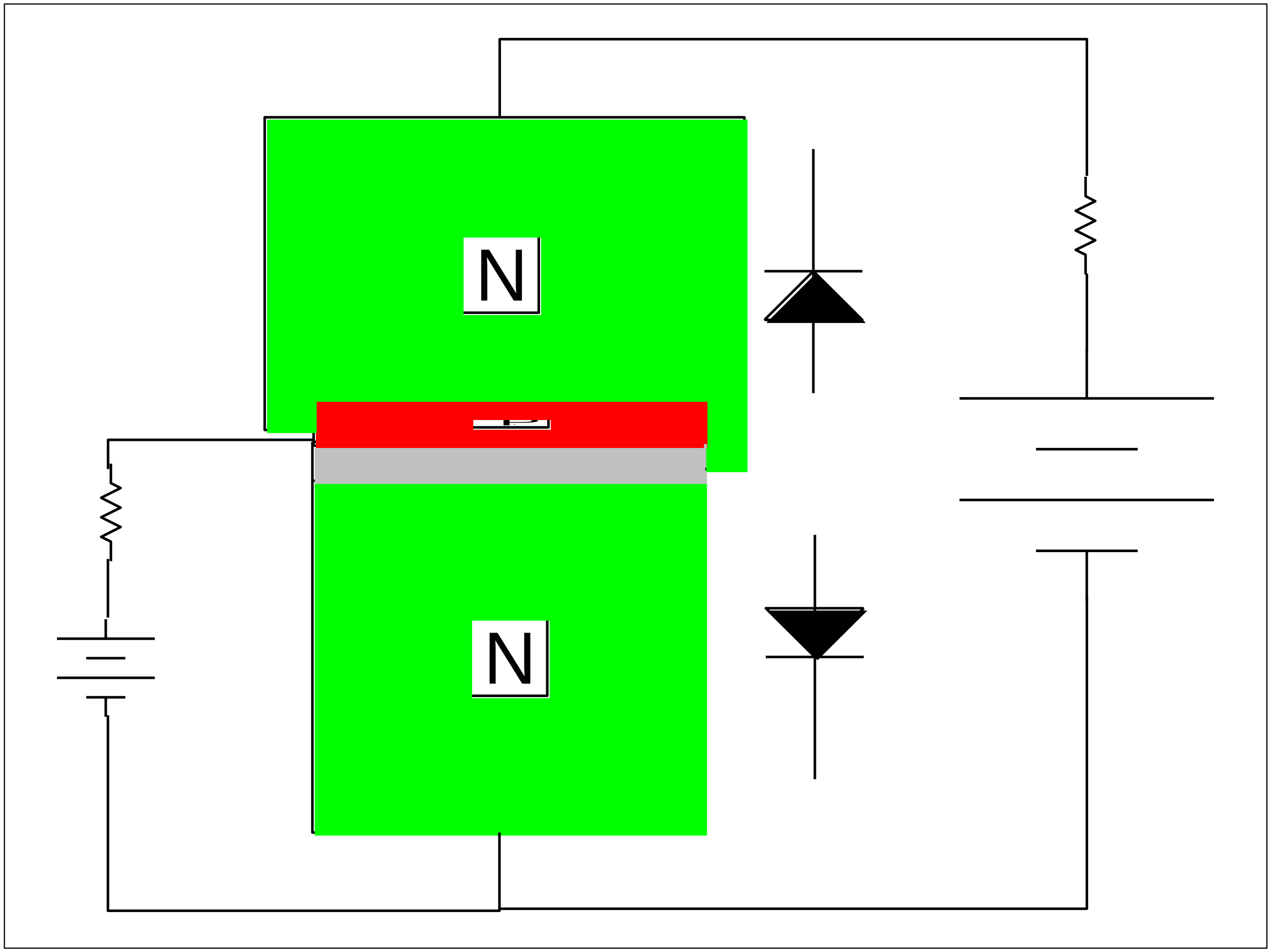
Note several things:

a. The base-emitter diode junction is forward biased.

b. The collector-base diode junction is reverse biased.

c. The collector-base junction is microscopically small … several dozen ATOMs thick.

