**In saturation mode, how is it possible that current is flowing from n type to p type material and the junction is still forward biased?**

From a circuit point of view saturation is rather like a water tap (faucet). There comes a point where you cannot turn in on any further. Look at the CE connection below



The transistor is biased just 'on'. That is its base is about 0.7 volts above the emitter. This causes a collector current Ic= beta times the base current to flow in the collector resistor RL. By ohms law there is a voltage across RL = IcRL. This sets the collector voltage at a point equal to the supply voltage minus the voltage across RL. If we now increase the base bias so that more base current flows this cause an increase in collector current. This increases the voltage across RL. Since the voltage across RL is now greater the collector voltage falls. The collector voltage always 'takes up the difference'. Obviously the collector cannot fall below zero volts as we crank up the base drive. In fact it falls to about 0.2 - 0.4 volts above the emitter. At this point the transistor is said to be bottomed or in saturation or saturated. Further increase in base drive beyond this point will not result in increased collector current.

Also worth mentioning is that a bjt is really 2 bjt devices in 1. The 1st device is the normal "right side up" device, the 2nd is upside down. Transistor action works both ways. When saturated, the b-c junction is forward biased. So holes from the base region enter the collector, and electrons from the collector enter the base. In addition e- from the emitter transit through the base, some recombine there, most go on into the collector. There is more than 1 thing happening here. The b-e & the b-c junctions are both forward biased for the saturated state. In cutoff or active state, the b-c junction is reverse biased. So analyzing the device in terms of charge transit must be done with this in mind. In the saturated state, an additional component of charge motion is present.

The same way that it does in a photo-diode (in photovoltaic mode), by having non thermal-equilibrium minority carrier concentrations. In a photovoltaic cell the diode is forward biased (anode +, cathode -) yet the current flows from cathode to anode! In BJT saturation mode there are very high excess minority carrier levels in the base resulting in a lot of diffusion current across the CB junction. Yes it’s true that the drift current is in the opposite direction, but the diffusion component is larger and so the net current is actually opposite to the electric field direction. Remember that diffusion current is driven by concentration gradient (and thermal motion) so yes it is possible for diffusion current to flow counter to the electric field! In summary. In the case of the photovoltaic diode it is because of the large number of optically generated minority carriers. In the case of the CB junction of a saturated BJT it is because of the large number of emitter-injected minority carriers.

To explain how current flows in a reverse biased c-b junction, consider the following. The device is npn. The b-e junction is not biased, and the c-b jcn is reverse biased. Only a small reverse leakage current is present, Ics, aka Ico or Iceo. Ib = 0.

But when the b-e jcn is forward biased, Ib > 0, and holes, h+, move from base to emitter, and electrons, e-, move from emitter towards the base region. Simple enough. But the base region is intentionally made to be very very thin. Also, the base region has light doping density, with the emitter having heavy doping density.

The h+ from the base recombine in the emitter region or in the depletion zone at the edge. The e- from the emitter incur very little recombination in the base, because nearly all pass right through the base region and continue into the collector where they are "collected". The emitter "emits" electrons towards the base which is forward biased wrt the emitter. But the electric field in the reverse biased c-b jcn points in the same direction as that in the forward biased b-e jcn. An e- entering the base from the emitter encounters a strong attractive force yanking it into the collector before it has a chance to recombine with a hole in the base.

Although the c-b jcn is reverse biased it conducts a lot of current. This is because the carriers, e- here, are not provided by the collector region, but by the emitter region. The collector collects the e- that the emitter emitted a moment ago. Outside charge carriers are being injected into the collector. Thus the equation of transistor action is:

Ic = alpha\*Ie.

Transistor action occurs because the base is so thin and lightly doped, that charges get swept into the collector before they have a chance to recombine in the base. A good signal level bjt has an alpha value of around 0.98 to 0.998, and a power bjt around 0.95 to 0.98, sometimes as low as 0.90.

In a diode, the n & p regions provide all the charge carriers. So a reverse biased jcn has low current since carriers are in short supply. But in a reversed c-b jcn in a bjt, the b-e jcn is forward biased. Charges carriers are abundent in the base & emitter. But the e- emitted from the emitter pass through the base being so thin, and get collected by the collector due to the electric field. In a nutshell that is transistor action. One more point is worth mentioning. "Current" is merely charge motion. In a bjt, charges move through 1 region, cross a junction, and then move through another region. Thus "collector current" is charge motion, most of which consists of charge carriers injected into the collector from a different location. So e- moving through the emitter region, constitute emitter current Ie. A moment later, nearly all of those e- are moving through the collector region. They now constitute collector current Ic. In other words, what we call "Ic", was only a moment ago called "Ie". Ic=alpha\*Ie. Pretty straight forward.