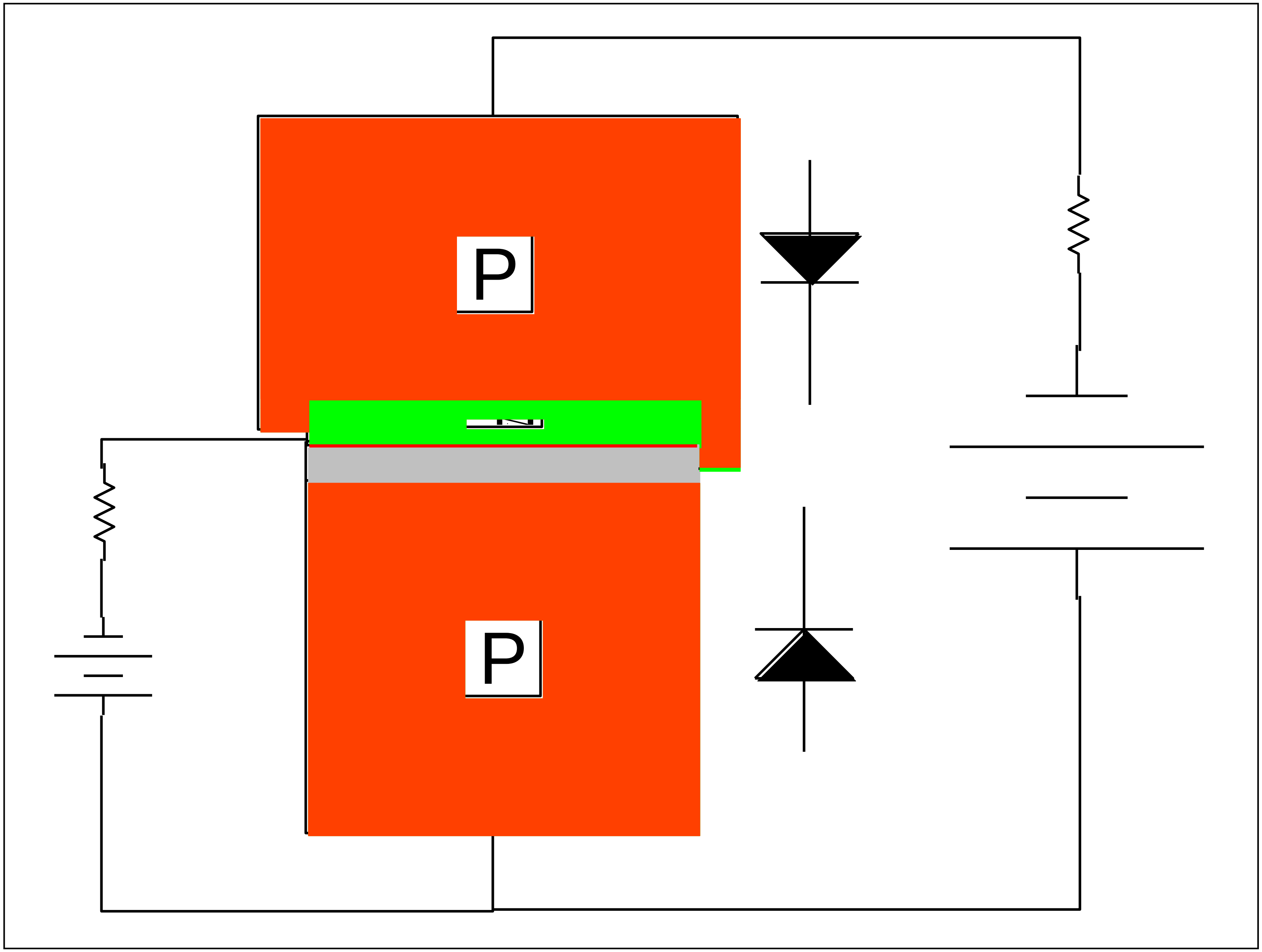
d. The voltage on the collector with respect to the emitter is large compared to the voltage on the base with respect to the emitter.



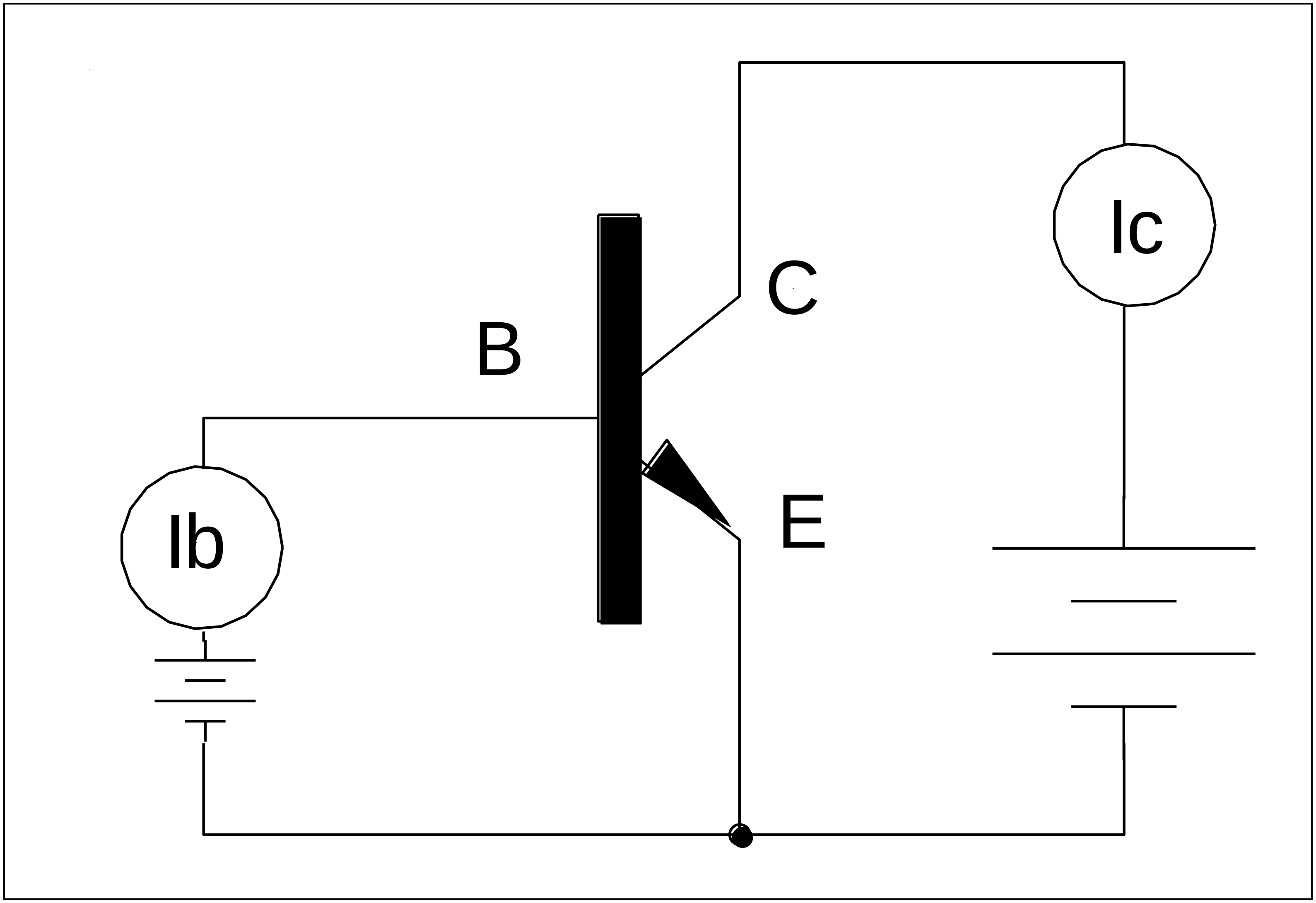
Let's follow the path of a typical electron that is injected into the emitter from the emitter-base battery current. It travels through the emitter area and arrives in the base area. Were it not for the collector voltage, the electron would be drawn to the positive pole of the emitter-base battery. However, just over that little reversed-biased collector-base junction is this large battery and the electron can be easily given enough energy to "jump" over the reverse biased junction, go through the heavily positive collector area, and arrive at the collector-emitter battery.

This "jumping" or tunneling was predicted by the whole Einstein quantum mechanics folderol, but it remained for BB&S to apply this theory to practice and then refine germanium to the point where the quantum tunneling could occur.

We call this configuration an "NPN" transistor. However, nothing says that we can't start off with P type material and make a "PNP" transistor.



While we said that most of the emitter electrons would eventually find their way to the collector, every now and again an electron that gets to the base will be drawn to the base battery. In general, for small signal transistors, about one in a hundred to one in two hundred emitter electrons will wind up as base current. The ratio of collector current to base current has a name, and it is BETA. Beta is the measure of the "goodness" of the transistor as regards current drain.



In the diagram to the right, notice that the EMITTER has an arrow (pointing OUT for NPN and pointing IN for PNP), the base is a "block", and the collector is a simple wire connecting to the base.

Beta (β) is defined as : $\beta = Ic/Ib$

Now, since we can have a SMALL current at the base controlling a LARGE current at the collector, we have an AMPLIFIER. We can inject a small signal into the base and have a large signal appear at the collector.

Where might such a device find use?

The microphone at a Stones concert puts out a few millivolts at a few microamperes, but the speakers that deafen the front row put out hundreds of volts at hundreds of amperes. It is due to a few hundred transistors inside the speaker amplifiers that such amplifications are possible.

The hard disk "heads" pick up a magnetic signal from the disk of a few microvolts at a few microamperes, yet the digital logic needs volts at milliamperes. Again, the transistor picks up the slack.

We can arrange the transistors so that some of the output is fed back to the input at a particular frequency so that we can generate a signal from within the circuit itself … an oscillator.

Literally millions of other uses.

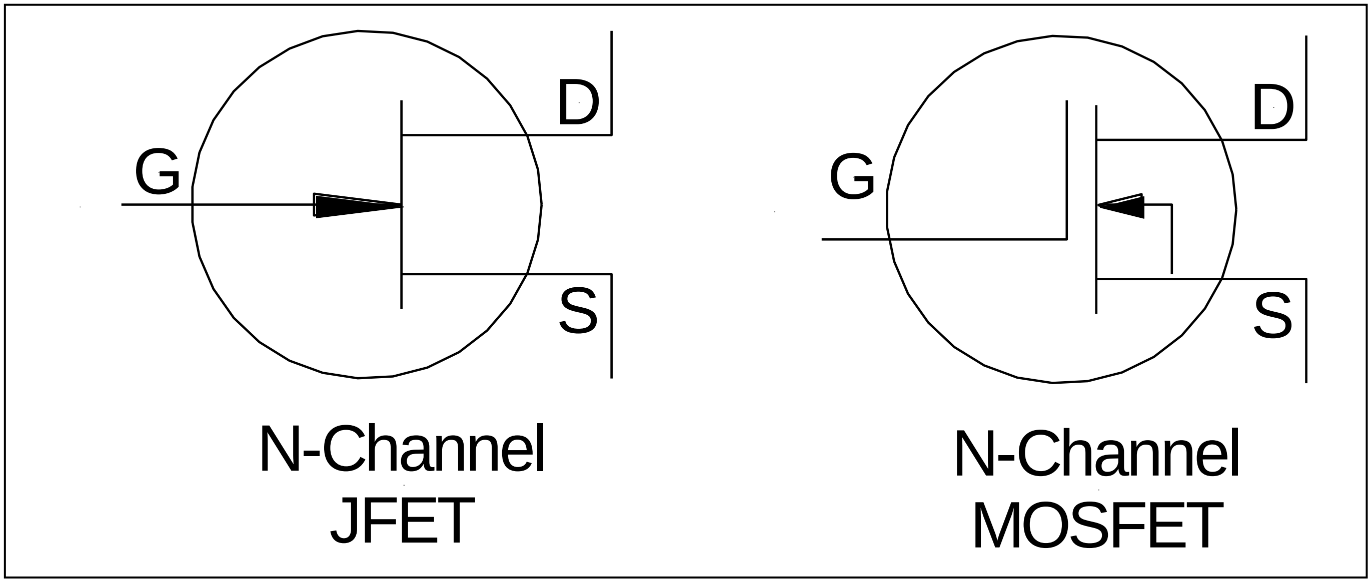
FIELD EFFECT TRANSISTORS   Strangely enough, the Field Effect Transistor (FET) was patented by Lilientheld in Germany some 20 years prior to the BB&S transistor. However, political unrest in Germany prevented the device from reaching the practical stage. Indeed, BB&S application for patent for the Bell Labs bipolar transistor was originally rejected because of the earlier work by Lilientheld.

There are two main distinctions in FETs, junction FETs (jfets) and insulated gate FETs (IGFETs, more commonly called MOSFETs).

Rather than go into a long song and dance about how FETs are made and how they work, refer to web page

http://micro.magnet.fsu.edu/electromag/java/transistor/index.html

Here you can see the process whereby FETs are made, and at the end a little graphic on how you can control current flow in the fet by controlling voltage on the gate. Note the following about the FET:



a. No current flows in the conduction channel until the gate voltage gets to a particular value, usually between two and three volts.

b. The gate has microscopic current flow (nearly zero). All the "charge" on the gate, once it gets there, simply produces a field that affects current flow

c. Since the gate current is nearly zero, and since Ohm told us that $R = E/I$, then it follows that for a given value of E, if I is very, very small, R is very, very large. From Ohm's power law, since $P = E^2/R$, and if R is very, very large, then no matter what E is (even E^2) then P is very, very small. All of this boils down to the fact that FETs are very, very efficient as far as wasting power, unlike their bipolar brethren and sistren.

The operation of a FET amplifier is quite similar to a bipolar amplifier with the exception (as noted above) that we can get large voltage gains with relatively low power losses.